Report to:

Civil Aviation Authority

on

Work hours of Aircraft Maintenance Personnel

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Executive Summary

The remit for this research was to assess the work hours of Aircraft Maintenance Personnel and produce recommendations for "good practice". This involved reviewing the literature with respect to the impact of various aspects of work hours on health, sleep, fatigue and safety, with special emphasis being given to safety considerations. In addition, a large-scale survey was undertaken of licensed aircraft maintenance engineers in the UK, and parallel surveys were conducted of both employers and contract employers. These surveys yielded substantial evidence on the range of shift systems in operation in aircraft maintenance within the UK. They also provided detailed information on the key aspects of work schedules that are known to influence safety, and on the proportion of individuals that might be affected if the various recommendations made were to be implemented.

In the light of both the survey results and the literature review a number of recommendations for "good practice" were made with respect to various specific features of shift systems. These included recommendations concerning the maximum periods of work, and minimum periods of rest, with breaks within a shift, daily work and rest periods involving work of up to, seven successive days. Recommendations were also made concerning the maximum number of successive night shifts taking account of the length of the night shift, and the maximum number of successive early morning or day shifts. In addition it was suggested that risk management systems should be further developed, and that educational programmes should be further developed and used to increase the awareness of aircraft maintenance personnel with regard to the times at which the risk of errors may be high. Finally, it was recommended that aircraft maintenance personnel should have a personal responsibility to turn up to duty adequately rested for work. It is clear that working on rest days may compromise this final recommendation.

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1. Introduction

The aviation maintenance system is heavily dependent upon people being able to perform their jobs reliably and efficiently. Whilst UK maintenance related accident and incident data do not show fatigue as a frequent contributing or causal factor, it is a continual threat to the safety system. Confidential reports submitted to the Confidential Human Incident Reporting Programme (CHIRP) have on a number of occasions indicated those excessive working hours and certain shift patterns being worked are a potential safety hazard. There have been limitations on the work hours of pilots for some considerable time, and more recently the work hours of Air Traffic Control Officers have also been limited (SRATCOH). However, no such limits[1] or recommendations presently exist for the work hours of aircraft maintenance personnel despite their obvious involvement in the overall safety of air transport operations

The Confidential Human Factors Incident Reporting Programme (CHIRP) has received several reports expressing concern that some maintenance personnel would appear to be working excessive hours. This is potentially hazardous to aviation safety.

Other factors have also contributed to concerns over the work hours of aircraft maintenance personnel. These include the current shortage of licensed engineers and the exacerbation of this problem by the increased opportunities for British engineers to work abroad, either on a full time basis or on their “rest days”. Also of relevance is the application of the Working Time Directive to aircraft maintenance personnel. Indeed, the concern over the work schedules of aircraft maintenance personnel is not confined to the UK. Studies of their work schedules have been conducted, or are in the process of being conducted in a number of countries worldwide, including Australia, Canada, France, Japan, New Zealand and the USA.

In response to the concerns highlighted by CHIRP and a need to identify what problems might exist and on what scale, the UK Civil Aviation Authority commissioned a research project to assess the work hours of Aircraft Maintenance Personnel in the UK and to produce recommendations for “good practice”.

The guidelines proposed in this report (Section 5) are based primarily on a review of the literature on the impact of work schedules on health and safety (Section 2). However, they also take account of the large-scale survey of licensed aircraft maintenance engineers (Section 3) and smaller surveys of their employers (Section 4). Thus, while the various proposals are based on objective scientific evidence, they also take account of the current work schedule practices within the UK. In this way, it is *hoped* that they should not only decrease the risk of errors in aircraft maintenance, but should also prove practicable and acceptable to those concerned.

In line with the remit for this research, the proposals concentrate on limiting features of shift systems in such a way as to try to minimise the build up of fatigue during periods of work, and to maximise the dissipation of fatigue during rest periods. They also attempt to minimise sleep problems and the disruption of the “body clock” (circadian rhythms). Finally, it is recommended that these proposals should form part of a wider risk management programme, and that they should be reviewed on a regular basis in the light of experience.

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[1] The latest version of the EU Working Time Directive, and its implementation in UK Law, should be consulted with reference to its applicability to aviation maintenance personnel

2. **Literature Review**

The advent of modern industrial processes, the globalisation of the economy, and the proliferation of information technology, among other factors, have contributed to the creation of a 24-hour society in recent times. As the demand for 24-hour availability of goods and services has risen over the past few decades, the prevalence of shiftwork has likewise increased. In the European Community approximately 20-25% of all non-agricultural workers experience some type of shiftwork (Wedderburn, 1996). Estimates for workers in the USA are quite similar (US Congress, Office of Technology Assessment, 1991).

Shiftwork is defined here as any arrangement of daily working hours that differs from the standard daytime hours, i.e. between about 07:00 and 19:00. Organizations that adopt shiftwork systems extend their hours of work past eight hours by using successive teams of workers. The nature of shift systems can vary widely along several dimensions, including the number and length of shifts, the presence or absence of night work, the direction and speed of the shift rotation (or whether the shift rotates or not), the length of the shift cycles, the start and stop times of each shift, and the number and placement of days off.

Many shift systems provide 24h-cover seven days a week and are referred to as continuous shift systems. The most common shift systems are based on 8-hour or 12-hour shifts and involve four teams who average 42 hours work per week. On 8-hour shift systems the shifts are normally referred to as “Morning”, “Afternoon” and “Night” Shifts, with the shift change times typically taking place at 06:00 to 08:00, 14:00 to 16:00 and 22:00 to 24:00. On 12-hour systems the shifts are normally referred to as the “Day” and “Night” shifts, with the shift changes typically taking place at 06:00 to 08:00 and 18:00 to 20:00.

The scientific community has long maintained that individuals who regularly work atypical hours (i.e., shiftwork of some type) are at greater risk for physical and psychological impairment or disease than typical day workers (e.g., Costa, 1996; Costa, Folkard, & Harrington, 2000). This risk is assumed to originate from the physical and psychological stress that develops from work schedule-related disruptions of their biological functions, sleep, and social and/or family life. The risk is further exacerbated by extended hours of work beyond the standard 40-hour week, a trend that has also been increasing over the past several years (Costa et al., 2000).

This review will explore the relationships between shiftwork and health and safety, broadly defined. First, it provides general background information on circadian rhythms and then reviews the empirical literature on shiftwork and various types of health-related strains or outcomes. Next, it explores the various types of interventions that have been attempted to enhance shiftwork effectiveness. It then summarizes the research findings and discusses the implications for the design of shift systems.

2.1 Circadian Rhythms and the Internal Body Clock

Life on earth has evolved in an environment subject to regular and pronounced changes produced by planetary movements. The rotation of the earth on its own axis results in the 24-hour light/dark cycle, while its rotation around the sun gives rise to seasonal changes in light and temperature. During the process of evolution, these periodic changes have become internalised, and it is now widely accepted that living organisms possess a ”body clock”, such that organisms do not merely respond to environmental changes, but anticipate them.

The anticipation of environmental events is mediated by regular cyclic changes in body processes. In humans, the most pronounced of these are the ~24hour 'circadian' ('around a day') rhythms that occur in almost all physiological measures (Minors & Waterhouse, 1981). Evidence that these circadian rhythms are at least partially controlled by an internal, or ‘endogenous’, body clock comes from studies in which people have been isolated from their normal environmental time cues or “zeitgebers”[2]. In their pioneering studies, Aschoff and Wever (1962) isolated individual subjects from all environmental time cues in a temporal isolation unit for up to nineteen days, while Siffre (1964) lived in an underground cave for two months. In both studies, people continued to wake up and go to sleep on a regular basis, but instead of doing so every 24 hours, they did so approximately (~) every 25 hours. The circadian rhythms of other physiological measures, including body temperature and urinary electrolytes, typically showed an identical cycle length (or *period*) to that of their sleep/wake cycle.

Approximately a third of the people who have subsequently been studied in this way, however, have spontaneously shown a rather different pattern of results. In these cases, the sleep/wake cycle and body temperature rhythms have become 'internally desynchronized', meaning that the temperature rhythm continues to run with an average period of ~25h, while the sleep/wake cycle shows either a much shorter or a much longer period than either ~25h or 24h (Wever, 1979). Interestingly, this phenomenon of 'spontaneous internal desynchronization' occurs more frequently in older people and in those with higher neuroticism scores (Lund, 1974), and this is discussed later in this review.

2.1.1. Endogenous and Exogenous Components

At a more theoretical level, the fact that the body temperature rhythm and sleep/wake cycle can run with distinctly different periods from one another suggests that the human 'circadian system' comprises two, or perhaps more, underlying processes. The first of these is a relatively strong endogenous body clock that is dominant in controlling the circadian rhythm of body temperature (and of other measures, such as urinary potassium, and plasma cortisol) and is relatively unaffected by external factors. The second is a weaker process that is more exogenous in nature (i.e., it is more prone to external influences) and is dominant in controlling the sleep/wake cycle (and other circadian rhythms, such as those in plasma growth hormone and urinary calcium). Some debate exists regarding whether this second process truly has a clock-like nature, but there seems to be general agreement that some circadian rhythms are dominantly controlled by the endogenous (internal) body clock or oscillator, while others are more influenced by external factors.

These two processes are thought to be asymmetrically coupled, such that the endogenous clock exerts a considerably greater influence on the weaker process than vice versa. For example, internally desynchronized individuals show such a strong tendency to wake up at a particular point of the temperature rhythm, regardless of when they fell asleep, that their sleep periods can vary in duration from four to sixteen hours (Czeisler, Weitzman, Moore-Ede, Zimmerman and Kronauer, 1980). Therefore, sleep is likely to be disrupted unless the temperature rhythm has adjusted to any changes in the sleep-wake cycle.

2.1.2. Adjustment to Shiftwork

Under normal circumstances, both the internal body clock and the weaker externally driven functions are entrained (or synchronised) to a 24h period by strong natural zeitgebers, including the light/dark cycle. As a result, all circadian rhythms normally show a fixed temporal relationship to one another. For example, urinary adrenaline reaches a maximum around midday, while body temperature peaks at about 8.00 p.m. Similarly, all other circadian rhythms reach their maxima at their appointed time, allowing us to fall asleep at night and wake up in the morning. The occasional late night may affect those rhythms controlled by the weaker process, but are less likely to upset the strong oscillator and, hence, our body temperature rhythm and the time at which we

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[2] From the German for “time givers”.

spontaneously wake up.

This inherent stability in the human circadian system, however, can pose problems if a mismatch arises between the internal timing system and external time cues. The simplest example of this occurs when people fly across time zones, because all the zeitgebers change. A flight from Europe to the USA involves crossing several time zones, so that on arrival the timing system is 5 to 9 hours too early for the local zeitgebers, such as the light-dark cycle. Body temperature rhythms usually take over a week to delay their timing by the appropriate amount (Wegmann and Klein, 1985). For the first few nights, this often results in people waking up in the early hours of the morning and being unable to resume sleep. The rhythms in other processes adjust at different rates, presumably depending on the degree to which they are controlled by the internal clock or the weaker external process. As a result, the normal temporal relationship between rhythms breaks down and is only slowly re-established as the various rhythms adjust to the new time zone. This internal dissociation between rhythms is thought to be responsible for the disorientation and general malaise typical of 'jet-lag'.

These feelings of jet-lag are normally worse following an eastward flight, which requires an advancing of the body's circadian rhythms, than following a westward one, which requires a delay. This ‘directional asymmetry’ effect is related to the fact that the natural internal period of the circadian system is somewhat greater than 24h. Thus, in the absence of any zeitgebers, rhythms tend to delay rather than to advance, assisting adjustment to westward flights but inhibiting adjustment to eastward ones. This directional asymmetry has implications for the design of shift systems. When shiftworkers go on the night shift, most environmental zeitgebers remain constant and discourage adjustment of the circadian system. The natural light/dark cycle, the clock time, and most social cues do not change while the timing of shiftworkers’ work can be delayed by up to sixteen hours and that of their sleep by up to twelve hours. From what we know so far, it is clear that the adjustment of a shiftworker's body clock to these changes is likely to be very slow, if indeed it occurs at all.

2.2. Review of Empirical Literature on the effects of Shiftwork on Health

In the previous section, we discussed how the experience of shiftwork, especially night work, provokes circadian disharmony. This results in decreases in sleep quality and quantity. In the short term, the effects of these deficits are quite obvious (e.g., increased fatigue, sleepiness), and, if unabated, they can presumably lead to more serious medical conditions (Rajaratnam and Arendt, 2001). In this section, we discuss short-term and chronic health effects of working shifts.

2.2.1. Sleep and Fatigue

Sleep is the primary human function disrupted by shiftwork. Many bodily processes, such as temperature, blood pressure, and heart rate, are at their lowest ebb at night; so, it is not surprising that people who try to work at night and sleep during the day often report that they cannot do either very well. Shiftworkers who need to sleep during the day may have difficulty in falling asleep and remaining asleep because they are attempting sleep when they are at odds with their circadian rhythms. And, because of the conflict between work and personal demands, shiftworkers rarely achieve full adjustment to their shiftwork schedules.

The unfortunate outcome of shiftwork is that both the quality and quantity of shiftworkers’ sleep suffers (Costa, 1996). One almost immediate result is fatigue (Luna, French, & Mitcha, 1997; Tepas & Carvalhais, 1990). Severe sleep disturbances may develop over time and lead to chronic fatigue, anxiety, nervousness, and depression, any or all of which frequently demand medical intervention (Costa et al., 2000). Such effects are aggravated by working hours that are greater than the typical 35-40 hours per week, which often accompany extended (e.g., 12-hour) shifts, or multiple jobs or roles (e.g., “moonlighting”). However, the primary concern with disrupted sleep and resultant fatigue is that it may culminate in the development of more serious conditions, such as serious injury or disease. In the following sections we review the literature relating to health and individual susceptibility and end by considering the trends in accidents that allow us to pinpoint the most problematic features of shift systems.

2.2.2. Psychological/Emotional Disorders

A common finding in shiftwork research is that psychological and emotional distress frequently accompanies shiftwork (e.g., Barton, Smith, Totterdell, Spelten, & Folkard, 1993;Williamson, Gower, & Clarke, 1994), although the magnitude of the effects is sometimes low (e.g., Barton, 1994; Tucker, Barton, & Folkard, 1996). These findings are consistent with the psychological effects of shifting schedules and the resulting sleep disruption discussed previously.

Shiftworkers’ mental states are frequently assessed in empirical studies, although the physical disorders (e.g., gastrointestinal, cardiovascular) appear to have attracted the most attention. However, the psychological distress that often accompanies shiftwork from its onset may be the primary factor that provokes many (approximately 20 - 50%, depending on the data source) to leave shiftwork (Costa, 1996).

2.2.3. Gastrointestinal Disorders

Gastrointestinal disorders are the most prevalent health complaint associated with shift and night work (e.g., Angersbach et al., 1980,Vener, Szabo, & Moore, 1989). According to Costa et al. (2000), 20 - 75% of shift and night workers, compared to 10 - 25% of day workers, complain of irregular bowel movements and constipation, heartburn, gas, and appetite disturbances. Gastrointestinal complaints are commonly assessed in shiftwork studies, and most researchers report reliable effects, although the size of these effects is sometimes small (e.g., Barton et al., 1993). In many cases, these complaints eventually develop into chronic diseases, such as chronic gastritis and peptic ulcers (Costa, 1996).

Night work, not just shiftwork, appears to be the critical factor in the development of gastrointestinal disease (Angersbach et al., 1980). A review of 36 epidemiological studies, covering 50 years of data and 98,000 workers, indicated that disorders of the digestive tract were two to five times more common among shiftworkers who experienced night work than among day workers or shiftworkers who did not work at night (Costa, 1996). Tucker, Smith, Macdonald, & Folkard (1999) also reported that the development of digestive problems was associated with working longer shifts (i.e., 12 hours vs. 8 hours) and relatively early shift changeovers (i.e., 6 am vs. 7 am).

Researchers have often speculated that gastrointestinal problems may be greater for shiftworkers because they have less access to “healthy” food than day workers (i.e., restaurants and stores are often closed between 12 - 6 am), and their irregular hours encourage inconsistent dietary habits. However, the scant research that has addressed this issue (e.g., Lennernas, Akerstedt & Hambraeus. 1994) found no differences in nutritional intake between day and shiftworkers. Other factors, such as circadian disruption and/or sleep deficit, are therefore more likely to be the culprits in this case (Vener, Szabo & Moore, 1989).

2.2.4. Cardiovascular Disorders

Despite years of debate, most researchers now acknowledge that a relationship between shiftwork and cardiovascular disease exists (e.g., Tucker, Barton, & Folkard, 1996). In an impressive longitudinal study spanning 15 years, Knutsson, Akerstedt, Jonsson, & Ortho-Gomer (1986) reported an increased risk of cardiovascular disease in shiftworkers. Specifically, as a group, shiftworkers demonstrated increased cardiovascular risk factors (e.g., smoking) and increased morbidity from cardiovascular disease as years in shiftwork increased. Occupations with a high percentage of shiftworkers are also associated with a greater risk of heart disease (Costa et al., 2000). In a recent meta-analysis of the epidemiological literature on shiftwork and heart disease, Boggild and Knutsson (1999) reported that shiftworkers have a 40% greater risk of cardiovascular disease than day workers.

Similar to our discussion on the origin of gastrointestinal disorders in shiftworkers, the aetiology of cardiovascular disorders is unknown (Akerstedt & Knutsson, 1997). However, Boggild and Knutsson (1999) identify three, shiftwork-related, risk factors, namely (i) a mismatch between circadian rhythms and the timing of sleep, (ii) problems with family and social life, and (iii) the behaviour of shiftworkers including poor eating habits and increased tobacco and alcohol consumption. Shiftwork can also function as a stressor, thus exacerbating the stress response over time and resulting in increased blood pressure, heart rate, cholesterol, and alterations in glucose and lipid metabolism (Costa, 1996).

In a study of over 2,000 Swedish men, Peter, Alfredsson, Knutsson, Siegrist, and Westerholm (1999) reported that, in addition to the direct effects of shiftwork on cardiovascular risk, psychosocial work factors in the form of effort-reward imbalance mediated the effects of shiftwork on cardiovascular risk. Therefore, the evidence to date strongly suggests that shiftwork is a contributing factor in the development of cardiovascular disease, but the specific aetiology is complex and multi-faceted.

2.2.5. Other Individual Factors

Age. Over the age of 45 - 50 years, shiftworkers increasingly encounter difficulties in altering their sleep-wake cycles (Harma, 1993; Nachreiner, 1998). Specifically, with aging, people experience a decrease in slow wave (deep) sleep, an increase in stage 1 (light) sleep, and an increase in the number and length of arousals during sleep (Miles & Dement, 1980). The physiological effects of aging are also associated with a reduction in amplitude and a tendency toward internal desynchronization of circadian rhythms (Costa et al., 2000; Harma, 1993; 1996). Aging is also correlated with morningness, or the expressed preference for morning or early day activity (see next section), such that the circadian activity peak occurs almost two hours earlier in elderly (65+) relative to younger people (Lieberman, Wurtman, & Teicher, 1989). All of these changes in circadian functioning with age imply that shift changes and night work become more difficult to cope with in many shiftworkers over the age of 50.

In addition, health problems increase with advancing age, and the effect of shiftwork generally is to increase the risk to health and decrease shiftwork tolerance (Nachreiner, 1998: Tepas, Duchon, & Gersten, 1993). An interesting finding reported by Oginska, Pokorski, & Oginski (1993) is that female shiftworkers' reports of subjective health improved after age 50, whereas the opposite was true for males. This gender difference may reflect menopausal changes, decreased childcare, or the decreased domestic responsibilities of older women. Another study cited similar reasons for the increased alertness and decreased sleep difficulties reported by older female shiftworkers compared to their younger counterparts (Spelten, Totterdell, Barton, & Folkard, 1995).

Morningness and Circadian Type. Morningness-Eveningness (morning-evening orientation) is defined as the expressed preference for morning or evening activities; the guiding assumption is that people who express preferences for activities at the extremes of the 24-hour day (i.e., early morning or late evening), when feasible, behave in accord with those preferences (Horne & Ostberg, 1976; C. Smith, Reilly, & Midkiff, 1989).

Research has demonstrated that preference for early morning activity is related to phase advances (i.e., earlier circadian peaks), whereas preference for late evening activity is related to phase delays (i.e., later circadian peaks). Morning types are therefore thought to be especially suited to morning or early day shifts and evening types to evening or night shifts (see Tankova, Adan & Buela-Casal, 1994). Morningness is also related to rigidity in sleep habits, or the inability to change sleep schedules, which is especially true for extreme morning types (Hildebrandt & Stratmann, 1979). However, empirical evidence indicates that morningness is only weakly to moderately related to adverse health effects or reduced shiftwork tolerance (e.g., Bohle & Tilley, 1989; Steele, Ma, Watson, & Thomas, 2000), but several conflicting studies do exist (e.g., Costa, Lievore, Casaletti, Gaffure, & Folkard, 1989; Kaliterna, Vidacek, Prizmic, & Radosevic-Vidacek, 1995).

Folkard et al. (1979) hypothesized that flexibility-rigidity, or the flexibility of one's sleeping habits, and "vigour-languidity"[3] are important contributors to adjustment to shiftwork; specifically, people with flexible and low amplitude rhythms should better adjust to the demand of shiftwork. Both the flexibility and vigour dimensions have been reported to relate to long-term tolerance to shiftwork (Costa et al., 1989; Vidacek et al., 1987). In fact, in Vidacek et al.'s (1987) prospective study, "vigour-languidity" was the best predictor of shiftwork tolerance after three years. More recent studies have also supported the relationship between flexibility and vigour and shiftwork tolerance (e.g., Steele et al., 2000).

These individual differences in circadian rhythms have helped researchers to understand why some people prefer, and presumably adapt better to, different shift schedules. However, the use of morningness or circadian type measures as selection and/or placement instruments for night workers and shiftworkers would be premature because (i) relevant validation data are lacking and (ii) they typically account for less than 10% of the variance, although they may be helpful in shiftwork counselling and education programs.

2.2.6. Summary of Health Effects

The research evidence clearly indicates that the experience of shiftwork adversely affects sleep and promotes fatigue. It is also related to the development of mental, gastrointestinal, cardiovascular, and women's reproductive disorders. Although most of the data cannot prove a causal relationship, the convergence of the evidence is strongly suggestive. The most harmful component is the amount of night work, i.e., including work between 00:00 and 06:00, not simply shiftwork. Further, the impact of night work increases with age. However, other than identifying night work as a particular risk, it is not possible from the health literature to make specific recommendations as to the design of shift systems. All that is clear is that shift systems should avoid night work wherever possible, and attempt to minimise any disturbances or truncation of sleep.

2.3. Review of Empirical Literature on the effects of Shiftwork on Accidents and Injuries

Unlike health problems, accidents and injuries can, at least in theory, be attributed to a particular point within a shift system and hence be used to identify particularly problematic features of shift systems. It should be emphasised that most of the studies that have examined a sufficient number of accidents or injuries for valid conclusions to be drawn are from industrial settings such as mining or engineering, although there are a few studies from transport operations. However, shift-related differences in error or accident rates often reflect methodological confounders, such as the type of work performed and the workers' experience. Studies such as L. Smith et al. (1994) where the *a priori* risk was constant are rare. Further, supervision is usually decreased at night, and in some countries (e.g. the USA) night shift workers tend to be less experienced than day workers because of "seniority" systems in allocating shiftworkers to permanent shifts. True shift differences may also be masked by the fact that the day shift typically has the heaviest workload, while maintenance and repair activities are often reserved for the night shift (Costa et al., 2000; L. Smith et al., 1997),

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[3] A measure of peoples' ability to overcome drowsiness.

although this may be reversed in aircraft maintenance. The type of work performed may also vary across different types of shift systems (L. Smith et al., 1997).

Regardless of these issues, however, the potential risk for serious error and injuries on the night shift should not be underestimated. The infamous industrial mishaps in the nuclear facilities at Three Mile Island and Chernobyl, as well as the Exxon Valdez disaster, all occurred during the night shift. Shift schedules and fatigue were cited as major contributing factors to each incident (Price & Holley, 1990). It also seems that, relative to day workers, night workers are more frequently involved in accidents while driving home after work (Monk, Folkard, & Wedderburn, 1996). Sleep deprivation, fatigue, and "shift lag" are the obvious culprits in most of these incidents.

Regrettably, as indicated above, many published studies of accident risk have failed to ensure that the *a priori* risk is constant. Thus in many organisations the number of individuals at work is not constant over the 24-hour day while the level of supervision, etc., may also vary substantially. Further, in most shiftworking situations the nature of the job actually being performed can vary considerably across the 24-hour day because longer, and hence safer, production runs are kept for the night shift. Thus, for example, in the steel grinding industry longs runs of a particular product may be reserved for the night shift to avoid the potentially dangerous re-tooling required between runs of different products. This practice may be official policy within the company. This means that injury rates cannot legitimately be compared across the shifts since fewer injuries would be expected on the night shift, although this may be reversed in aircraft maintenance. When these contaminating factors are controlled for there appear to be four reasonably consistent trends in accidents associated with features of shift systems and/or work hours.

2.3.1 Differences between Shifts

The first consistent trend relates to the relative risk of accidents on morning, afternoon and night shifts on 8-hour shift systems. There are several studies of which the author is aware that are based on relatively large numbers of injuries or accidents, that appear to have overcome the potential contaminating factors, and that have reported accident rates separately for the morning, afternoon and night shifts. The main details of these studies are summarised in Table 1.

Table 1. Summary of the studies of accidents across the three shifts

Author(s)	Industry	Location	Measure	Overall N
Wanat (1962)	Coal Mining	Underground	Injuries	3699
Wanat (1962)	Coal Mining	Above ground	Injuries	1328
Quaas & Tunsch (1972)	Metallurgic Plant	N/A	Injuries	1577
Quaas & Tunsch (1972)	Metallurgic Plant	N/A	Accidents	688
Levin et al. (1985)	Paint Manufacturing	N/A	Injuries	119
L. Smith et al. (1994)	Engineering	Site 1	Injuries	2461
L. Smith et al. (1994)	Engineering	Site 2	Injuries	2139
Wharf (1995)	Coal Mining	"Industrial"	Injuries	c.1970
			Total	**c.13981**

It should be noted that while in some of these studies there were equal numbers of shiftworkers on each shift (namely those of Quaas & Tunsch 1972 and L. Smith et al.1994), in the others the authors had to correct the data to take account of any inequalities (Wanat 1962, Levin et al.1985, and Wharf 1995). In addition, three of the studies report two separate sets of data, for different areas or measures, giving a total of eight sets of data across the three shifts. By expressing the risk on the afternoon and night shifts in each data set relative to that on the morning shift, direct comparisons could be made between the various studies. On average, risk increased in an approximately linear fashion across the three shifts, showing an increased risk of over 17.8% on the afternoon shift, and of about 30.6% on the night shift, compared to the morning shift, and this is shown in Figure 1.

The conclusion to be drawn would seem to be that in situations where the *a priori* risk appears to be constant across the three shifts, there is a fairly consistent tendency for the relative risk of accidents to be highest on the night shift. A similar conclusion can be drawn from the results of Sammel et al (1999) who examined the frequency of airline pilots reporting what they defined as "critical" fatigue scores at different points within long-haul flights during the day and night. Their results showed two main trends. First, in line with the relative risk results, rather more pilots reported critical fatigue scores on night flights than on day flights. Secondly, there was a clear tendency for critical fatigue scores to increase over the course of the flight, and this was particularly marked in the case of the night flights.

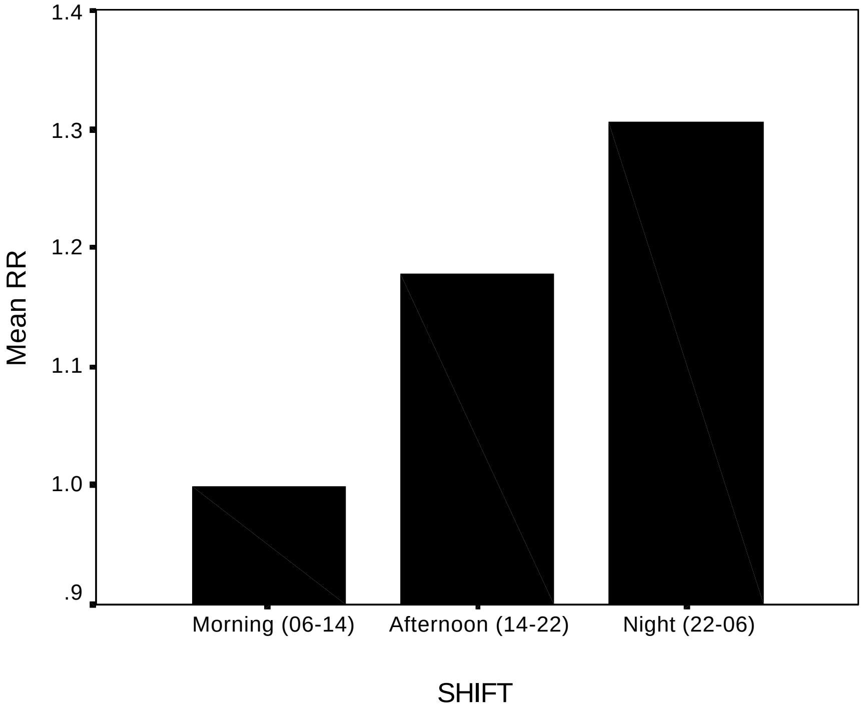

Figure 1. The Mean Relative Risk across the three shifts.
Typical timings of the shifts are shown in brackets.

2.3.2. The Trend in risk over the Night Shift

This second finding of Sammel et al (1999) parallels that of many authors reporting that fatigue increases, or alertness decreases, over the course of the night shift (e.g. Folkard et al 1995, Tucker et al 1999). However, studies of accident and injury rates over the course of the night shift have found a rather different pattern to that which might be expected, and this brings us to the second reasonably consistent trend in accident risk. Vernon (1923) reported one of the earlier studies in this area. He examined trends over the night shift in the frequency of cuts treated at a surgery in two munitions factories and found that, far from increasing over the course of the night shift, the injury rates actually decreased substantially over at least the first few hours of it. Vernon (1923) also reported an indirect measure of productivity, namely the power consumed by the plant, and noted that although this roughly paralleled risk during the day shift, it failed to do so at night. From this observation he concluded that while productivity may have been the major determinant of risk on the day shift, some other factor must have determined risk at night.

More recent studies have also provided hourly accident/injury rates over the course of the night shift and these, together with that of Vernon (1923), are summarised in Table 2. As before, the risk for each hour was expressed relative to that for the first hour in each study in order to enable a comparison across the studies. On average, relative risk rose by 0.2 (i.e. 20%) from the first to second hour, but then fell by about 0.5 (i.e. 50%), and in an approximately linear fashion, to reach a minimum in the eighth hour, and this is shown in Figure 2. It is notable that there was a slight increase in risk between 03:00 and 04:00 when performance and alertness are thought to be at their lowest ebb, but this effect was relatively small compared to the massive decrease in risk over most of the night shift. Thus it would seem that the trend in risk over the night shift does not simply reflect fatigue, but rather that complex factors such as changes in work pressure and/or in risk taking may underlie it.

Table 2. Summary of the studies of accidents over the course of the night shift.

Author(s)	**Industry**	**Measure**	**Total Number (over 8 hours)**
Vernon (1923)	Munitions	Accidents	666
Adams et al (1981)	Coal Mining	Injuries	829
Ong et al (1987)	Steel Mill	Injuries	150
Wagner (1988)	Iron Mining	Accidents	775
L. Smith et al. (1994)	Engineering	Injuries	902
Åkerstedt (1995)	All Occupations	Injuries	c. 2500
Wharf (1995)	Coal Mining	Accidents	777
Macdonald et al (1997)	Steel Manufacturing	Injuries	774
L. Smith et al. (1997)	Engineering	Injuries	657
Tucker (2000)	Engineering	Accidents	274
		Total	**c. 8304**

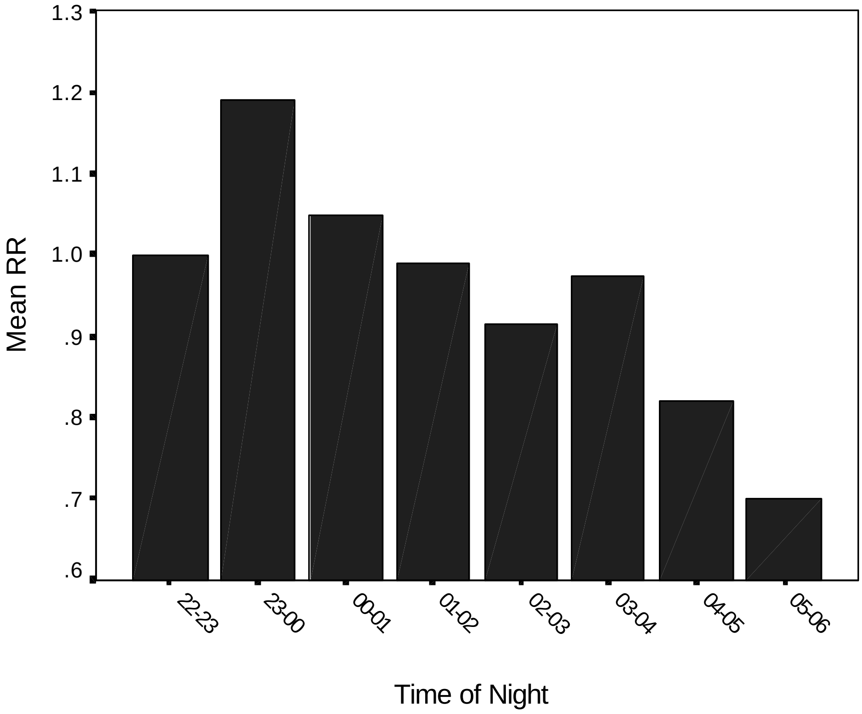

Figure 2. The mean Relative Risk over the course of the night shift

2.3.3. The Trend in risk over Successive Night Shifts

The third reasonably consistent trend in accident risk is that over successive night shifts. The authors are aware of a total of seven studies that have reported accident and/or injury data separately for each night of a span of at least four successive night shifts and these are summarised in Table 3. Note that the data reported by Monk & Wagner (1989) was not included since they were a subset of those reported by Wagner (1988). As before, in order to compare across these studies the risk on each night was expressed relative to that on the first night shift. On average, risk was about 13% higher on the second night, more than 25% higher on the third night, and nearly 45% higher on the fourth night shift than on the first night, and this is shown in Figure 3. This trend is substantially greater than that over successive morning or afternoon shifts.

Table 3. Summary of the studies of accidents across successive night shifts

Author(s)	**Industry**	**Measure**	**Total Number (over 1st 4 nights)**
Quaas & Tunsch (1972)	Metallurgic Plant	Accidents	261
Vinogradova et al. (1975)	Dockers	Accidents	272
Wagner (1988)	Iron Mining	Accidents	442
L. Smith et al. (1994)	Engineering	Injuries	1686
L. Smith et al. (1997)	Engineering	Injuries	842
Tucker (2000)	Engineering	Accidents	286
Oginski et al (2000)	Steel Mill	Injuries	63
		Total	**3852**

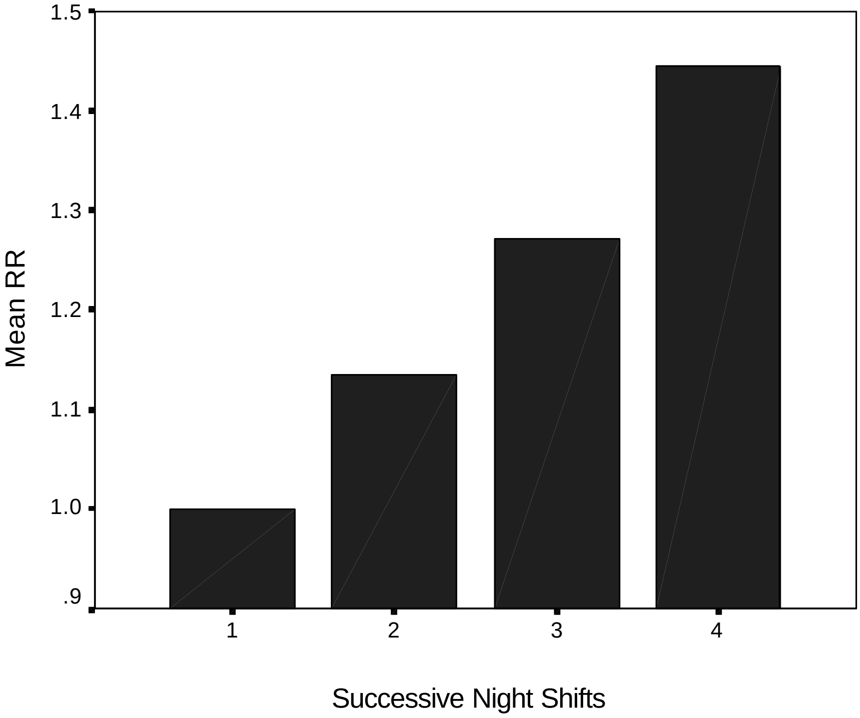

Figure 3. The mean Relative Risk over four successive night shifts

A similar conclusion can be drawn from the results of Sammel et al (1999) who examined the frequency of airline pilots' micro-sleeps over two successive long-haul night flights from Frankfurt to the Seychelles and back. They found that micro-sleeps were more common on the second successive night flight and that this was particularly pronounced during the later hours of the flight. However, again this increase in risk over successive night shifts is inconsistent with ratings of alertness that tend to remain relatively constant over a span of successive night shifts (see, for example, Folkard et al 2000).

2.3.4. The Trend over Hours on Shift

The fourth and final consistent trend in risk concerns the effects of time on shift on accident frequency. The four available studies of these effects, namely those of Akerstedt (1995), Folkard (1996), Haenecke et al (1998) and Nachreiner et al (2000), were recently reviewed by Nachreiner (2000) who gives full details of the studies. By setting the mean risk for the first eight hours at one, it was possible to average across the four studies and the results are shown in Figure 4. It is clear from this figure that apart from a slightly increased risk from the second to fifth hour risk increased in an approximately exponential fashion with time on shift, with the main increase occurring after eight hours on duty. These effects are described in more detail in Folkard (1997).

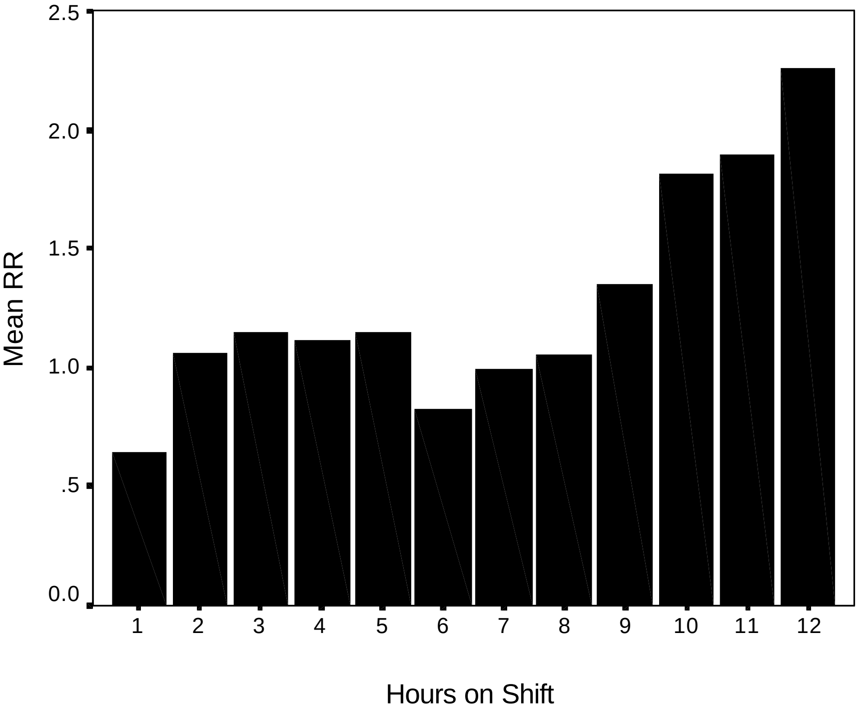

Figure 4. The mean Relative Risk over hours on duty.

2.4. Other Features of Shift Systems

The relative merits of different types of shift systems (i.e., Is there one best type of shift system?) have probably been debated more than any other issue in shiftwork research. The debate has often focused on the advantages and disadvantages of fixed versus rotating systems or different types of rotating systems (e.g., Folkard, 1992; Wedderburn, 1992; Wilkinson, 1992). Although the general consensus is that no best shift system exists, shiftwork researchers agree that some systems are definitely worse than others. To simplify this discussion, each of the major components of shift systems is examined (fixed versus rotating, length of rotation, direction of rotation, number of days off, number of night shifts, length of shift, weekly hours, annual hours, and overtime).

2.4.1. Permanent Shift Systems

Regarding health effects, working during the same period each workday (i.e. permanent) shifts and with normal working hours are certainly preferable than rotating shifts because workers can easily maintain their diurnal (or day-active) orientation. However, an important question is whether shiftworkers on permanent night shifts achieve complete adaptation to their hours of work, i.e. what proportion of people adjust to permanent night shifts?

The increased day sleep durations of permanent night workers relative to that of rotating shiftworkers (Wilkinson, 1992, Pilcher et al, 2000) does not necessarily imply greater adjustment of the circadian system. Rather, it could simply reflect a greater "pressure" for sleep due to the typically greater span of successive night shifts. Indeed, there is some evidence that the average sleep duration per 24 hours over a complete shift cycle is somewhat less in permanent nightworkers than in rotating shift workers (Folkard, 1992). Further, studies of many circadian rhythms (such as temperature) confound adjustment with "masking"[4]. There have been a few studies that have "unmasked" or "purified" temperature data and these typically suggest that the endogenous component of the temperature rhythm adjusts by less than one hour per day when an individual changes from rest days to night work or *vice versa* (see Harma, 2000).

A reliable physiological measure of the internal clock is the rhythm of melatonin, a hormone produced in a brain structure known as the pineal gland. Under normal conditions, melatonin is synthesised and secreted during the night, hence coinciding with the time people normally sleep. There are a very limited number of studies of permanent night workers working in relatively normal situations, i.e. where individuals have been in a normal social environment and exposed to normal daylight and night, in which melatonin rhythms have been measured. First, Waldhauser et al (1986) studied two male permanent night (19:00-04:00) bakers. Both showed abnormal rhythms relative to five control participants, but both showed a peak outside (after) their day sleep period and one had elevated melatonin during the work period. In day workers melatonin normally peaks during hours of sleep). Thus, depending on the criterion used only 1 or 0 out of 2 showed "good" adjustment of their melatonin rhythms, i.e. adjustment demonstrating appropriate resynchronisation of the internal clock to night working.

Sack et al (1992) studied 10 permanent nightworkers from health care and industrial organisations. Only one out of nine participants who completed the study showed the normal timing relationship between their melatonin rhythm and their day sleep, with raised levels during sleep. Six out of nine had elevated melatonin levels during their night work periods. However, all but one showed some phase shift of their rhythm, i.e. depending on criterion used a maximum of 3 out of 9 showed appropriate adjustment of their melatonin rhythms.

Roden et al (1993) studied 9 young, male, permanent night workers (night guards with high work satisfaction) at the end of a week of night work. Only 1 out of 9 showed a clear phase shift of their melatonin rhythm with increased levels occurring at about 12:00 (instead of about 22:00). The remaining eight nightworkers showed melatonin rhythms that were indistinguishable from day working controls. They conclude that "even during permanent night work the setting of the endogenous clock does not normally lose its diurnal orientation" (p R266).

Koller et al (1994) studied 14 male permanent night watchmen. The timing of melatonin in 5/14 was more than 6 hours after midnight, but in only 2/14 the phases were outside the timing of normal nights sleeps, i.e. depending on criterion used only 5 or 2 out of 14 showed appropriate adjustment of their melatonin rhythms (estimate is 35.7% or 14.3%).

Quera-Salva et al (1996 &1997) report a (single) study of 20 permanent night working nurses and 20 permanent day working nurses on both work and rest days, with 16 females and 4 males in each group. On rest days the melatonin rhythm of nightworkers peaked about two hours later (at about 07:00) than that of day workers. The melatonin rhythm of dayworkers peaked at about the same time on work days as on rest days, whereas that of nightworkers showed a "random distribution" on work days. The authors distinguished two sub-groups of nightworkers. The larger group had a

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[4] The direct influence of external factors such as activity level on the variable under consideration. Thus, for example, body temperature is known to rise with physical or mental activity and to fall during sleep, irrespective of any circadian changes. These externally induced changes can "mask" what is happening to the endogenous circadian rhythm.

similarly timed melatonin peak on work days as on rest days. The smaller group (N=6) had a peak that was delayed by an average of five hours (i.e. to about 12:00), although the large standard deviation (± 40 mins) suggests considerable variation across individuals.

To summarise, a total of 31 male and 24 female permanent nightworkers have been examined in five studies with respect to their circadian rhythms in melatonin on a permanent night shift. Of these 55 individuals, between 10 and 16 (i.e. between 18% and 29%) of them showed appropriate adjustment of their melatonin rhythms to night work, depending on the criterion used. It is also noteworthy that there was no evidence of any difference between the studies in which females predominated and those that confined their attention to males. Thus, using the less conservative criteria of appropriate ("good") adjustment, in the studies in which females predominated 9 out of 24 individuals(i.e. 38%) showed evidence of good adjustment, while in the studies of males only, 7 out of 25 (i.e. 28%) showed evidence of adjustment. Unfortunately, not all the studies report the results for each individual, and those that do fail to identify the males and females.

Thus it seems reasonable to conclude (i) that only a relatively small minority of permanent night workers show evidence of appropriate adjustment of their circadian systems to night work, and (ii) that there is little, if any, evidence of a gender difference in this respect. Thus the available evidence suggests that the use of permanent night shifts is unlikely to result in improved safety and reduced health risk relative to those found on rotating shift systems. Of course, if one could identify and select the minority of permanent nightworkers who do show good adjustment, then, at least in theory, this might result in improved safety and health.

2.4.2. Rotating Shift System

Rotating shifts present a wide array of options. One of the most common rotating shifts is the weekly rotation, in which shiftworkers change their shift schedule every week. Unfortunately, the weekly rotating shift is also one of the worst from a circadian perspective: just as the shiftworker starts to adapt (i.e., circadian rhythms begin to shift), the shift changes, and adaptation must begin again. Indeed, complete adaptation to an 8-hour night shift theoretically requires at least 14 nights with no rest days, and it is questionable as to whether complete adaptation does occur in most individuals (see above). It has been argued that very slowly rotating shifts (e.g., this shift changes every 3- 4 weeks) are more acceptable, but this assumes that shiftworkers adapt to the night shift and maintain their night-oriented routine on rest days, an assumption that is normally not true.

When considering circadian effects, most shiftwork researchers advocate a rapidly rotating shift system (i.e., one that changes every 2-3 days). Such a rapid rotation limits the number of consecutive night shifts, thus permitting shiftworkers to retain a diurnal orientation. Thus, no re-adaptation to a new shift is required, and night work only has to be endured for two or three nights. This minimises the build up of a cumulative sleep debt and, as we have already seen, should also result in a decreased risk of accidents and injuries (Folkard, 1992; Knauth, 1993).

2.4.3. Number of Successive Nights

Indeed it is possible to use the results plotted in Figure 3 above to estimate the relative risk of shift systems involving different numbers of successive night shifts. In order to further explore the trend shown in Figure 3 over successive night shifts a linear function was fitted to the mean values for the four successive nights, and which accounted for over 96% of the variability. This curve was then extrapolated to estimate the risk for up to 7 successive night shifts, and suggested that, relative to the first night shift, risk would be 87% higher on the seventh night shift. Indeed, when a better fitting exponential curve that accounted for over 99% of the variability was used, estimated risk more than doubled by the seventh night shift. Using the more conservative linear fit it was then possible to work out the relative risk of shift systems involving between one and seven successive night shifts, and this is shown in Figure 5. From this Figure it is possible to estimate the relative risk of any given block size (i.e. the number of successive night shifts). Thus, for example, the average risk for a block size of two successive night shifts is 1.066 while that for five successive night shifts is 1.274, and from this it can be calculated that blocks of five nights have a 19.5% increased risk compared to blocks of only two nights.

Of course, these estimates assume that risk would continue to increase over more than four night shifts. If the shiftworkers' body clocks start to adjust to night work then there is some reason to suppose that risk might actually decrease over subsequent night shifts. Indeed it is noteworthy that two of the studies shown in Table 3, namely those of Quaas & Tunsch (1972) and Tucker (2000), actually show a slight decrease in risk from the third to the fourth night shift. Further, the studies of both Vinogradova et al (1975) and Wagner (1988) showed a decrease in risk from the fourth to the fifth night shift and this decrease was maintained until the seventh, and final, night shift in Wagner's (1988) study. However, these changes may simply reflect chance variations, and in this context it is noteworthy that these studies examined relatively small numbers of accidents/injuries. Thus there is a possibility that risk may decrease over numbers of successive night shifts greater than four, but there is insufficient evidence to conclude that this is actually the case.

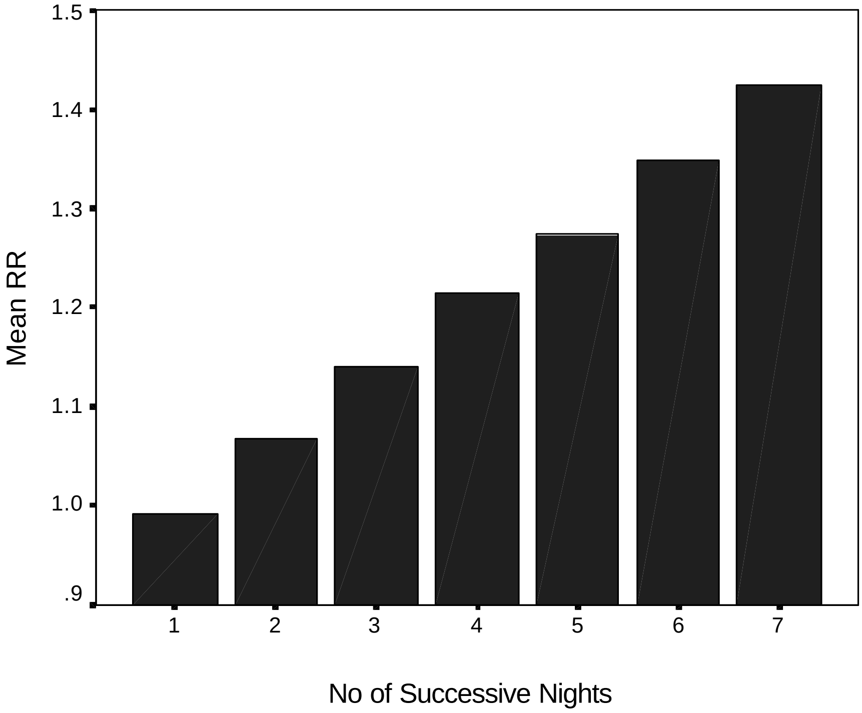

Figure 5. The Relative Risk of different sized blocks of successive night shifts.

2.4.4. Direction of Rotation

The direction of the rotation is another shift characteristic that may influence the physiological adaptation to the shift schedule (see Knauth, 1993, for a review; Totterdell & Folkard, 1990). A shift system that progresses from morning to evening to night shift is a forward rotating system because it rotates in a clockwise fashion (phase delay); a shift system that progresses from night to evening to morning shifts is a backward rotating system because it rotates in a counter clockwise (phase advance). The forward rotating system is preferable from a physiological perspective because it complements the body's endogenous circadian rhythms, which have a cycle of slightly more than 24 hours (see above). In other words, a forward rotating system is equivalent to flying west, thus gaining time. The existing data favour the forward rotating system's hypothesized superiority, especially in terms of less fatigue, higher alertness, and fewer sleep disturbances (e.g., Barton & Folkard, 1993; Tucker, Smith, Macdonald, & Folkard, 2000). However, too few studies have compared forward and backward rotating systems to permit any generalization (Tucker et al., 2000).

2.4.5. Number of Rest Days

When designing shift schedules, the number of days off between shifts must be considered (Knauth, 1993). Sufficient time off between shifts is necessary to reduce sleep debt and fatigue and maintain well-being. After more than two-three days on the night shift, several days of leisure time may be needed to recuperate before the next shift (e.g., Tepas & Mahan, 1989; Totterdell, Spelten, Smith, Barton, & Folkard, 1995).

2.4.6. Shift Length

The effects of shift length, usually 8 versus 12 hours, have been debated without any real resolution. The 12-hour shift or compressed workweek has been very popular in industry and health care because this type of compressed schedule permits longer blocks of free or leisure time, reduces the number of shift changeovers and the total commuting time and cost. Indeed, not only are 12-hour shifts typically very popular with the workforces concerned, but there is no good evidence to suggest that they exacerbate health problems (see below). However, in 12-hour shifts, increased fatigue is a major concern and if the shift involves night work, these effects may be problematic. Shiftwork researchers have therefore typically recommended that 12-hour night shifts be limited to one or two consecutive nights. Longer shifts also permit longer exposure to environmental toxins, such as industrial by-products; most threshold values are based on an 8-hour working day, and the risk for a 12-hour day (longer exposure) is usually unknown (Knauth, 1993).

Empirical comparisons of the health and sleep-related effects of 12-hour shift systems have generally been positive (e.g., Johnson & Sharit, 2001; Mitchell & Williamson, 2000;Williamson, Gower, & Clarke, 1994), with a few exceptions (e.g., Bourdouxhe et al., 1999). In a recent review of the research evaluating shift length, L. Smith, Folkard, Tucker, and Macdonald (1998) also concluded that shiftworkers on 12-hour shifts, compared to those on 8-hour shifts, do not experience greater difficulties with sleep, health, and well-being, and may even show improvements. They cautioned, however, that several factors need to be taken into account in each case before adopting 12-hour systems. Specifically, older shiftworkers may be at greater risk for excessive fatigue and medical complaints. Shiftworkers who must perform physically demanding tasks, endure exposure to toxic substances, and/or cope with an accumulation of job-related stressors (e.g., noise, adverse weather, etc.) may also be at greater risk.

It is possible to utilise the mean trend shown in Figure 4 to estimate the relative risk of shifts of different lengths. This is shown in Figure 6. Note that the risk of an eight-hour shift has been set at one based on the procedure described above. From this figure it is clear that variations in shift length from about 3 to 9 hours 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 from the present perspective is that we can now estimate the increased risk on longer shifts. Thus it would appear that, on average over the entire shift, ten hour shifts are associated with an 11.6% increased risk, and twelve hour shifts with a 27.6% increased risk, relative to eight-hour shifts.

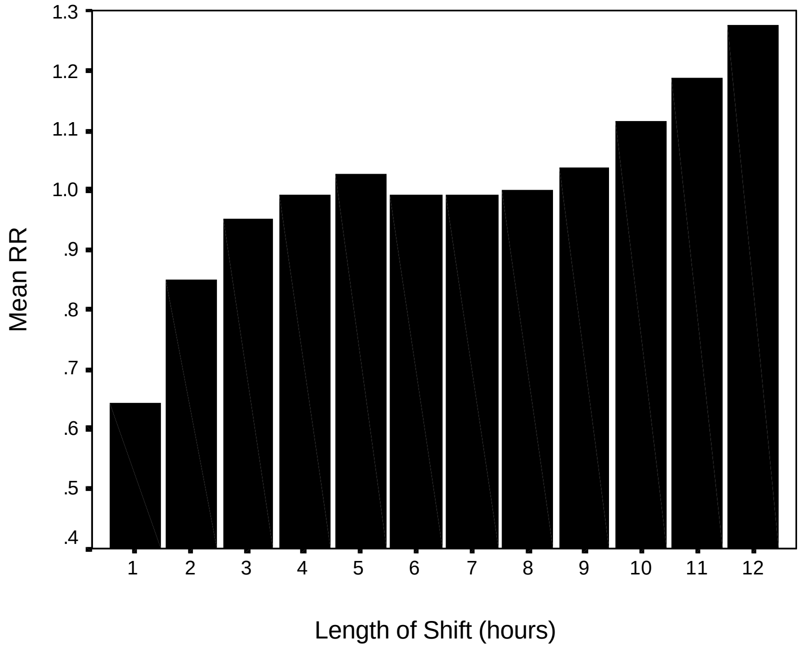

Figure 6. The estimated Relative Risk on different lengths of shift.

2.4.7. Shift length and number of Successive Night Shifts

Clearly the increased risk on twelve hour shifts shown in Figure 6 needs to be considered in the light of the reduced number of successive night shifts typically worked on 12-hour shift systems. Thus it is necessary to combine the estimates shown in Figure 6 with those shown in Figure 5. The most assumption-free manner of doing this is to simply add the increased risk associated with 12-hour shifts to the values plotted in Figure 5, and this is shown in Figure 7. From this figure it is clear that the span of two successive 12-hour night shifts found in many 12-hour shift systems is associated with almost exactly the same risk as a span of six successive 8-hour night shifts. Likewise, a span of three 12-hour shifts has almost the same risk as a span of seven 8-hour shifts. From this it may be concluded that on average 12-hour shifts are associated with more accidents per hour of work than are eight-hour shifts.

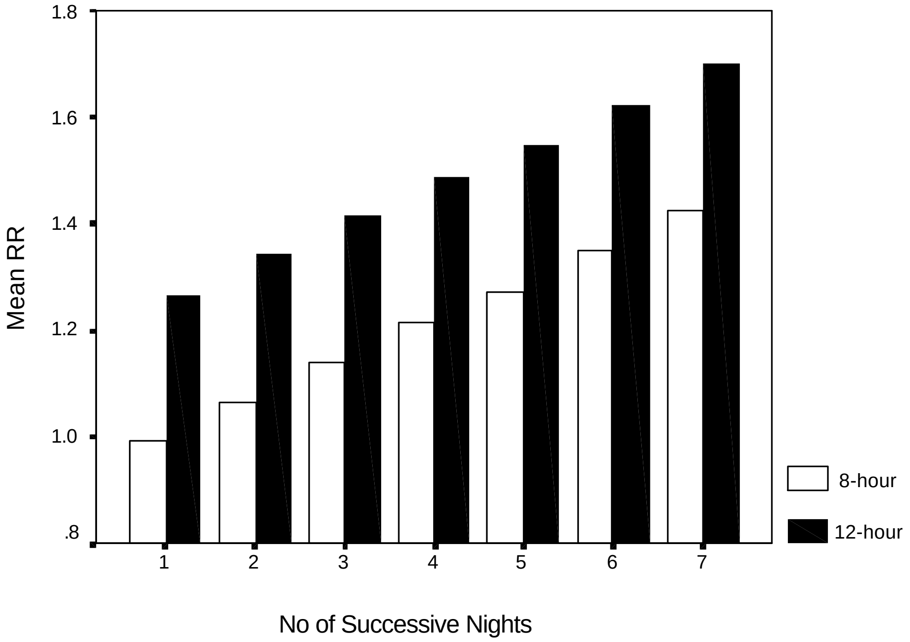

Figure 7. The estimated Relative Risk on different spans of 8- and 12-hour shifts.

2.4.8. Early starts

Early starts are a prominent feature of some shift systems, and shifts as early as 04:00 are sometimes scheduled. These early shifts are usually associated with a reduction in sleep duration. Difficulties in obtaining adequate sleep prior to the start of duty have been reported in a number of studies (Knauth et al 1983, Folkard et al 1990, Folkard & Barton 1993). Indeed Folkard & Barton (1993) were able to estimate that for every hour earlier that the shiftworkers had to leave home to start their morning/day shift, they slept for 46 minutes less. Full-length 8-hour sleeps were only obtained when those concerned left home after 08:00. Thus earlier start times resulted in a progressive and substantial truncation of sleep duration. In addition, even a 1-3 hour curtailment of sleep has been shown to reduce levels of alertness during the following day (Kecklund et al 1994, Akerstedt et al 1982).

An earlier bedtime to compensate for an early start may not be practical, partly as a result of social pressures, but also because of the influence of the so-called 'forbidden zone' for sleep (Lavie, 1986). This is a period, lasting for about 4 hours in the evening, when the body's higher level of alertness hinders the onset of sleep. Thus, even if shift-workers retire to bed early, they may experience difficulties in falling asleep. A further problem is that sleep prior to an early shift may be disturbed by the fear of not being able to wake up sufficiently early (Folkard & Barton 1993). In sum, it would seem desirable to avoid early start times, and if they are unavoidable, to minimise any resultant cumulative sleep debt by restricting the number of successive early shifts.

2.4.9. Weekly and Annual hours

Excessive weekly hours, annual hours, and overtime are critical factors to consider in the workplace, especially for shiftworkers (Spurgeon, Harrington, & Cooper, 1997). In their meta-analyses on the effects of hours of work on health, Sparks, Cooper, Fried, and Shirom (1997) reported small, but significant, positive mean correlations between health symptoms, physiological and psychological health symptoms, and hours of work. This issue has become especially salient with the popularity of 12-hour shifts, which afford shiftworkers sufficient free time to "moonlight" or obtain alternate employment; their schedule also permits them to 'double-shift' i.e. work two shifts if needed. The problems of excessive fatigue, sleep deficits, and over-exposure to workplace toxins may become very serious in these situations, and the health of the shiftworkers in question should be closely monitored.

2.5. Education and Counselling Programs

Before making specific recommendations for best practice, it is worth considering the efficacy of education and counselling programs that have been used to impart information that can aid adaptation to shiftwork. Programs or workshops that deliver mostly general information about shiftwork and its effects on human functioning, as well as recommendations for coping with these issues, have been reported, for example, for emergency room physicians (Smith-Coggins et al., 1997). Smith-Coggins and colleagues devised a well-controlled study using both objective and subjective criteria to assess the effectiveness of the workshop they presented to a group of physicians. However, their results indicated that, although the physicians in the experimental group used the strategies they learned 85% of the time according to their logbook entries, the intervention did not significantly improve the criteria (performance and mood).

The disappointing results in this well-controlled study support Tepas' (1993) argument that educational information alone is often not particularly helpful, and in some cases, may actually be misleading or confusing. The workshop content usually has face validity but questionable criterion-related validity, or the assessment of the workshop material relative to its ability to change important criteria (e.g., sleep, mood; see Smith-Coggins et al., 1997). Tepas maintained that "educational workshops are best used in the context of a larger effort to improve the existing shift schedule". Such a process was employed by Sakai, Watanabe, & Kogi (1993); they used an educational program to aid them in analysing, planning, and implementing an improved shift rotation schedule in a disabled persons' facility.

3. The Survey of Aircraft Maintenance Personnel

3.1 Questionnaire administration

This survey studied all licensed British aircraft maintenance engineers who worked both inside and outside of the UK. The study was introduced to the potential population in the CHIRP "Feedback" newsletter that was sent to all the engineers concerned before the questionnaires were administered.

3.2 Participants

Completed questionnaires were returned by 2210 engineers of the initial 8,000 (approximately) who received the survey, giving a response rate of 27.6% overall. However, 117 of these were excluded from further analysis for various reasons. 12 were returned by retired engineers while a further 74 did not complete their shift system details. In addition, questionnaires arrived after the cut-off date and were thus too late to be included in the analyses, leaving a total of 2093 analysed questionnaires. These questionnaires were returned from workers at 197 different companies, across 156 sites. Although over 100 different work patterns were found, for the purposes of analysis, these were grouped into 5 main categories, of which: (1) 32.49% worked rotating shifts involving nights; (2) 30.24% worked rotating shifts without nights; (3) 9.13% worked permanent nights; (4) 1.43% worked permanent afternoons; and (5) 26.71% worked permanent mornings.

3.3. Biographic Details

The following sections summarise the biographic details for each group (see Tables 4 & 5).

3.3.1 Rotating shifts with nights

Of the 680 engineers who worked a rotating shift involving night work, the majority were male (99.3%) and based in the UK (94.9%). Mean age was 43.15 years (SD 9.74) with a range from 23 to 65 years. As expected this was reflected in the wide extent of work and shiftwork experience. For example, the number of years spent as an engineer ranged from 2 to 47 years ($\bar{x}$ 23.74; SD 9.89), whilst the number of years in the present job ranged from 0.5 to 41 years ($\bar{x}$ 9.11; SD 8.27). In terms of shiftwork experience, the average was 17.57 years (SD 9.19), although, again, this showed a wide range (1-43 years), whilst the number of years spent working the present shift pattern was much less at 6.96 years (SD 6.05; range 0.5-30 years). Of those sampled 96.3% had a high level of responsibility with 96.9% being directly employed by the company. Mean commuting time was 38.7 minutes (SD 25.12) although some took 5 minutes whilst others took up to 5 hours.

In terms of the shift patterns within this category, the mean number of hours scheduled to work per week was 42.63 (SD6.74; range 8-84), although the hours normally worked was somewhat higher at 46.13 (SD 8.53; range 20-90). By far the most common work pattern within this category was the 2 day/2 night/4 rest ('D2N4R) schedule, accounting for 66.57% of those working a rotating shift with nightwork. The second most popular was '4D4R4N4R', accounting for 8.84% of the population. The day shift involving work at any time between 08:00hrs and 22:00hrs.

3.3.2. Rotating shifts without nights

As with the previous group, of the 633 engineers who worked a rotating shift without nights, the majority were male (99.7%) and based in the UK (95.6%). Mean age was 45.66 years (SD 9.90) with a range from 17-65. The number of years spent as an engineer ranged averaged at 26.25 years

(SD 9.93; range 5-50), whilst the number of years in the present job ranged averaged at 12.81 years (SD 10.22, range 0.5-43). Shiftwork experience varied from .5 through to 47 years ($\bar{x}$ 20.51; SD 9.61), whilst the number of years spent working the present shift pattern showed similar results with a range of 0.5-40 years, but a lower mean of 6.71 years (SD 8.15). Of those sampled 93.2% had a high level of responsibility with 97.6% being directly employed by the company. Mean commuting time amongst this group was 33.8 minutes (SD 20.4) although some took less than 5 minutes whilst others took up to 3 hours.

In terms of work patterns, the mean number of hours scheduled to work per week was 39.77 (SD 5.07; range 20-64), although the hours normally worked was slightly higher at 42.29 (SD 6.35; range 24-70). The shift system worked by the largest number of engineers within this sample was a '7M4R7A3R' schedule, worked by 22.7%, although this was closely followed by the '3M4A3R4M3A4R' pattern, worked by 18.61%.

3.3.3. Permanent nights

Of the 191 engineers who worked a permanent night shift, all were male, with 96.9% based in the UK. Mean age was 43.83 years (SD 10.29) with a range from 23-68. The number of years spent as an engineer ranged averaged at 24.56 years (SD 10.07; range 5-48), whilst the number of years in the present job ranged averaged at 9.90 years (SD 8.74, range .5-44). Shiftwork experience varied from 1 to 44 years ($\bar{x}$ 17.73; SD 9.54), whilst the number of years spent working the present shift pattern ranged between 0.5-36 years, with a mean of 6.35 years (SD 7.53). Of those sampled 92.1% had a high level of responsibility with 94.2% being directly employed by the company. Mean commuting time amongst this group was 36.7 minutes (SD 36.62; range 4.8 mins-7 hours).

In terms of work patterns, scheduled work hours averaged at 40.53 (SD 7.25; range 12-84), although, as with previous groups, the hours normally worked was slightly higher at 44.32 (SD 8.21; range 30-80). The most popular shift system within this sample was a '4N4R' schedule, worked by 36.1%, although the alternative '4N3R' schedule was worked by a comparative number (27.7%). The only other prominent pattern within this category was a '7N4R7N3R' schedule worked by 16.2%.

3.3.4. Permanent afternoons

The smallest cohort, only 30 engineers working permanent afternoons returned a survey. All were male and based in the UK. Mean age was 44.47 years (SD 10.71) but ranged from 21-65. The number of years spent as an engineer ranged averaged at 22.77 years (SD 10.62; range 3.5-46), whilst the number of years in the present job ranged averaged at 8.27 years (SD 7.35, range .5-25). Shiftwork experience varied from 0.5-37 years ($\bar{x}$ 16.91; SD 10.05), whilst the number of years spent working the present shift pattern was much lower at just 2.09 years (SD2.17; range 0.5-11). Of those sampled 90.0% had a high level of responsibility with 93.3% being directly employed by the company. Mean commuting time amongst this group was 34.2 minutes (SD 14.96; range 10mins-1 hour 10 mins).

In terms of work patterns, scheduled work hours averaged at 40.77 (5.12; range 37-60), although, as with previous groups, the hours normally worked was slightly higher at 43.80 (SD 7.63; range 16-60). The shift system worked by the largest number of participants within this category was a '4A4R' schedule, worked by 37.9% of those concerned. The only other prominent patterns within this category were a '6A4R4A6R4A4R' schedule worked by 10.3% and a '3A3R' schedule worked by 6.9%.

Table 4. Biographic details by shift type

	Rotating with nights (n=680)	Rotating without nights (n=633)	Permanent nights (n=191)	Permanent afternoons (n=30)	Permanent mornings (n=559)
	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$ (SD)
Age (yrs)	43.15 (9.74)	45.66 (9.90)	43.83 (10.29)	44.47 (10.71)	45.14 (10.48)
Engineering experience (yrs)	23.74 (9.89)	26.25 (9.93)	24.56 (10.07)	22.77 (10.62)	25.50 (10.76)
Present job experience (yrs)	9.11 (8.27)	12.81 (10.22)	9.90 (8.74)	8.27 (7.35)	7.79 (7.52)
Shiftwork experience (yrs)	17.57 (9.19)	20.51 (9.61)	17.73 (9.54)	16.91 (10.05)	16.44 (9.79)
Present shift experience(yrs)	6.96 (6.05)	6.71 (8.15)	6.35 (7.53)	2.09 (2.17)	4.82 (6.35)
Commuting time (mins)	38.70 (25.12)	33.79 (20.44)	36.71 (36.62)	34.22 (14.96)	36.58 (27.07)
Scheduled hrs/week	42.63 (6.74)	39.77 (5.07)	40.53 (7.25)	40.77 (5.12)	40.82 (7.06)
Actual hours/week	46.13 (8.53)	42.29 (6.35)	44.32 (8.21)	43.80 (7.63)	45.86 (9.26)

Table 5. Biographic details by shift type*

	Rotating with nights (n=680)		Rotating without nights (n=633)		Permanent nights (n=191)		Permanent afternoons (n=30)		Permanent mornings (n=559)	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Gender:										
Male	675	99.3	631	99.7	191	100	30	100	551	98.6
Female	5	0.7	2	0.3	0	-	0	-	8	1.4
Level of responsibility:										
High	655	96.3	590	93.2	176	92.1	27	90.0	484	86.6
Low	18	2.7	40	6.3	13	6.8	3	10	67	12.0
Contract type:										
Employed directly	659	96.9	618	97.6	180	94.2	28	93.3	519	92.8
Contracted	16	2.4	14	2.2	8	4.2	2	6.7	35	6.3
Country of work:										
UK	644	94.9	605	95.6	185	96.9	30	100	540	96.6
Outside UK	26	3.8	28	4.4	6	3.1	-	-	15	2.7

*N.B. Note that the percentages do not always sum to 100% because of missing information.

3.3.5. Permanent mornings

Of the 559 engineers who worked a permanent morning shift, 98.6% were male, with 96.6% based in the UK. Mean age was 45.14 years (SD 10.48; range 21-67). The number of years spent as an engineer ranged averaged at 25.50 years (SD 10.76; range 0.5-50), whilst the number of years in the present job ranged averaged at 7.79 years (SD 7.52, range 0.5-40). Shiftwork experience varied from .5 to 50 years ($\bar{x}$ 16.44; SD 9.79), whilst the number of years spent working the present shift pattern ranged between 0.5-48 years, with a mean of 4.82 years (SD 6.35). Of those sampled 86.6% had a high level of responsibility with 92.8% being directly employed by the company. Mean commuting time amongst this group was 36.6 minutes (SD 27.07; range 4.8 mins-4.5 hours).

In terms of work patterns, scheduled work hours averaged at 40.82 (SD 7.06; range 8-96), although, as with previous groups, the hours normally worked was slightly higher at 45.86 (SD 9.26; range 3-84). By far the most common work pattern within this category was the '5D2R' schedule, accounting for 51.9% of those working permanent mornings/days. The second most popular was '4D4R', accounting for 27.7% of the population.

3.4. Comparison of groups

Table 6 shows a summary of the group comparisons. Comparisons between the 5 shift types on the demographic variables showed that the groups differed on age ($F_{(4,2080)}$=5.901, p<.001): those working rotating shifts with nights were significantly younger than those working permanent mornings or rotating shifts without nights. A similar trend was observed in the number of years spent in engineering in that those working rotating shifts with nights had been involved for less time than those working permanent mornings or rotating shifts without nights ($F_{(4,2018)}$=5.584, p<.001).

Table 6. Analysis of Variance summary of group comparisons

	F	df	sig
Age (yrs)	5.901	4,2080	.000
Engineering experience (yrs)	5.584	4,2018	.000
Present job experience (yrs)	26.064	4,2004	.000
Shiftwork experience (yrs)	13.671	4,1910	.000
Present shift experience (yrs)	9.995	4,1945	.000
Commuting time (mins)	3.011	4,2002	.017
Schedules hours/week	15.730	4,1919	.000
Actual hours/week	19.783	4,1836	.000

In terms of the experience of the present job, most groups, apart from permanent afternoon workers, differed significantly from one another ($F_{(4,2004)}$=26.064, p<.001) with rotating shifts without nights having the greatest, and permanent mornings having the least. Similarly, for overall shiftwork experience, those working rotating shifts without nights had the greatest experience, whilst permanent morning workers had the least. Here all groups, with the exception of permanent afternoon workers, had significantly less experience ($F_{(4,1910)}$=13.671, p<.001) than those working rotating shifts without nights.

As can be seen in Table 4, both permanent morning and afternoon shiftworkers had less experience of their present shift pattern than those working permanent nights or rotating shifts ($F_{(4,1945)}$=9.995, p<.001). This was supported in post hoc comparisons where experience of the morning shift was significantly lower than that for rotating shifts, whilst those working permanent afternoons had significantly less experience than those working permanent nights or rotating shift patterns. Only the two rotating shift categories showed a significant difference in commuting time ($F_{(4,2002)}$ =3.011, p<.05), where those working rotating shifts with nights travelled for an average of 5 minutes longer than those who did not work nights as part of their shift pattern.

In terms of scheduled work hours all groups, with the exception of afternoon workers, differed significantly from those working rotating shifts with nights ($F_{(4,1919)}=15.730$, $p<.001$) who worked the highest number of hours. However, those working permanent morning shifts also differed from those working rotating shifts without nights who had the shortest hours. For actual work hours ($F_{(4,1836)}=19.783$, $p<.001$), all groups, with the exception of permanent afternoons, differed significantly from those working rotating shifts without nights who worked the fewest hours.

3.5 Survey results

3.5.1. Hours per week

The mean number of scheduled, normal and maximum hours worked per week is shown in table 7. The use of related t-tests indicated that the engineers normally worked significantly longer (by 3.41 hours) than they were scheduled to ($t=26.55$, $df=1863$, $p<0.001$), and also that the maximum hours worked per week was significantly higher (by 7.69 hours) than the normal hours worked ($t=46.53$, $df=1709$, $p<0.001$).

Table 7. Hours worked per week

Hours per week	Mean	Standard Deviation	Valid N
Scheduled	42.43	4.48	1969
Normal	45.84	6.48	1891
Maximum	53.53	7.53	1764

Inspection of the frequency histograms (Figures 8a-c) indicates that the majority (over 64%) of engineers were scheduled to work between 36.1 and 40 hours per week, but that a significant minority (over 28%) were scheduled to work between 40.1 and 48 hours per week. Very few engineers were scheduled to work either l36.0 hours or less, or more than 48.0 hours per week, although it is perhaps somewhat alarming to note that a few individuals (1.4%) said that they were scheduled to work in excess of 60.0 hours per week.

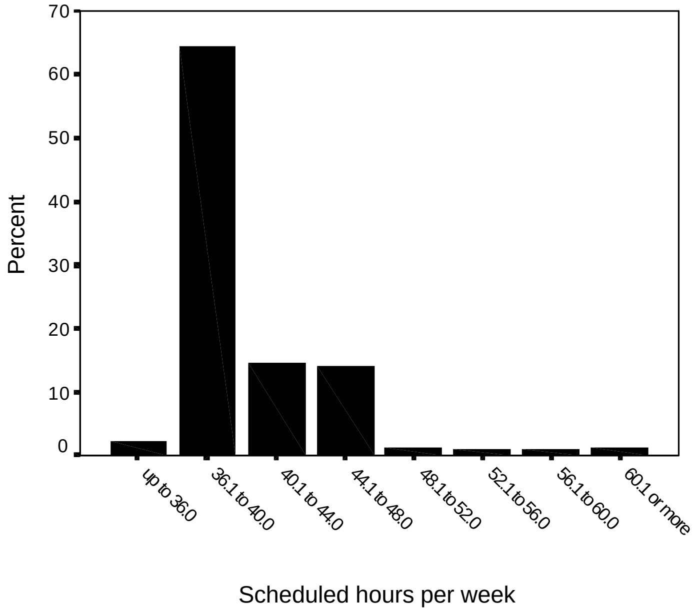

Figure 8a. Frequency distribution of scheduled hours per week.

However, the situation with respect to the hours normally worked per week was rather different (Figure 8b) Here, substantially fewer engineers (36.2%) stated that they normally work 36.1 to 40.0 hours per week than were scheduled to do so, while substantially more worked in excess of 44.0

hours per week. This spread of work hours towards longer working weeks was even more marked when the maximum work hours per week were considered (Figure 8c). Here, less than 20% of the engineers stated that the maximum number of hours that they worked in any one week was 44.0 hours or less, while 34% stated that their maximum was in excess of 60.0 hours.

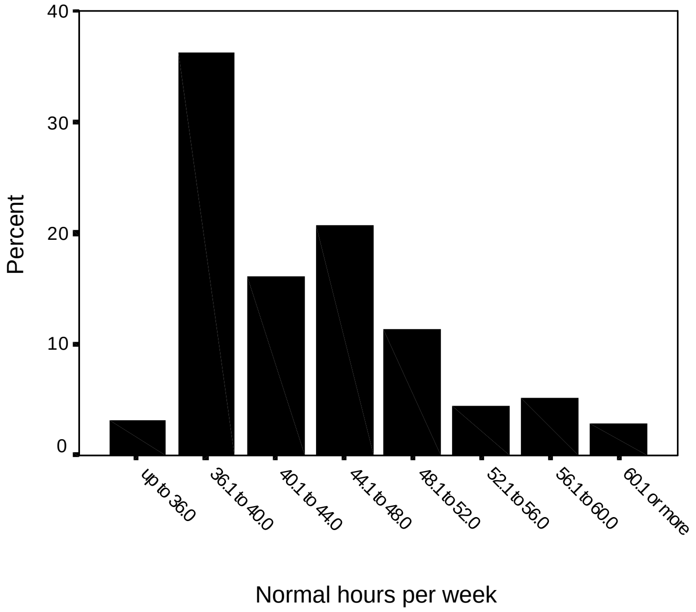

Figure 8b. Frequency distribution of normal hours per week.

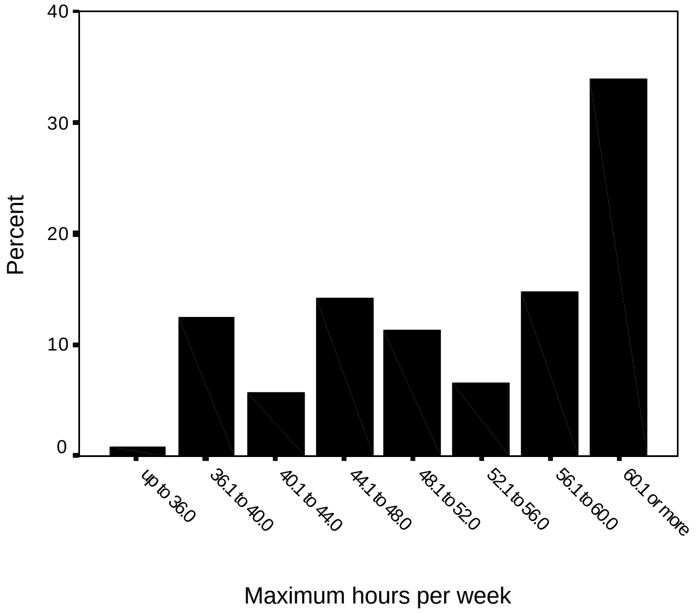

Figure 8c. Frequency distribution of maximum hours per week.

Recommendation: A limit on scheduled hours per week of 48 hours would seem appropriate, and would restrict only 4.8% of those sampled. Similarly, a maximum of 60 hours per week, to include both paid and unpaid overtime, would restrict only 2.9% of the "normal hours" worked, but some 34% of the maximum hours worked. While this figure may seem rather large, it is clear that the maximum values reported by many individuals were really quite extreme and would, presumably, seldom have been worked.

3.5.2. Length of Shifts

It is clear from the next three graphs (Figures 9a-c) that the three shifts differed substantially from one another in terms of their scheduled lengths. The Morning or Day shift was most frequently (over 45.1%) between 7.1 and 9 hours long, but for a substantial minority (43.4%) it was 12 hours long. More specifically, if the engineers were on a rotating shift system that included nights their system was normally a 12-hour one. In contrast, if their shift system excluded nights then their shifts were normally about 8 hours long. This is supported by inspection of the scheduled lengths of the afternoon and night shifts. The former were almost always between 7.1 and 9.0 hours long, while the latter were normally 12 hours long. Indeed, the few engineers who worked night shifts that were less than 12 hours long were almost always on a permanent night shift.

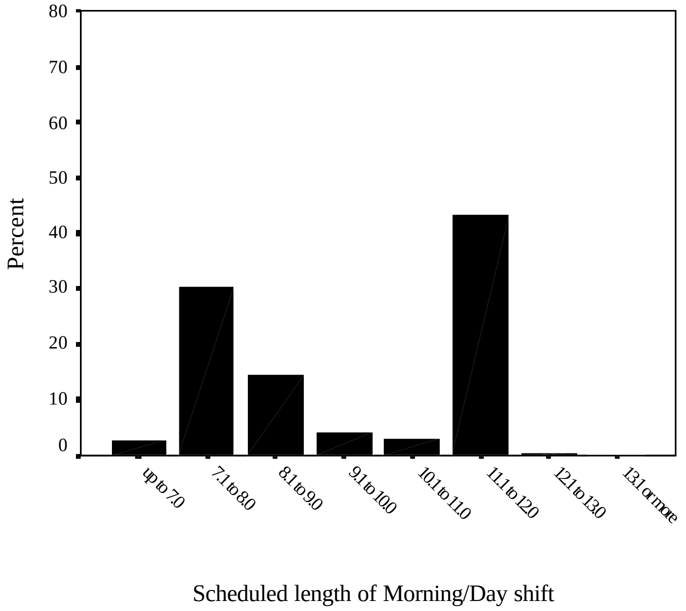

Figure 9a. Frequency distribution of the scheduled length of the Morning/Day shift.

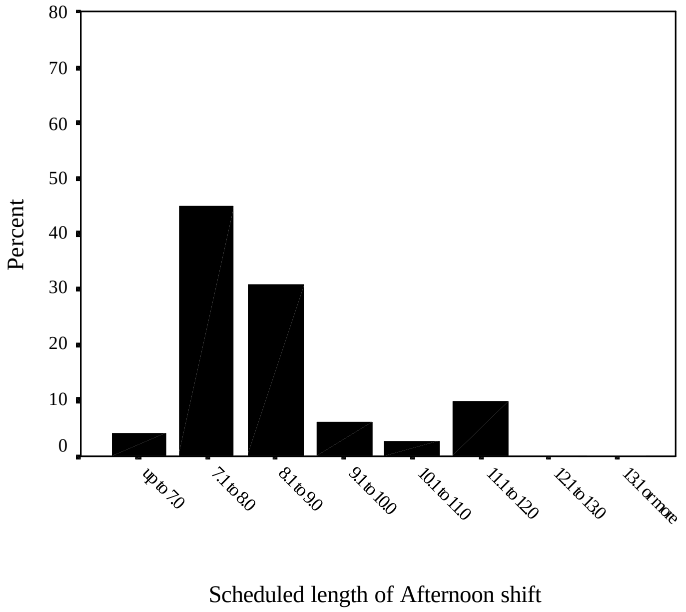

Figure 9b. Frequency distribution of the scheduled length of the Afternoon shift.

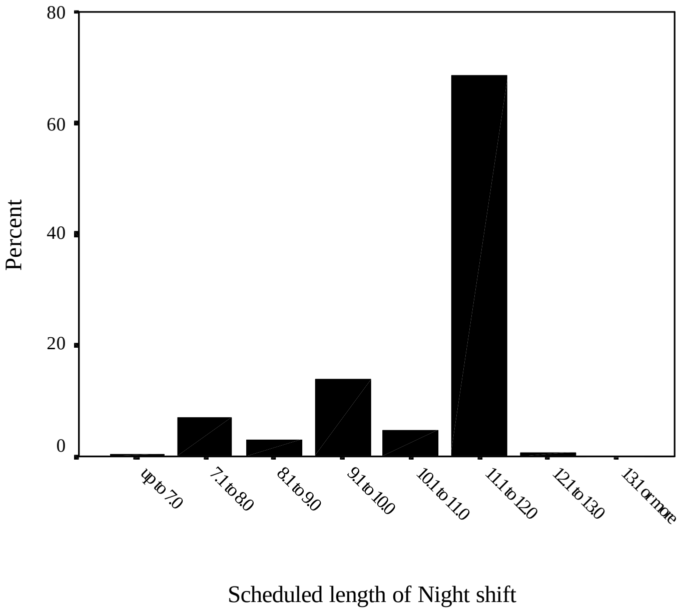

Figure 9c. Frequency distribution of the scheduled length of the Night shift.

The normal shift lengths (Figures 10a-c) showed a similar difference across the three shifts to the scheduled lengths. However, as might be expected, the mean number of hours normally worked on each shift was slightly higher than the scheduled number of hours and this is shown in Table 8. Related t-tests indicated that this difference, although small, was statistically significant for each of the three shifts (Morning/Day shift: t = 12.91, df=1752, p<0.001; Afternoon shift: t = 4.65, df = 766, p<0.001, Night shift: t = 2.25, df = 922, p=0.025).

Table 8. Scheduled and Normal hours for the three shifts

	Morning/Day Shift		Afternoon Shift		Night Shift	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Scheduled	10.063	1.867	8.893	1.325	11.264	1.297
Normal	10.300	1.875	9.027	1.369	11.333	1.489

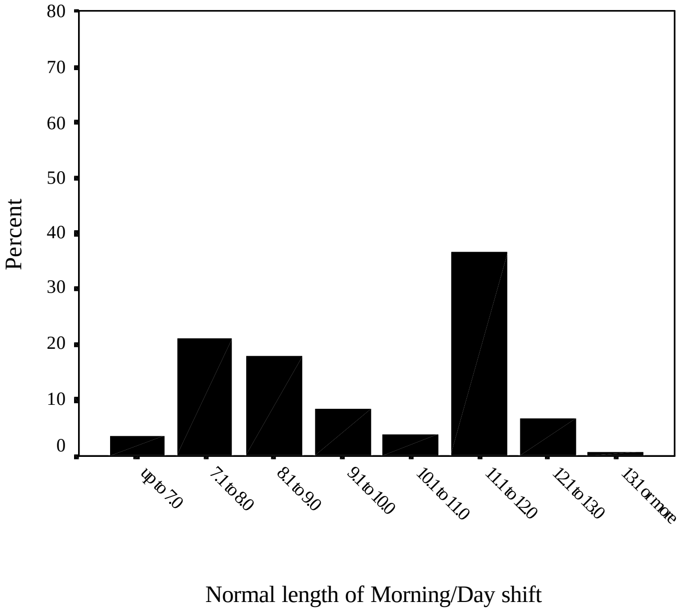

Figure 10a. Frequency distribution of the normal length of the Morning/Day shift.

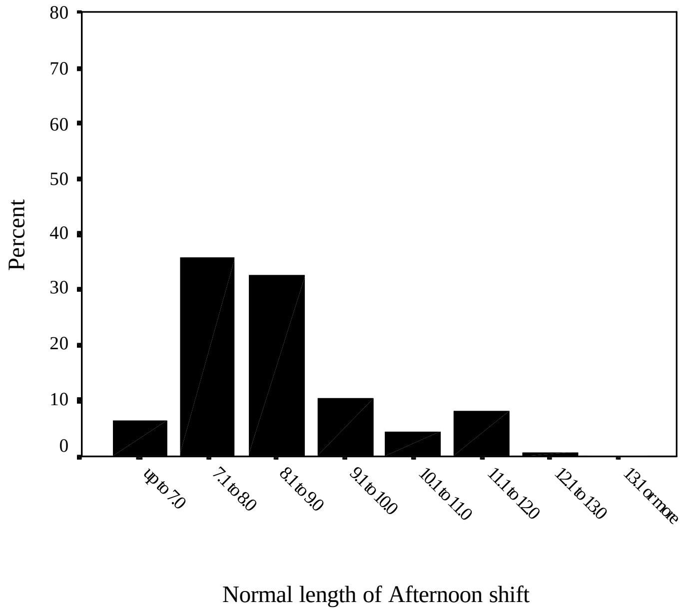

Figure 10b. Frequency distribution of the normal length of the Afternoon shift.

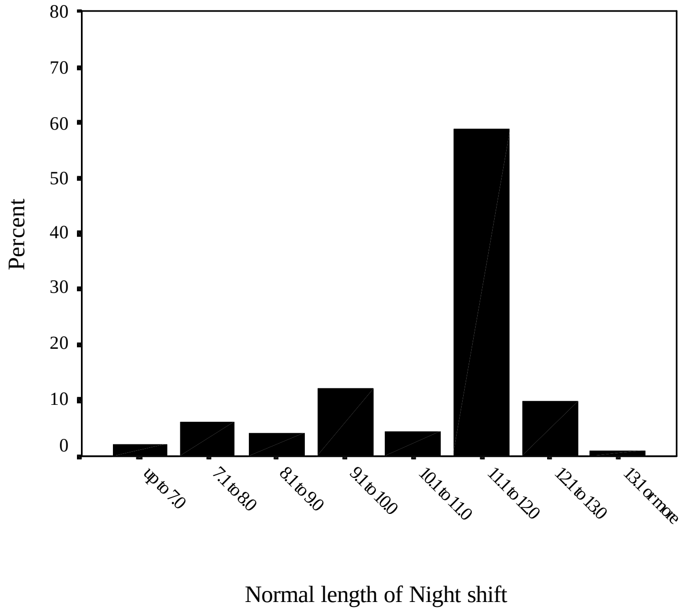

Figure 10c. Frequency distribution of the normal length of the Night shift.

More detailed examination of the data indicated that these small mean differences were largely due to the percentage of engineers working more than 12 hours. Thus only 0.8 % of engineers were scheduled to work more than 12 hours on the morning shift, but 7.6% normally did so. The comparable figures for the afternoon shift were 0.4% and 1.2%, and for the night shift were 0.9% and 11.1%. Clearly for some individuals the "normal" shift lengths were rather longer than scheduled ones.

As might be expected, the maximum lengths of the shifts showed a far wider distribution of lengths, with a greater proportion of engineers claiming that the maximum length of their shifts was in excess of 12 hours (Figures 11a-c). Thus on the morning/day shift some 38.2% of engineers claimed that their maximum shift length exceeded 12 hours while the comparable figures for the afternoon and night shifts were 24.9% and 42.5% respectively.

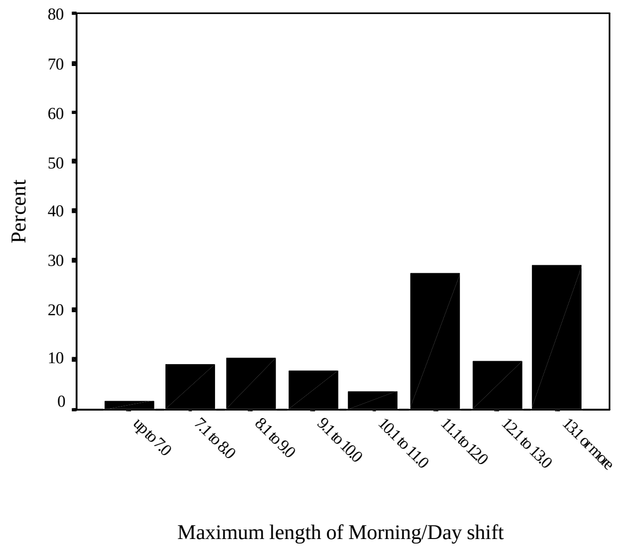

Figure 11a. Frequency distribution of the maximum length of the Morning/Day shift.

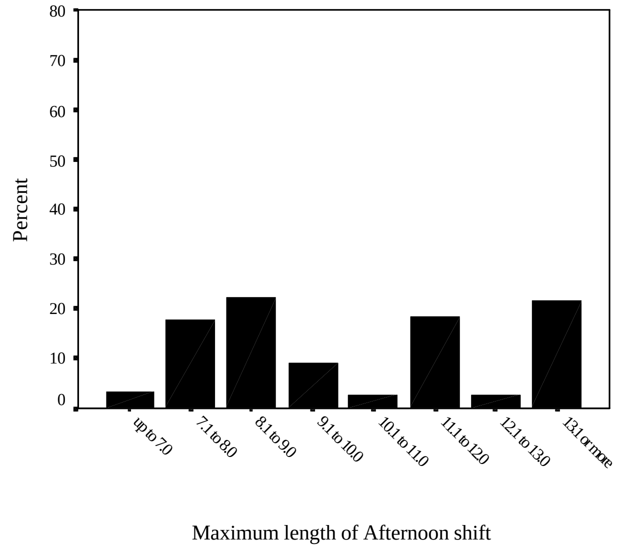

Figure 11b. Frequency distribution of the maximum length of the Afternoon shift.

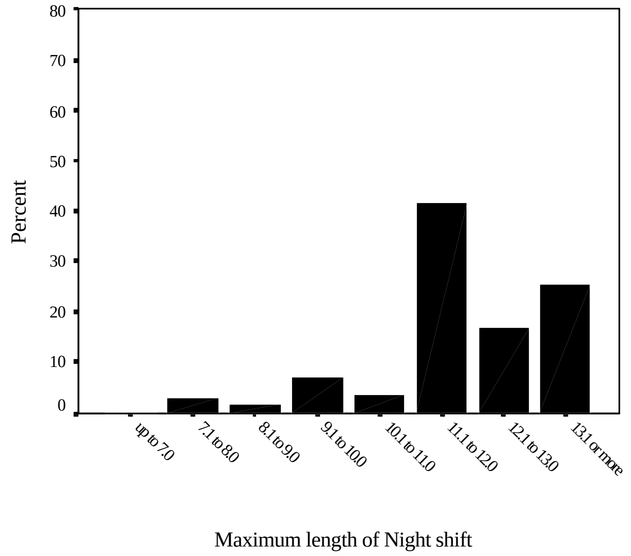

Figure 11c. Frequency distribution of the maximum length of the Night shift.

Recommendation: A limit on scheduled hours per shift of 12 hours would seem appropriate, and would restrict only 0.8%, 0.4% and 0.9% of the scheduled lengths of the morning/day, afternoon and night shifts. If the maximum length of shift, including paid and unpaid overtime was set at 13 hours, this would still allow a break of 11 hours between shifts and would restrict only 0.8%, 0.3% and 1.3% of the normal lengths of the morning/day, afternoon and night shifts. Although it is clear that many engineers claimed that their "maximum" shift lengths exceeded 13 hours, the maximum values reported by many individuals would, presumably, seldom have been worked.

3.5.3. Breaks

The mean numbers of hours worked before a break are shown in table 9. It is clear that the scheduled and normal mean number of hours were very similar to one another, and indeed the use of a related t-test indicated that they did not differ significantly from one another (t=0.330, df=1427, p=0.742). In contrast, the maximum number of hours worked before a break was considerably longer and differed significantly from, for example, the normal number (t=43.486, df=1558, p<0.001). It is also noteworthy that the valid N was rather higher for the normal value than for the scheduled one, implying that many engineers had no scheduled breaks but were nevertheless able to take them.

Table 9. Hours worked before a break

Hours worked before a break	Mean	Standard Deviation	Valid N
Scheduled	3.30	1.21	1517
Normal	3.26	1.35	1707
Maximum	4.91	1.68	1609

Inspection of Figures 12a-c indicates that the large majority of engineers were scheduled (87.0%) to have, or normally (85.2%) had, a break within four hours of the start of their shift, and indeed a substantial minority (45.5%) did so even when the maximum values were considered.

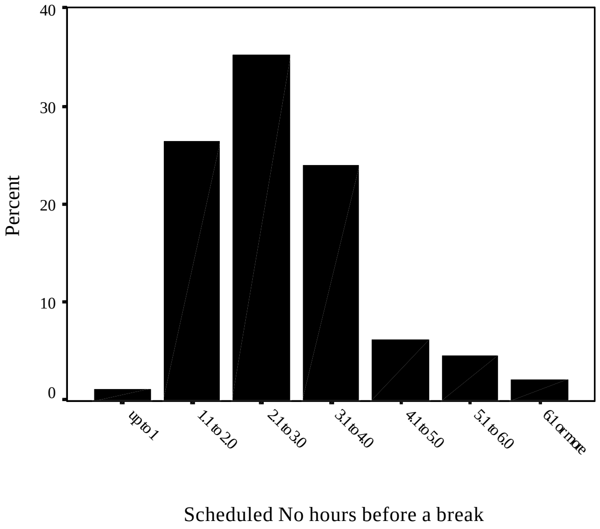

Figure 12a. Frequency distribution of the scheduled No. hours before a break.

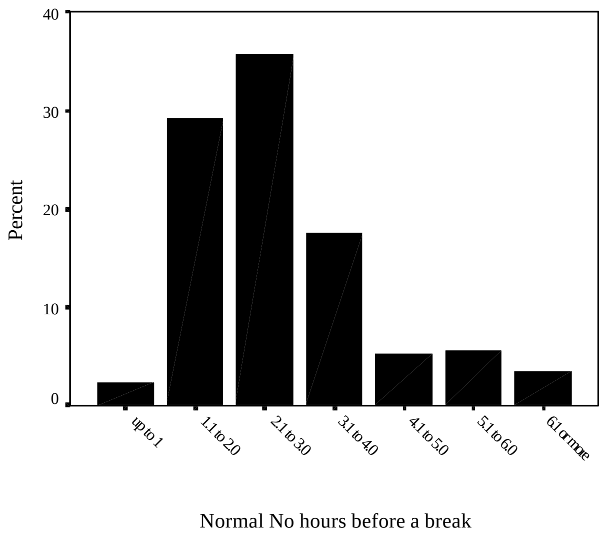

Figure 12b. Frequency distribution of the normal No. hours before a break.

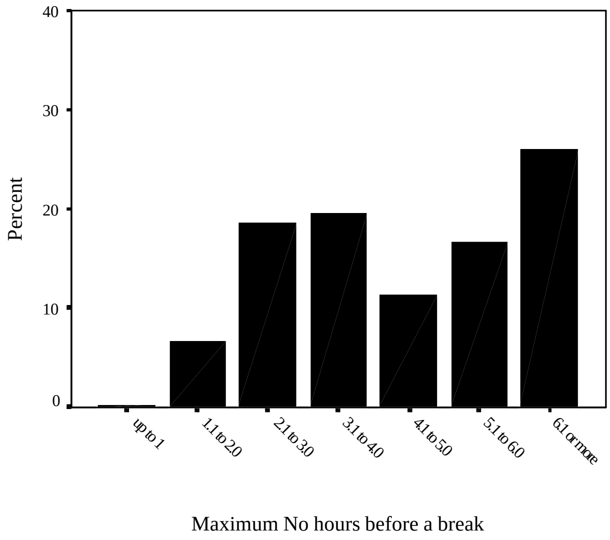

Figure 12c. Frequency distribution of the maximum No. hours before a break.

The mean duration of breaks (in minutes) is shown in table 10. It is clear that the scheduled and normal mean lengths of breaks were fairly similar to one another, although the use of a related t test indicated that the scheduled breaks were significantly longer than the normal ones (t=3.115, df=1507, p=0.002).

Table 10. Duration of breaks

Hours worked before a break	Mean	Standard Deviation	Valid N
Scheduled	26.95	12.75	1590
Normal	26.30	12.32	1732
Minimum	17.32	9.84	1420

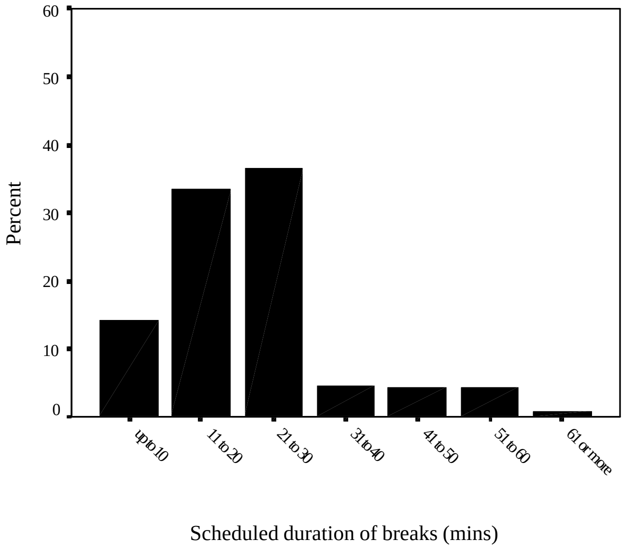

Figure 13a. Frequency distribution of the scheduled duration of breaks.

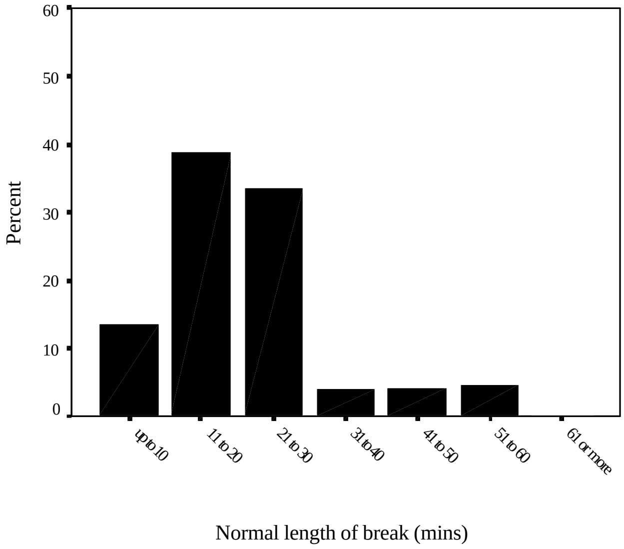

Figure 13b. Frequency distribution of the normal duration of breaks.

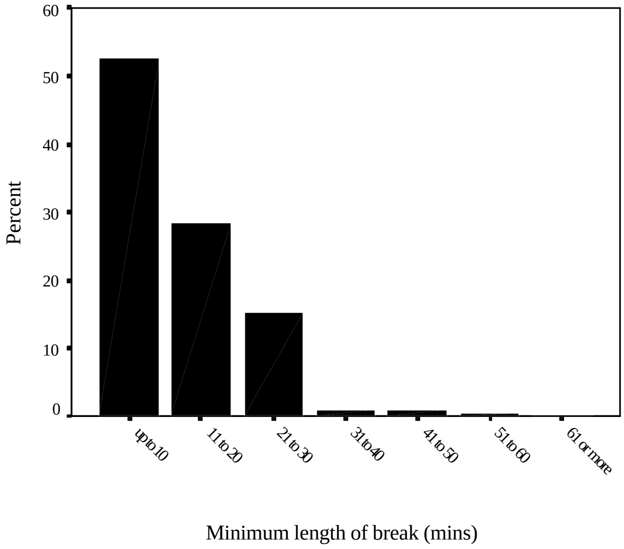

Figure 13c. Frequency distribution of the minimum duration of breaks.

Both were, however, significantly longer than the minimum lengths of breaks reported (t>25.00 df>1200, p<0.001 in both cases). It is also noteworthy that the valid N was again rather higher for the normal value than for the scheduled one, implying that many engineers had no scheduled breaks but were nevertheless able to take them. Inspection of Figures 13a-c indicates that the large majority of engineers were scheduled (85.7%) to have, or normally (86.4%) had, a break that was at least 11 minutes long, and indeed a substantial minority (47.3%) did so even when the minimum lengths of breaks were considered. Breaks of between 11 and 30 minutes were the most common for both scheduled (70.6%) and normal (72.5%) breaks.

Further analyses indicated that the length of scheduled breaks was significantly correlated with the scheduled number of hours worked before a break (r= +0.379, df=1433, p<0.001). The use of linear regression indicated that the scheduled length of break after a single hour's work was about 15 minutes, and that this increased by about 5 minutes for each additional hour worked.

Recommendation: In the light of the above it would seem reasonable to recommend a maximum of fours hours' work before a break, and a minimum break length of ten minutes plus five minutes for each hour worked. Such a recommendation would restrict 13% of current scheduled work lengths before a break and ensure a minimum of a 30-minute break after 4 hours' work.

3.5.4. Number of successive work days

The mean number of scheduled, normal and maximum work days before a rest of at least one day are shown in Table 11. The use of related t-tests indicated that the engineers normally worked significantly longer before a rest day than they were scheduled to (t=6.13, df=1883, p<0.001), and also that the maximum number of successive days worked before a rest day was significantly higher than the normal number (t=21.18, df=1741, p<0.001).

Inspection of Figures 14a-c indicates that the majority (over 63.6%) of engineers were scheduled to work between 4 or 5 successive days before at least one rest day, but that a significant minority (20.5%) were scheduled to work seven successive days before a rest day. Very few (2.8%) engineers were scheduled to work eight or more successive days, while spans of less than four scheduled successive work days were also unusual (8.0%).

Table 11. No. of successive days before a rest day

No. Successive work days	Mean	Standard Deviation	Valid N
Scheduled	4.88	1.48	2021
Normal	5.06	1.52	1903
Maximum	5.98	1.66	1757

When the scheduled and normal number of successive works days are compared (Figures 14a and 14b) it is clear that the percentage of engineers normally working 4 successive days was less than that scheduled, while the percentage working 6 successive days doubled from a scheduled 5.1% to a normal 10.2%. As would be expected, when the maximum values are examined (Figure 14c), the percentage of engineers working 8 or more successive days increased from a scheduled 2.8%and normal 4.3% to 23.2%.

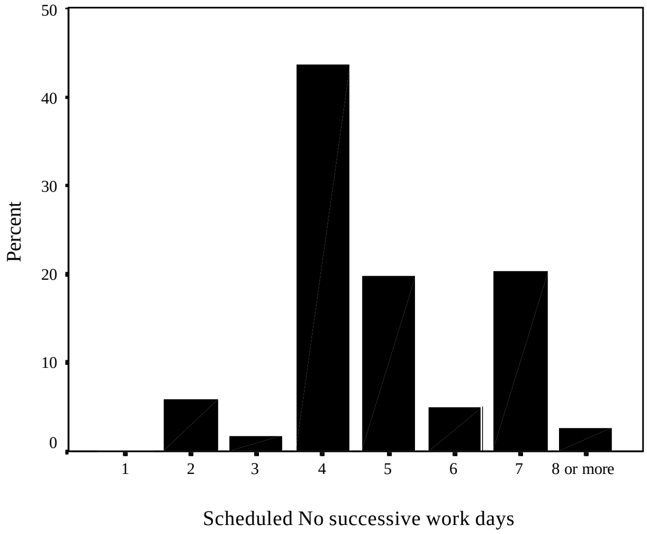

Figure 14a. Frequency distribution of the scheduled number of successive work days.

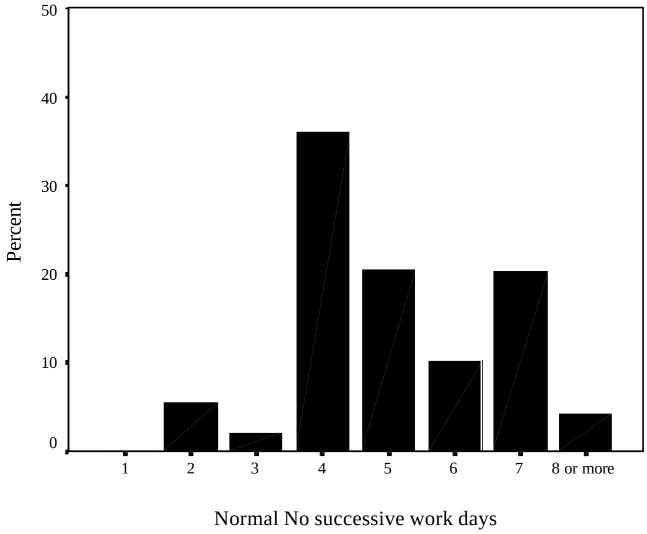

Figure 14b. Frequency distribution of the normal number of successive work days.

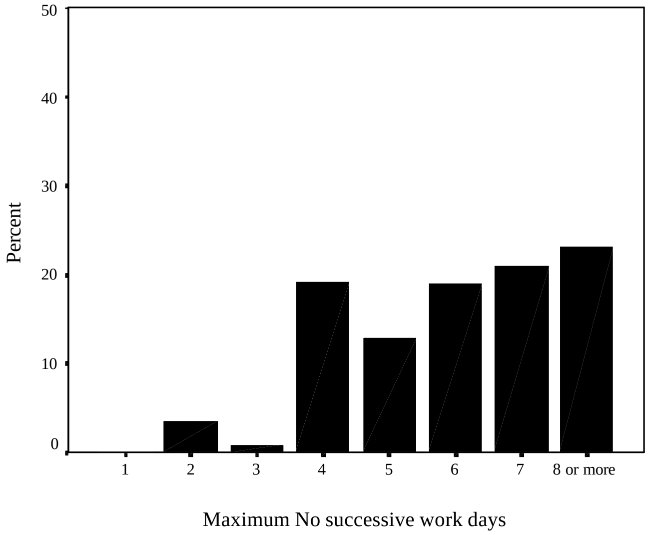

Figure 14c. Frequency distribution of the maximum number of successive work days.

Recommendation: In the light of the above it would seem reasonable to recommend an absolute maximum of seven successive work days before a break of at least two rest days (see below). Such a recommendation would restrict only 2.8% of current scheduled numbers of successive work days, and only 4.3% of what is normally worked.

3.5.5. Number of work hours before a rest day

The above recommendation fails to take account of the fact that the work days may themselves differ in their length. Thus, while seven successive eight-hour work days may be acceptable, seven successive twelve-hour work days may not. In order to examine this issue the length of the day shift was multiplied by the number of successive work days before a rest day in order to estimate the accumulated work hours before a rest day. It should be noted that very few engineers reported that the various shifts that they worked differed in their length, and this procedure thus provided reasonably accurate estimates. This was performed for both the scheduled and normal values (Table 12), but not for the maximum values because this would give unreliable estimates since these extreme values would occur together. The use of a related t-test indicated that the engineers normally worked for significantly longer before a rest day than they were scheduled to (t=14.40, df=1626, p<0.001).

Table 12. Estimated accumulated hours before a rest day

Accumulated hours	Mean	Standard Deviation	Valid N
Scheduled	48.36	12.55	1770
Normal	51.40	13.82	1646

Inspection of Figures 15a and 15b indicates that relatively few engineers (4.9%) were scheduled to work more than 60 hours before a rest day, and that even when the normal values were considered this only rose to 13.1%.

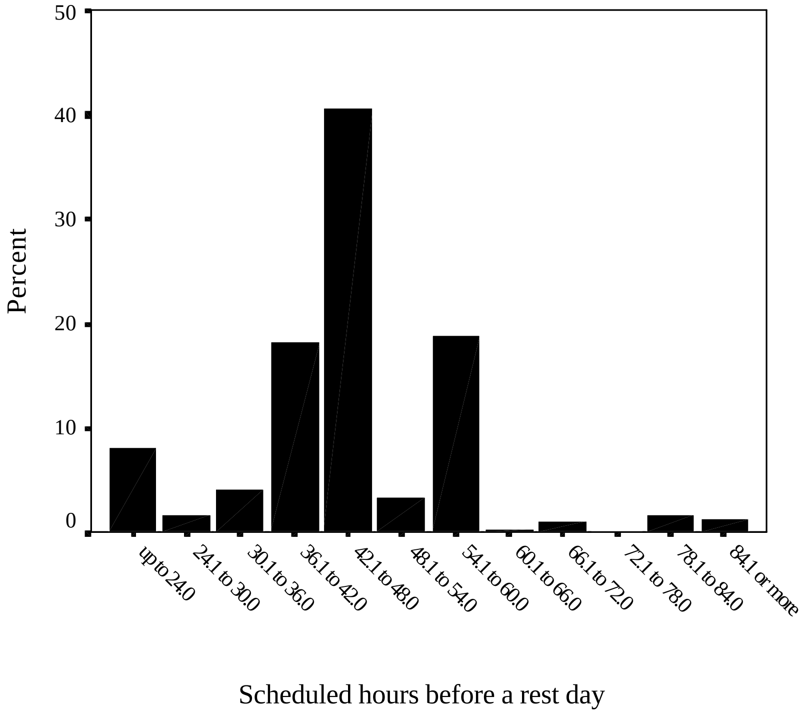

Figure 15a. Frequency distribution of the estimated scheduled number of hours before a rest day.

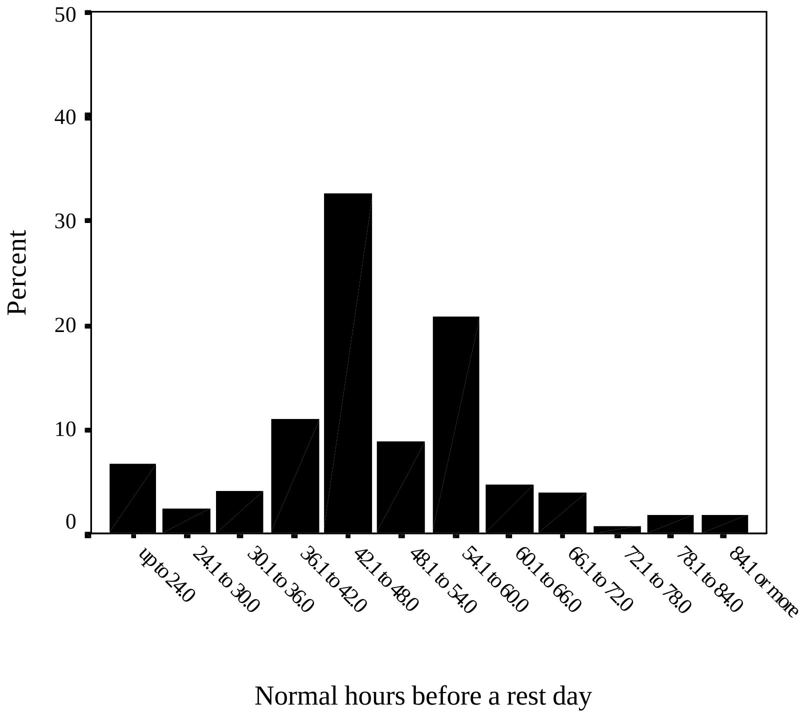

Figure 15b. Frequency distribution of the estimated normal number of hours before a rest day.

Recommendation: In the light of the above it would seem reasonable to recommend an absolute maximum of 60 accumulated hours work before a break of at least two rest days (see below). Although such a recommendation would restrict 13.1% of normally worked hours, it would restrict only 4.9% of current scheduled hours .

3.5.6. Number of successive rest days

The mean number of scheduled, normal and minimum rest days between spans of work days are shown in Table 13. The use of related t-tests indicated that the engineers normally had significantly fewer rest days than they were scheduled to have (t=14.20, df=1802, p<0.001), and also that the minimum number of successive rest days was significantly lower than the normal number (t=24.61, df=1527, p<0.001).

Table 13. No. of successive rest days

No. Successive rest days	Mean	Standard Deviation	Valid N
Scheduled	3.39	1.09	1945
Normal	3.23	1.17	1824
Minimum	2.61	1.33	1556

Inspection of Figures 16a-c indicates that the vast majority (94.3%) of engineers were scheduled to have between 2 and 4 successive rest days. Very few (4.4%) engineers were scheduled to have more than four successive rest days, while even fewer (1.3%) were scheduled to have a single rest day between spans of work days. The normal number of successive rest days showed a similar distribution to the scheduled number, although the engineers were less likely to have 4 rest days and somewhat more likely to have only three or one rest day. In contrast, when the minimum number of successive rest days was considered (Figure 16c), the percentage of engineers reporting only a single rest day rose from 1.3 % (scheduled) or 4.9% (normal) to 23.6% (minimum). This reflected mainly on a large reduction in the percentage of engineers reporting that they had four successive rest days from a scheduled value of 48.6% to a minimum value of 22.2%.

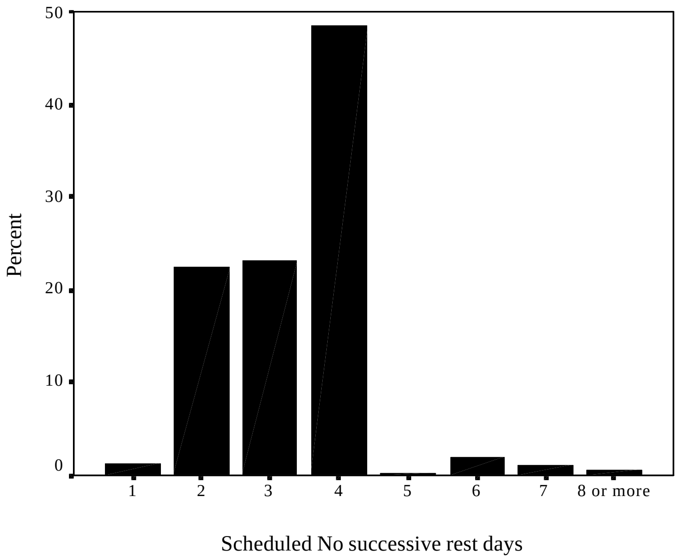

Figure 16a. Frequency distribution of the scheduled number of successive rest days.

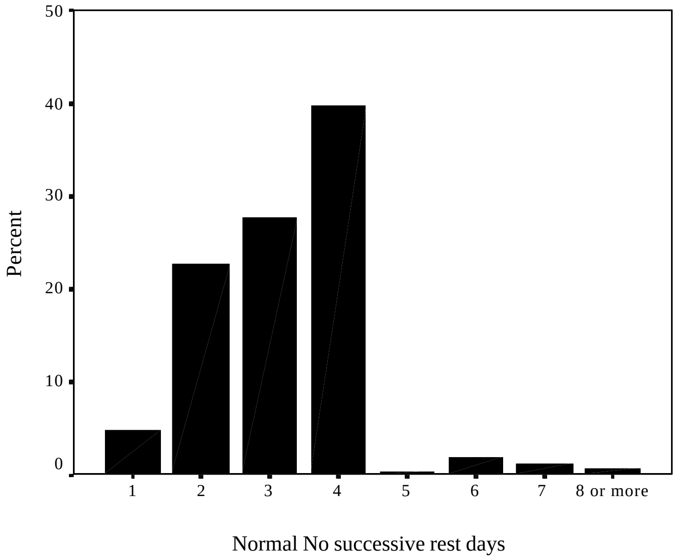

Figure 16b. Frequency distribution of the normal number of successive rest days.

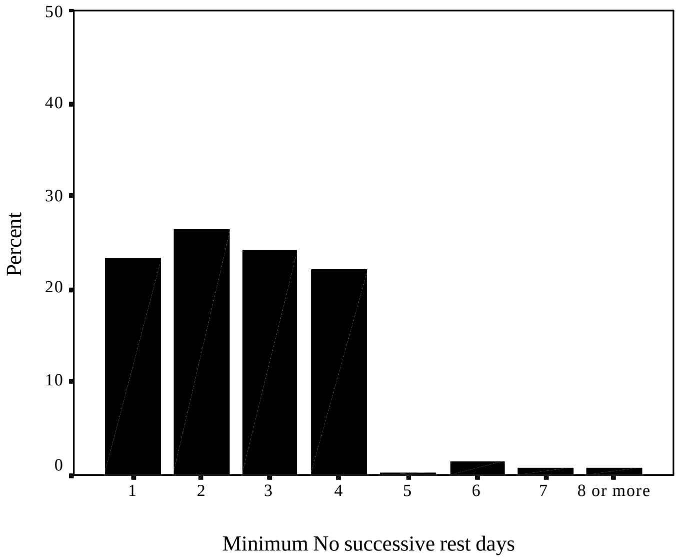

Figure 16c. Frequency distribution of the minimum number of successive rest days.

Further analyses indicated that the scheduled number of successive rest days was significantly correlated with the scheduled span of successive work days (r= +0.350, df=1917, p<0.001). The use of linear regression indicated that the average scheduled number of rest days after a span of three work days was three, and that this increased to four when the span of work days increased to eight.

When the accumulated number of work hours before a rest day was considered, linear regression analysis indicated that the scheduled number of successive rest days was significantly correlated with the accumulated work hours (r= +0.555, df=1685, p<0.001). This analysis indicated that the average scheduled number of rest days was two after as little as 8 hours work, and that it increased by one rest day for each additional 28 hours work. Thus, on average, three rest days were scheduled after 36 hours work, four after 64 hours work, etc.

Recommendation: In the light of the above it would seem reasonable to recommend an absolute minimum of two successive rest days between spans of work days involving 16 or more hours of work. Such a recommendation would restrict only 1.3% of current scheduled numbers of successive work days, and only 4.9% of what is normally worked.

3.5.7. Number of days annual leave

The mean number of scheduled, normal and minimum annual leave days are shown in Table 14. The use of related t-tests indicated that the engineers normally had significantly fewer annual leave days than they were scheduled to have (t=6.32, df=1778, p<0.001), and also that the minimum number of annual leave days was significantly lower than the normal number (t=11.50, df=1617, p<0.001). However, inspection of Table 14 indicates that although these differences were statistically highly reliable, the magnitude of the differences was small.

Table 14. No. of Annual Leave days

No. annual leave days	Mean	Standard Deviation	Valid N
Scheduled	28.58	6.21	2005
Normal	28.40	6.29	1805
Minimum	27.76	6.50	1620

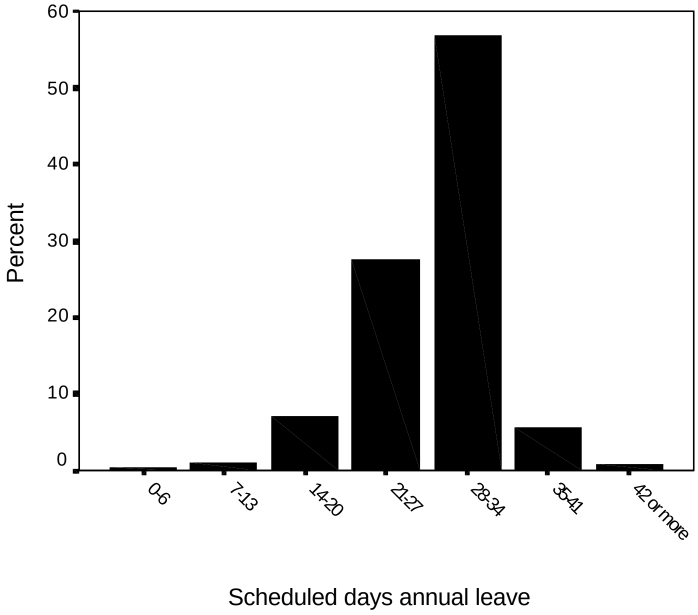

Figure 17a. Frequency distribution of the scheduled number of annual leave days.

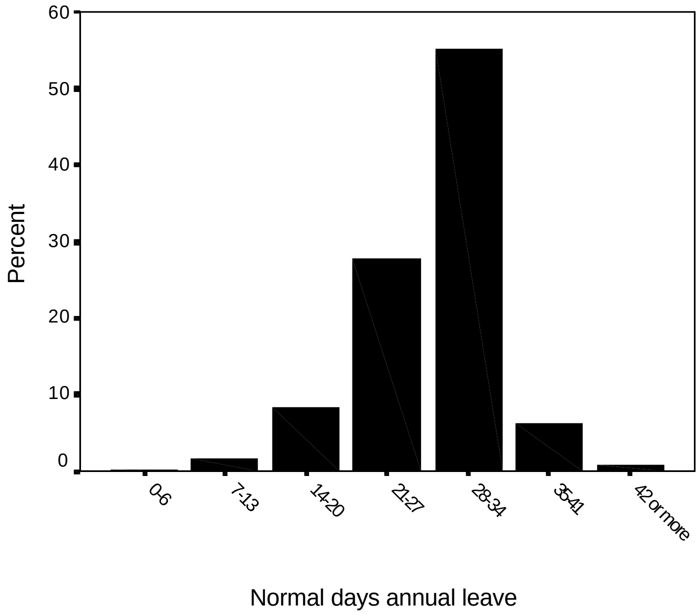

Figure 17b. Frequency distribution of the normal number of annual leave days.

Inspection of Figures 17a-c indicates that the large majority (91.4%) of engineers were scheduled to have 21 or more days annual leave. Very few (6.7%) engineers were scheduled to have more than 34 annual leave days, while even fewer (1.6%) were scheduled to have less than 14 days annual leave. The normal number of annual leave days showed a very similar distribution to the scheduled number. In contrast, when the minimum number of successive rest days was considered, the percentage of engineers reporting that they had less than 21 days annual leave rose from 8.6 % (scheduled) or 10.2% (normal) to 13.2%. Similarly, the percentage of engineers reporting that they had 28 or more annual leave days fell from 63.7 % (scheduled) or 62.0% (normal) to 58.0%.

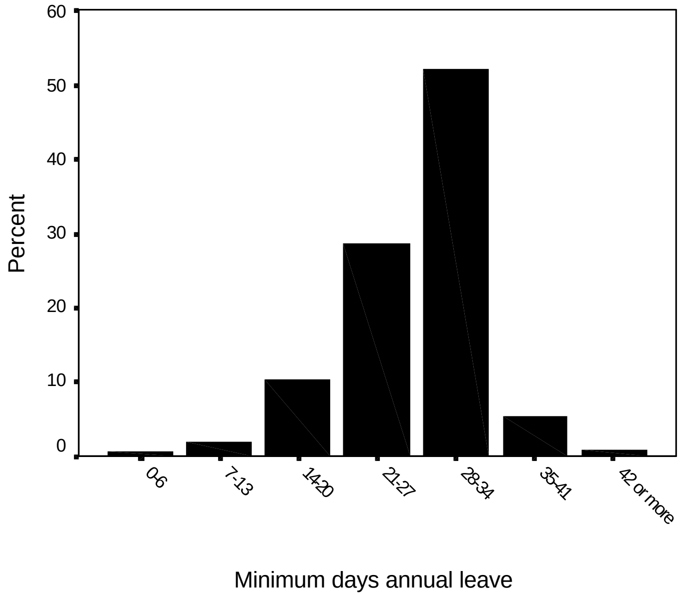

Figure 17c. Frequency distribution of the minimum number of annual leave days.

Some residual fatigue may accumulate over weeks and months despite the provision of rest days, therefore annual leave is important to allow engineers to take additional time off when they feel they need a break. However, there is little evidence to indicate what might be an 'ideal' number of days annual leave. Accordingly, based on the survey results and the premise that the majority of organisations provision for a 'reasonable' number of days annual leave, it is suggested that 28 days leave is probably a good figure to aim for (and this aligns with the EU working time directive), with 21 being the minimum. This would be particularly pertinent for those engineers working beyond the recommendations contained in this report, since it is they who would be most in need of recuperative time in the form of annual leave.

Recommendation: In the light of the above it would seem reasonable to recommend 28 days annual leave, with an absolute minimum of 21 after overtime is taken into account. This would allow time for those engineers suffering from build-up of fatigue, to recuperate. 21 days annual leave would exclude 8.6% of current scheduled rosters, and 10.2% of current normal practices.

3.5.8. Shift change times

Although all shift change times were recorded, it is only the start time of the morning/day shift and the finishing time of the night shift that are critical from a fatigue standpoint. Consequently this section will concentrate on these two values.

3.5.8.1. Start time of the morning/day shift

The scheduled, normal and earliest start times of the Morning/Day shift are shown in Table 15. The use of related t-tests indicated that the engineers normally started their morning/day shift significantly earlier than they were scheduled to ($t=9.97$, $df=1807$, $p<0.001$), and also that the earliest start time was significantly earlier than the normal one ($t=18.21$, $df=1665$, $p<0.001$).

Table 15. Start times of the morning/day shift (in hours)

Start time of morning/day shift	Mean	Standard Deviation	Valid N
Scheduled	06.83	0.84	1896
Normal	06.77	0.84	1832
Earliest	06.27	1.19	1678

However, careful inspection of Table 15 indicates that although both these differences were statistically highly reliable the magnitude of the difference between the scheduled and normal start times was relatively small (i.e. an average of only 3.6 minutes).

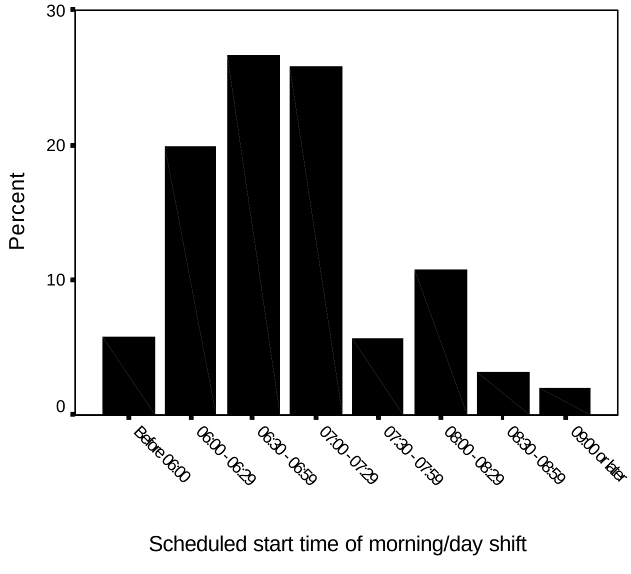

Figure 18a. Frequency distribution of the scheduled start time of the Morning/Day shift.

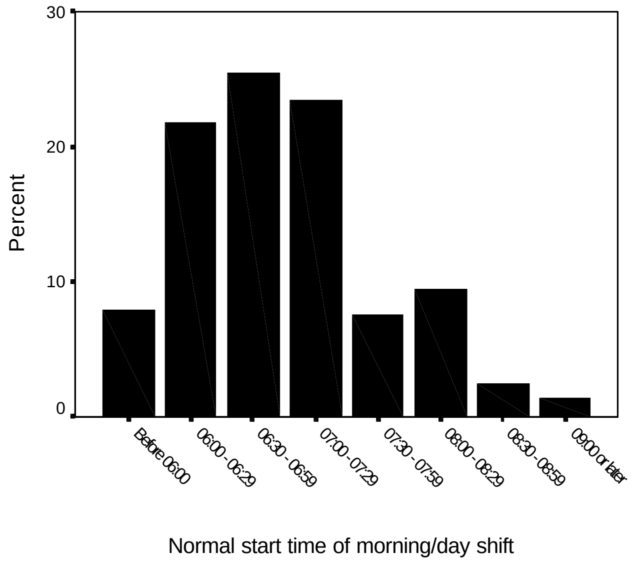

Figure 18b. Frequency distribution of the normal start time of the Morning/Day shift.

Inspection of Figures 18a-c indicates that the large majority (78.1%) of engineers were scheduled to start their morning/day shift between 06:00 and 07:59. Only 5.9% of the engineers were scheduled to start before 06:00, but this value increased to 8.0% when the normal start time was considered, and to 23.3% when the earliest start time was considered.

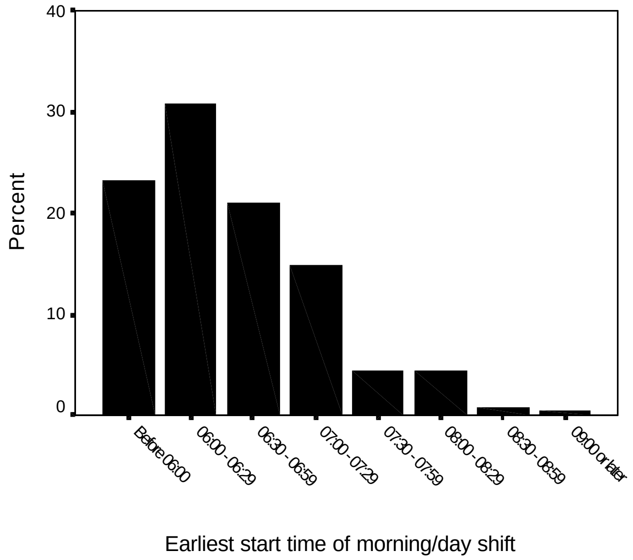

Figure 18c. Frequency distribution of the earliest start time of the Morning/Day shift.

Recommendation: In the light of the above it would seem reasonable to recommend that the start time of the morning/day shift should not be earlier than 06:00, and that it should be delayed until 07:00 or 08:00 whenever possible. The recommendation that the start time should not be earlier than 06:00 would restrict only 5.9% of the current scheduled start times, and only 8.0% of the normal ones.

3.5.8.2. Finish time of the night shift

The scheduled, normal and latest finish times of the night shift are shown in Table 16. The use of related t-tests indicated that the engineers' scheduled and normal finish times did not differ significantly from one another (t=0.16, df=931, p=0.872), but that the latest finish time was reliably later than the normal one (t=13.70, df=838, p<0.001).

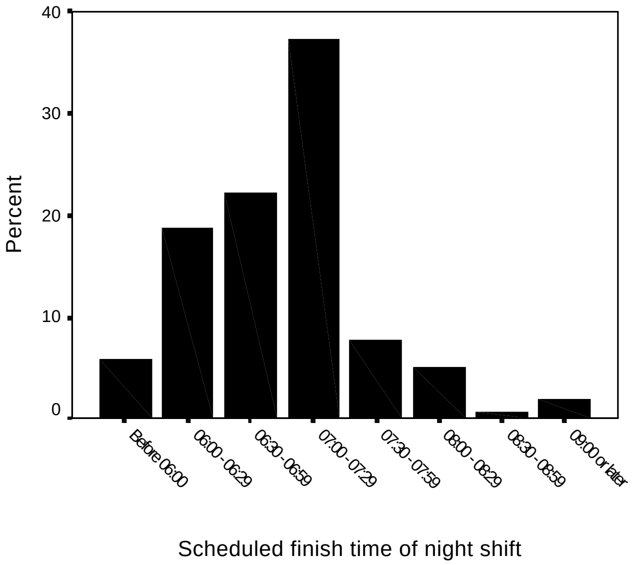

Figure 19a. Frequency distribution of the scheduled finish time of the Night shift.

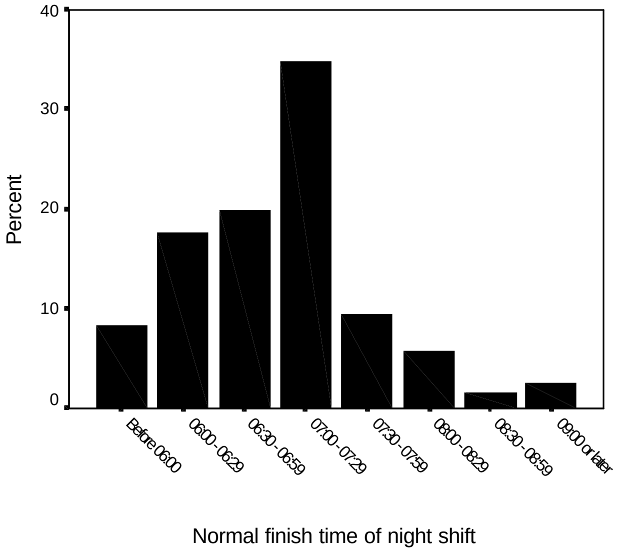

Figure 19b. Frequency distribution of the normal finish time of the Night shift.

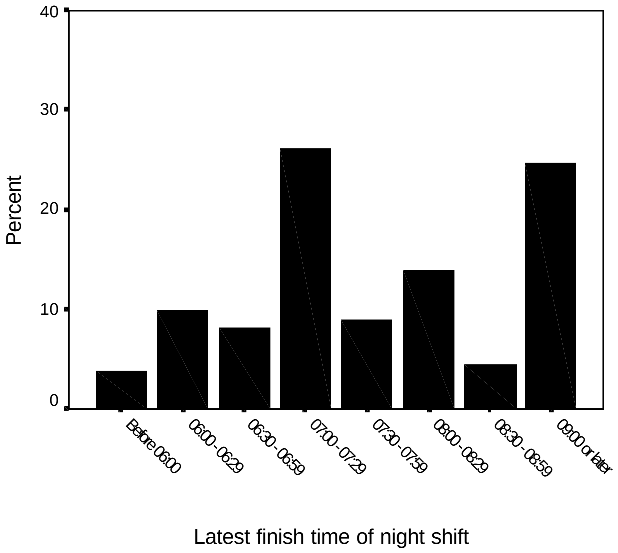

Figure 19c. Frequency distribution of the latest finish time of the Night shift.

Table 16. Finish times of the night shift (in hours)

Finish times of the night shift	Mean	Standard Deviation	Valid N
Scheduled	06.85	1.64	988
Normal	06.84	1.88	943
Latest	08.07	2.52	846

Inspection of the Figures 19a-c indicates that the large majority (86.2%) of engineers were scheduled to finish their night shift between 06:00 and 07:59. Only 7.9% of the engineers were scheduled to finish after 07:59, but this value increased to 9.8% when the normal finish time was considered, and to 43.0% when the latest finish time was considered.

Recommendation: In the light of the above it would seem reasonable to recommend that the finish time of the night shift should not be later than 08:00. Such a recommendation would restrict only 8.7% of the current scheduled finish times, and only 9.9% of the normal ones.

3.5.9. Sleep Durations

The normal and minimum durations of sleeps between two shifts of the same type, or rest day, need to be considered, both overall and in relation to shift change times. The normal and minimum average sleep durations are shown in table 17.

Table 17. Average sleep durations between shifts/rest days in hours.
(Valid Ns in brackets)

Sleep Duration between two successive:	Normal	Minimum
Morning/Day shifts	6.83 (1849)	5.27 (1765)
Afternoon Shifts	7.50 (744)	6.25 (716)
Night Shifts	6.52 (965)	5.01 (922)
Rest Days	7.99 (1836)	6.76 (1747)

Not surprisingly, the use of related t-tests indicated that the minimum sleep durations were reliably shorter than the corresponding normal sleep durations (t=32.4, df=714, p<0.001 in all cases). More importantly, the normal sleep duration between night shifts was reliably shorter than the normal sleep duration between morning/day shifts (t=6.60, df=778, p<0.001), afternoon shifts (t=7.83, df=109, p<0.001), or rest days (t=28.71, df=921, p<0.001). Likewise, the minimum sleep duration between night shifts was reliably shorter than the corresponding duration between morning/day shifts (t=2.39, df=734, p=0.017), afternoon shifts (t=8.00, df=102, p<0.001) or rest days (t=29.345, df=872, p<0.001).

Further analyses indicated that both the normal and minimum sleep durations between morning/day shifts were reliably shorter than their corresponding durations between both afternoon shifts (Normal, t=19.38, df=724, p<0.001; Minimum, t=21.43, df=695, p<0.001) and rest days (Normal, t=36.38, df=1630, p<0.001; Minimum, t=43.31, df=1538, p<0.001). Finally, sleep durations between afternoon shifts were reliably shorter than those between rest days (Normal, t=13.58, df=688, p<0.001; Minimum, t=13.89, df=653, p<0.001).

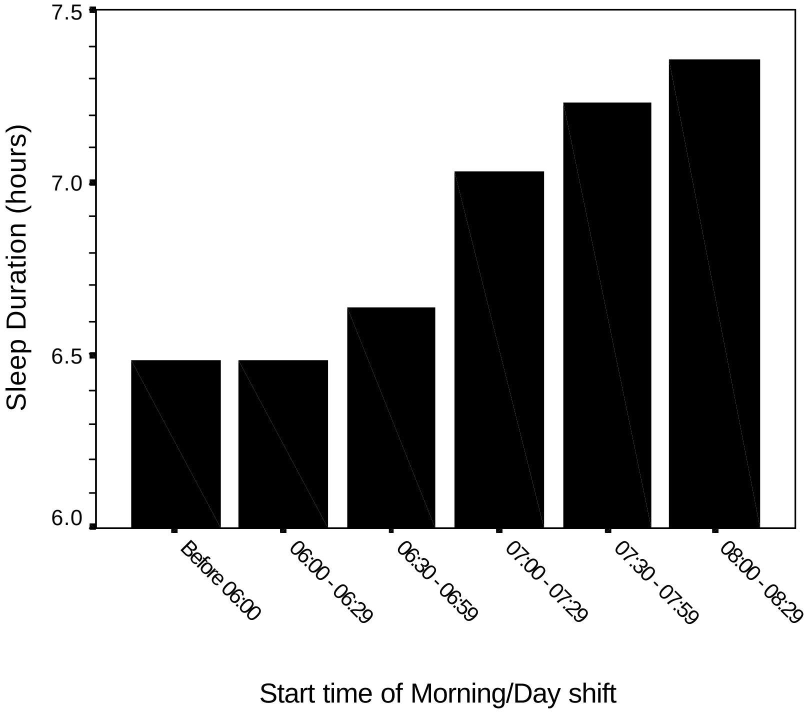

Figure 20. Normal sleep duration between Morning/Day shifts as a function of their start time.

The use of Pearson's r correlation coefficient indicated that the normal sleep duration between successive morning/day shifts was significantly related to the normal start time of the shift ($r = +0.263$, $df = 1773$, $p<0.001$). This relationship is shown in Figure 20 from which it is clear that later start times were associated with substantially longer sleeps. Thus the average sleep duration increased from less than 6.5 hours for starts before 06:29 to over 7.3 hours for start times between 08:00 and 08:29. Note that start times later than 08:29 have been excluded in view of the small numbers of engineers involved (see above).

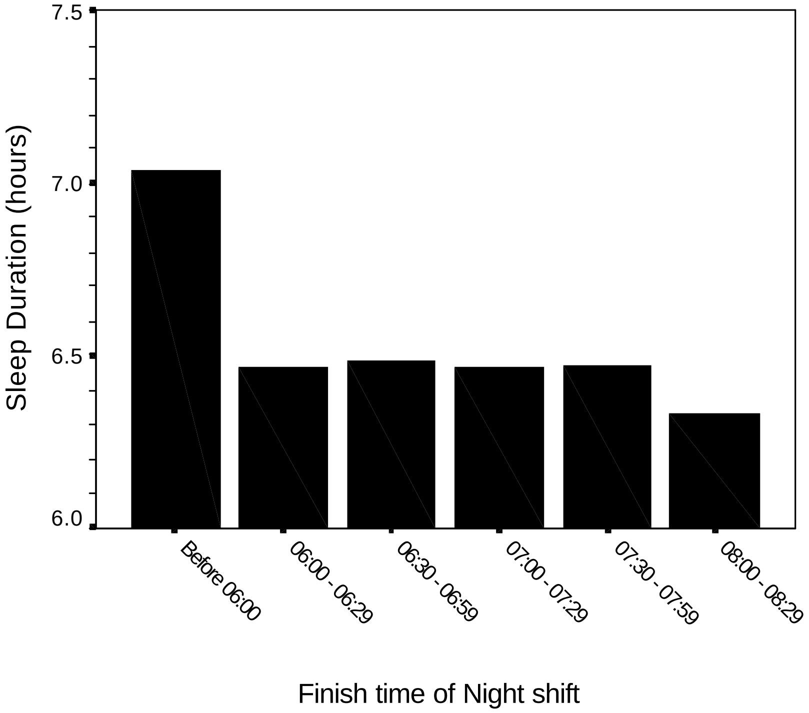

Figure 21. Normal sleep duration between Night shifts as a function of their finish time.

In contrast, and unexpectedly in the light of previous research, the use of Pearson's r correlation coefficient indicated that the normal sleep duration between successive night shifts was not significantly related to the normal finish time of the shift ($r = +0.040$, df = 900 $p=0.226$). This lack of a relationship is shown in the Figure 21 from which it is clear that unless the night shift finished before 06:00 (which was quite rare, see above), later finish times had virtually no influence on the normal sleep duration between successive night shifts unless they finished later than 07:59 when there was a slight reduction in sleep length. The use of (post-hoc) independent t-tests indicated that night shift finish times before 06:00 were associated with significantly longer sleeps than later finish times ($t=3.47$, df= 867, $p<0.001$), but that the slight reduction in sleep duration with finish times after 07:59, compared to earlier finish times, was not statistically reliable ($t=0.94$, df= 867, $p=0.346$). Note that again finish times later than 08:29 have been excluded from the figure in view of the small numbers of engineers involved (see above).

Taken together, these results relating sleep duration to the start time of the morning shift and the end time of the night shift suggest that a balance needs to be achieved in terms of minimising the truncation of sleep on these shifts. On the one hand later shift change times will result in longer sleep durations between successive morning/day shifts, but on the other hand too late a shift change over may compromise the sleep duration between successive night shifts. The present results tend to confirm those of previous studies that the "optimal" shift change time between the night and morning/day shifts is between about 07:00 and 08:00. Changes between these times will minimise the truncation of sleep between successive shifts of both types.

Recommendation: These findings relating sleep duration to the start and finish times of the morning/day and night shifts respectively lend support to the suggested limits made above, namely that "the start time of the morning/day shift should not be earlier than 06:00, and ideally should be delayed until 07:00 or 08:00", and "the finish time of the night shift should not be later than 08:00".

3.5.10. Days notice of schedule

The number of days' notice the engineers are normally given is shown in Figure 22. It is clear from this that 56.2% of engineers were normally given more than 28 days' notice of their shift schedule. In contrast, however, 6.9% of engineers claimed that they were normally given only up to 1 day's notice of their schedule, while a further 11.5% claimed to normally be given between 2 and 6 days' notice. Thus, almost 20% of the engineers claimed that they were normally given less than a week's notice of their schedule.

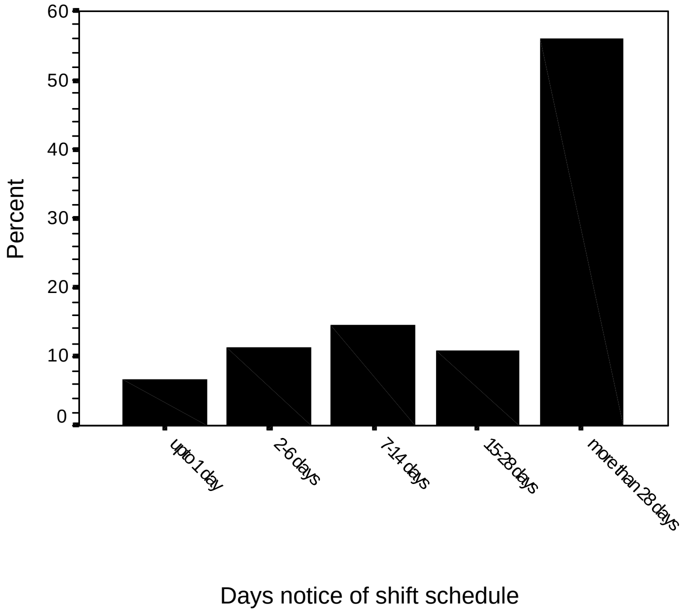

Figure 22. Frequency distribution of the days' notice of the shift schedule.

Recommendation: In the light of this it would seem reasonable to recommend that, wherever possible, engineers should be given at least 28 days notice of their shift schedule. Such a recommendation would clearly encourage employers to give as much notice as possible, but at the same time allow them to cope with unforeseen, and indeed unforeseeable, events.

3.6. Predicting outcome measures

The questionnaire included a number of "outcome measures". These included safety questions relating to alertness, the likelihood of making mistakes and confidence in driving home on the different shifts. They also included questions relating to health and satisfaction with the shift schedule. This section examines whether it is possible to predict these outcome measures on the basis of a range of variables including demographic ones, ratings of circadian type, the individuals control over their work schedule and various specific features of the shift systems concerned. It also addresses whether any relationships obtained are consistent with those described in the literature review in Section 2.

3.6.1. Factor Analyses

Factor analysis of the various outcome scales from all the respondents yielded five components (i.e. with eigenvalues of greater than 1)that between them accounted for 67.24% of the variance. Varimax rotation of these components converged in six rotations to give a very clear factor structure (Table 18). Factor 1 comprised the four health measures and will be referred to as the "Poor Health" outcome measure. Factors 2, 3 and 4 comprised the alertness, likelihood of making a mistake, and confidence in driving home measures for the night, morning and afternoon shifts respectively and will be referred to as the "Perceived Risk" outcome measures. Further analyses of the relationship between the ratings contributing to these risk measures indicated that they were linearly related to one another and that other functions (i.e. exponential, logarithmic, etc.) provided a less significant fit. The fifth and final factor comprised the two general dissatisfaction measures, namely the rated level of interference of the work schedule with various leisure and non-leisure activities and whether the disadvantages of the work schedule were rated as outweighing the advantages. This final measure will be referred to as the "Dissatisfaction" outcome measure.

Table 18. Factor Analysis of the Outcome Measures

Scale	Factor 1	Factor2	Factor 3	Factor 4	Factor 5
Gastrointestinal Symptoms	+0.762				
Muscular-Skeletal Pain	+0.697				
Cardiovascular Symptoms	+0.684				
Minor Infections	+0.664				
Night Shift Alertness		+0.848			
Night Shift Mistakes		+0.781			
Night Shift Driving		+0.771			
Morning Shift Mistakes			+0.824		
Morning Shift Alertness			+0.784		
Morning Shift Driving			+0.759		
Afternoon Shift Mistakes				+0.868	
Afternoon Shift Alertness				+0.755	
Afternoon Shift Driving				+0.684	
Interference: leisure, etc.					+0.852
Advantages outweigh					-0.783

N.B. Only loadings of ≥ 0.40 are shown

3.6.2 Perceived Risk on the Night shift

Hierarchical multiple regression analyses were performed separately for the permanent night and rotating (with nights) shiftworkers in an attempt to predict the perceived night shift risk. The details of the blocks of measures are given in Table 19. The first block comprised various demographic measures, the second block comprised the two ratings of circadian type, the third block comprised three measures of the perceived rigidity of the work schedule, while the fourth, and final block, comprised various specific features of the work schedule.

Table 19. Results from the Hierarchical multiple regression analyses for the two groups involved in nightwork.

Block 1: Demographic Measures	**Rotating with Nights (n=679)**		**Permanent Nights (n=191)**	
	Standardized Beta	**Significance**	**Standardized Beta**	**Significance**
Age	+0.154	0.155	+0.161	0.509
Engineering experience	-0.111	0.314	-0.147	0.581
Present job experience	+0.007	0.891	-0.038	0.747
Shiftwork experience	-0.037	0.581	-0.148	0.312
Present shift experience	-0.098	0.054	+0.052	0.680
Block 2: Circadian Type Measures				
Morningness	**+0.181**	**0.000**	**+0.179**	**0.051**
Sleep Flexibility	**-0.251**	**0.000**	**-0.232**	**0.014**
Block 3: Rigidity of Work Schedule				
Control over specific shifts	-0.030	0.641	**-0.257**	**0.032**
Control over start/finish times	**-0.129**	**0.043**	-0.028	0.819
Notice given of shift schedule	**-0.141**	**0.002**	-0.002	0.988
Block 4: Work Schedule Features				
Hours worked per week	+0.049	0.318	+0.013	0.900
Length of Night Shift	**+0.187**	**0.018**	+0.131	0.584
Hours worked before a rest	+0.069	0.156	+0.053	0.579
Length of rest break (minutes)	-0.007	0.882	+0.047	0.650
No. Successive Night Shifts	**-0.237**	**0.001**	**-0.337**	**0.041**
No. Successive Work-days	**+0.266**	**0.009**	+0.119	0.253
No. Rest days between blocks	**-0.206**	**0.013**	**+0.183**	**0.058**
No. Days annual Leave	**-0.118**	**0.021**	-0.077	0.452
Start time of Night Shift	+0.074	0.210	**+0.481**	**0.065**
Finish time of Night Shift	-0.024	0.583	-0.234	0.161

N.B. Standardized beta values significant at the 10% ($p<0.10$) level are shown in bold

Table 19 presents the results from the final model of the hierarchical regression analyses. Inspection of this table reveals that for neither group were the demographic variables significant predictors. However, within the block of circadian type measures, morningness was positively related to perceived night shift risk, i.e. morning types perceived the night shift as riskier than evening types, while sleep flexibility was negatively related to risk in both groups. The standardized betas of the two groups were very similar for these two circadian type measures, although they were clearly more significant in the larger group of rotating shiftworkers.

In contrast, the two groups differed substantially over which measures of work schedule rigidity were related to perceived night shift risk. For the permanent night workers increased control over which specific shifts they worked was associated with reduced perceived night shift risk, but there was no such relationship for the rotating shiftworkers. However, in the rotating group greater control over the start and finish times of their shifts, and greater notice of their shift schedule, were both associated with a reduced perceived night shift risk.

A number of the work schedule features were related to perceived night shift risk. Longer night shifts were associated with greater perceived risk, although this only achieved significance within the larger rotating group. Somewhat surprisingly, in view of the objective evidence showing an increase in risk over successive night shifts, both groups showed a negative relationship between perceived risk and the number (span) of successive night shifts involved in the shift system. This is illustrated for the rotating group in Figure 23. It is clear from this Figure that risk was only perceived as reducing when the span of successive night shifts exceeded four, and this is not entirely inconsistent with the available objective evidence reviewed above since only two of the studies reviewed examined more than four successive night shifts. What is difficult to reconcile with the objective evidence is the lack of any increase in perceived risk shown in Figure 23 as the span of successive night shifts increases from two to four.

Within the rotating group the number of successive work-days before a rest day was positively related to perceived risk and this is in line with expectations. The fact that this was not the case for the permanent night workers presumably reflects on the fact that within this group the number of successive night shifts would normally be the same as the number of successive work-days before a rest day. Indeed, the slight difference shown in Table 19 for this group may well reflect the fact that a night shift normally spreads over two days since it starts on one day and finishes on the next. Thus some of the engineers may have considered the number of successive work-days to be one greater than the number of night shifts.

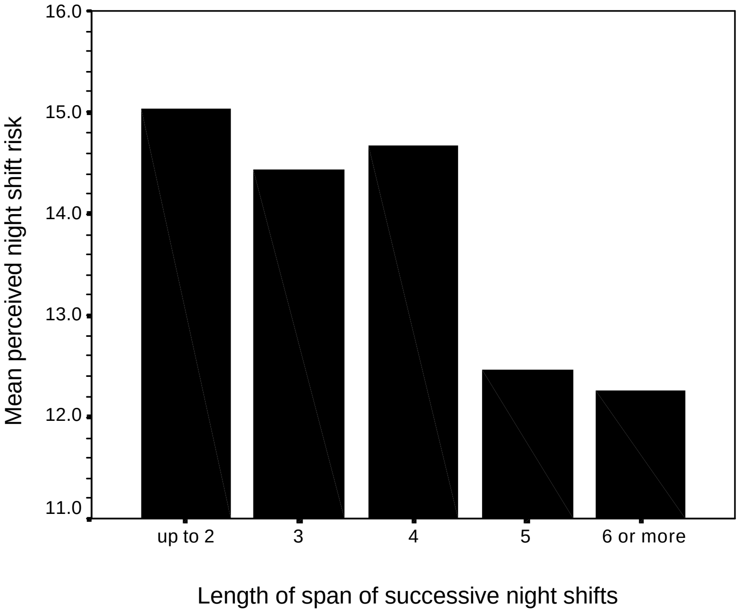

Figure 23. Perceived night shift risk as a function of the span of successive night shifts in the group of rotating shiftworkers.

Both groups of shiftworkers showed a negative relationship between the number of days annual leave and perceived night shift risk, and a positive relationship (later start times being associated with increased perceived risk) for the start time of the night shift. However the former was only significant within the larger rotating group of engineers, while the latter only approached significance for the permanent night workers. More interestingly, the number of rest days between blocks of shifts was related to perceived night shift risk in opposite directions within the two groups, although it should be emphasised that within the smaller permanent group this relationship failed to reach statistical significance at the 5% level. Within the group of rotating shiftworkers, longer spans of rest days were associated with a reduced rating of perceived night shift risk, but the permanent night workers showed an increased rating of perceived risk with longer spans of rest days.

These rather different trends are illustrated in Figure 24 from which it is clear that, with the exception of spans of rest days of 5 or more, the rotating shiftworkers perceived night shift risk as rather higher than the permanent night workers. Further, the permanent night workers clearly rated risk as higher with greater spans of rest days. The finding that the rotating shiftworkers showed a modest, but statistically reliable, reduction in risk with increasing numbers of rest days presumably reflected on an increased ability to dissipate any cumulative build up of fatigue.

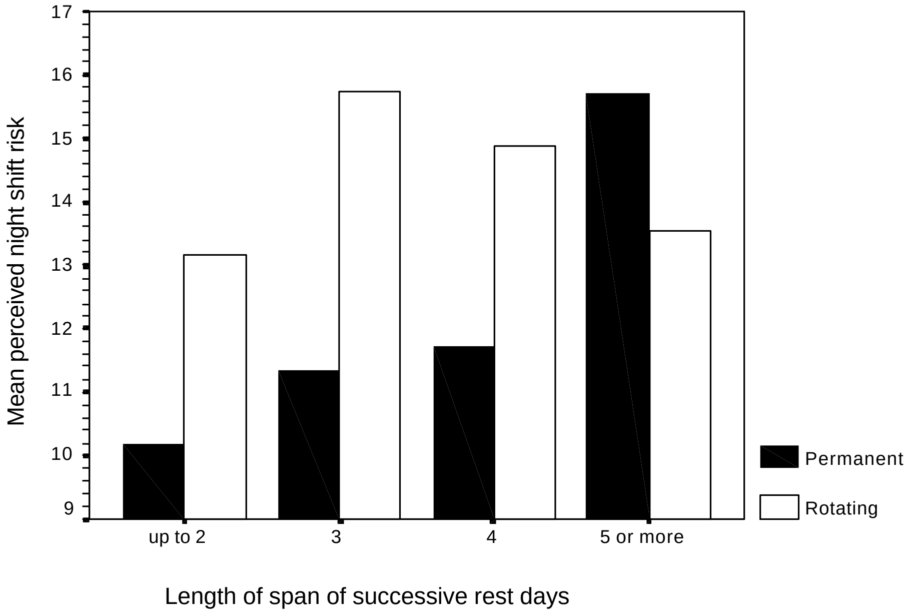

Figure 24. Perceived night shift risk as a function of the span of successive rest days.

3.6.3 Perceived Risk on the Morning/Day shift

Parallel hierarchical multiple regression analyses were performed separately for the permanent morning/day and rotating shiftworkers in an attempt to predict the perceived morning/day shift risk. The details of the blocks of measures are given in Table 20. The first block comprised various demographic measures, the second block comprised the two ratings of circadian type, the third block comprised three measures of the perceived rigidity of the work schedule, while the fourth, and final block, comprised various specific features of the work schedule.

Table 20 presents the results from the final model of the hierarchical regression analyses. Inspection of this table reveals that in both groups the demographic variables were significant predictors, although in most cases greater experience was associated with greater risk. However, the most reliable finding was that increased experience of the present shift was associated with decreased perceived risk in the permanent workers, and this may reflect on increased adjustment of their circadian system to morning or day shifts. Within the block of circadian type measures, rotating morning types perceived the morning/day shift as less risky than evening types, but this effect was not present in the permanent workers. Sleep flexibility showed no significant relationship to risk in either group.

Table 20 Results from the Hierarchical multiple regression analyses for the two groups involved in Morning/day work.

Block 1: Demographic Measures	**Rotating with Morning/days (n=1313)**		**Permanent Morning/days (n=560)**	
	Standardized Beta	**Significance**	**Standardized Beta**	**Significance**
Age	-0.111	0.133	0.096	0.477
Engineering experience	-0.072	0.329	-0.218	0.115
Present job experience	**0.078**	**0.036**	0.078	0.293
Shiftwork experience	**0.094**	**0.057**	**0.276**	**0.002**
Present shift experience	0.038	0.277	**-0.295**	**0.000**
Block 2: Circadian Type Measures				
Morningness	**-0.159**	**0.000**	-0.044	0.481
Sleep Flexibility	-0.023	0.429	-0.011	0.853
Block 3: Rigidity of Work Schedule				
Control over specific shifts	**-0.110**	**0.005**	0.013	0.892
Control over start/finish times	-0.021	0.587	**-0.188**	**0.045**
Notice given of shift schedule	**-0.056**	**0.066**	**0.200**	**0.008**
Block 4: Work Schedule Features				
Hours worked per week	-0.037	0.268	0.023	0.746
Length of Morning/Day shift	0.079	0.301	**0.270**	**0.024**
Hours worked before a rest	0.021	0.496	**0.178**	**0.010**
Length of rest break (minutes)	0.004	0.898	-0.034	0.597
No. Successive Morning/Day Shifts	**0.085**	**0.014**	**-0.396**	**0.001**
No. Successive Work-days	**0.136**	**0.001**	**0.812**	**0.000**
No. Rest days between blocks	-0.045	0.246	**-0.645**	**0.000**
No. Days annual Leave	0.034	0.288	**-0.144**	**0.059**
Start time of Morning/Day Shift	**-0.187**	**0.000**	0.000	0.998
Finish time of Morning/day Shift	**-0.193**	**0.022**	**-0.206**	**0.040**

N.B. Standardized beta values significant at the 10% ($p<0.10$) level are shown in bold

In contrast, the two groups differed substantially over how the measures of work schedule rigidity were related to perceived morning/day shift risk. For the permanent night workers increased control over the timing of the shifts they worked was associated with reduced perceived morning/day shift risk, but there was no such relationship for the rotating shiftworkers. In the rotating group greater control over the specific shifts they worked was associated with reduced perceived morning/day shift risk. These differences between the groups may well reflect on their different opportunity to control these different aspects of their work schedule. However, the most striking difference was for the notice given of the schedule, where increased notice was associated with an increased perceived risk in the permanent morning/day workers while this effect was reversed, although not quite significantly so, in the rotating workers. The most likely explanation for this unexpected effect within the permanent workers is that it is an artefact that reflects on different work sites/companies that differ in both the notice given and the perceived risks associated with the job.

A number of the work schedule features were related to perceived night shift risk. Within the rotating group, both the number of successive morning/day shifts and the number of successive work-days before a rest day were positively related to perceived risk. Further, later start and finish times were associated with a reduced risk. These findings for the rotating group are in line with expectations. Rather more significant relationships were found within the smaller group of permanent morning/day shift workers. As might be expected, longer morning/day shifts were associated with greater risk, as were longer periods of work before a break. Somewhat surprisingly, this group showed a negative relationship between risk and the span of successive morning/day shifts. However, this finding should be interpreted with caution in the light of the substantially stronger positive relationship between the number of successive work-days and risk since clearly these two work schedule features would normally be the same within this group. Finally, an increased number of rest days between blocks of shifts and increased annual holidays were both associated with a reduction in perceived risk, as was a later finish time to the morning/day shift.

3.6.4. Perceived Risk on the Afternoon shift

Finally, in view of the very small number of permanent afternoon shift workers (N=30), a single hierarchical multiple regression analyses was performed for all the engineers involved in afternoon work in an attempt to predict the perceived afternoon shift risk. The details of the blocks of measures are given in Table 21. The first block comprised various demographic measures, the second block comprised the two ratings of circadian type, the third block comprised three measures of the perceived rigidity of the work schedule, while the fourth, and final block, comprised various specific features of the work schedule.

Inspection of Table 21 reveals that there were only three predictors of afternoon shift risk at the 10% level. First, there was a suggestion that increased experience of the present job was associated with increased perceived afternoon shift risk. It seems probable that this effect should be interpreted as reflecting an increased awareness of risk with experience, rather than as a genuine increase in risk with experience. Secondly, morningness was significantly related to perceived afternoon shift risk such that morning types rated the risk as higher than evening types. This is the opposite of the relationship found for the morning shift within the rotating group and is very much in line with expectations. Finally, later start, but not finish, times to the afternoon shift were associated with an increased perceived risk.

Table 21 Results from the Hierarchical multiple regression analysis for all the shiftworkers involved in afternoon shift work.

Block 1: Demographic Measures	**(n=639)**	
	Standardized Beta	**Significance**
Age	-0.092	0.314
Engineering experience	-0.049	0.595
Present job experience	**0.051**	**0.091**
Shiftwork experience	0.057	0.329
Present shift experience	-0.004	0.930
Block 2: Circadian Type Measures		
Morningness	**0.277**	**0.000**
Sleep Flexibility	-0.033	0.389
Block 3: Rigidity of Work Schedule		
Control over specific shifts	-0.056	0.309
Control over start/finish times	-0.048	0.380
Notice given of shift schedule	-0.038	0.354
Block 4: Work Schedule Features		
Hours worked per week	0.004	0.929
Length of Afternoon shift	0.035	0.469
Hours worked before a rest	0.036	0.364
Length of rest break (minutes)	-0.042	0.284
No. Successive Afternoon Shifts	0.006	0.883
No. Successive Work-days	-0.002	0.959
No. Rest days between blocks	0.000	0.994
No. Days annual Leave	0.043	0.313
Start time of Afternoon Shift	**0.101**	**0.022**
Finish time of Afternoon Shift	-0.011	0.794

N.B. Standardized beta values significant at the 10% ($p<0.10$) level are shown in bold

3.6.5. Poor Health and Dissatisfaction

Hierarchical multiple regression analyses were performed for the entire sample in an attempt to predict the poor health and dissatisfaction outcome measures. The details of the blocks of measures are given in Table 22. As for the perceived night shift risk analyses, the first block comprised various demographic measures, the second block comprised the two ratings of circadian type, the third block comprised three measures of the perceived rigidity of the work schedule, while the fourth, and final block, comprised various specific features of the work schedule.

Table 22 presents the results from the final model of the hierarchical regression analyses. Inspection of this table reveals that for the poor health measure, the only predictors that approached significance were the length of experience as an aircraft maintenance engineer, with greater experience (which itself will be associated with increasing age) being associated with poorer health, and the perceived control over the specific shifts worked with greater control being associated with better health.

Table 22 Results from the Hierarchical multiple regression analyses for the Poor Health and Schedule Dissatisfaction measures

Block 1: Demographic Measures	**Health**		**Dissatisfaction**	
	Standardized Beta	**Significance**	**Standardized Beta**	**Significance**
Age	-0.071	0.699	0.126	0.406
Engineering experience	**0.359**	**0.056**	-0.058	0.706
Present job experience	0.039	0.684	0.025	0.750
Shiftwork experience	-0.030	0.734	**-0.242**	**0.001**
Present shift experience	-0.143	0.223	0.019	0.848
Block 2: Circadian Type Measures				
Morningness	-0.099	0.204	**-0.163**	**0.013**
Sleep Flexibility	-0.062	0.428	-0.089	0.170
Block 3: Rigidity of Work Schedule				
Control over specific shifts	**-0.189**	**0.088**	**-0.184**	**0.046**
Control over start/finish times	-0.039	0.724	**-0.156**	**0.087**
Notice given of shift schedule	-0.074	0.354	**-0.231**	**0.001**
Block 4: Work Schedule Features				
Hours worked per week	0.026	0.747	**0.185**	**0.007**
Hours worked before a rest	-0.017	0.838	**-0.117**	**0.092**
Length of rest break (minutes)	-0.073	0.396	**0.165**	**0.022**
No. Successive Work-days	-0.068	0.524	**0.302**	**0.001**
No. Rest days between blocks	-0.044	0.682	**-0.424**	**0.000**
No. Days annual Leave	-0.073	0.392	**-0.164**	**0.022**
Includes Nights	0.044	0.646	-0.017	0.834
Shift Length	0.071	0.527	-0.013	0.885

N.B. Standardized beta values significant at the 10% ($p<0.10$) level are shown in bold

In contrast, the dissatisfaction measure was reliably predicted by variables in all four blocks. Dissatisfaction with the work schedule was less in those with greater shiftwork experience, and less in those who rated themselves as morning types. This latter finding may well reflect on the fact that evening types typically have higher scores on various scales of psychological ill health than morning types (e.g. Folkard & Hunt, 2000). Dissatisfaction was also less in those who perceived themselves as having greater control over both the shifts worked and their start times, and in those who claimed that they were given greater notice of their shift schedule. Finally, a number of work schedule features significantly predicted dissatisfaction with the schedule. As might be expected, both increased hours scheduled per week and increased numbers of successive work-days were associated with increased dissatisfaction, while increased scheduled rest days and annual leave were associated with decreased dissatisfaction. However, rather surprisingly, longer periods of duty before a rest break were associated with decreased dissatisfaction while longer breaks were associated with increased dissatisfaction. It seems probable that these latter two findings reflect on the distribution of breaks over relatively popular and unpopular shift systems. Perhaps more importantly, neither the inclusion of nights shifts within a schedule, nor the length of the shifts, were reliable predictors of either the health or schedule dissatisfaction measures.

3.6.6. Conclusions

With respect to perceived risk, in most cases the trends observed in this study were reasonably consistent with established trends in either performance capability or accident and injury frequency. This was true for the measures of circadian type and the extent of control over the shift schedule, but not for the various specific features of the scheduled shift system. The most obvious discrepancy was the lack of any increase in risk as the span of successive night shifts increased from two to four (Figure 23). It is now well established that objectively measured risk shows a fairly substantial increase over at least the first four successive nights shifts, clearly implying that risk should increase as the span of successive night shifts involved in a shift system is increased from one up to four (see section 2.4.3.). This failure of the subjective ratings of perceived risk to increase as the span of night shifts increases from two to four clearly brings into question the validity of the questionnaire based assessments of risk on which many recent models have been based. Finally, it implies that individuals' assessments of risk are not always accurate, and suggests the need for educational programmes designed to alert engineers to the times at which they are most likely to make mistakes.

4. The Surveys of Aircraft Maintenance Personnel Employers

In addition to the large-scale survey of aircraft maintenance personnel, surveys were conducted of aircraft maintenance companies and of aircraft maintenance contract companies. The purpose of these was primarily to check on the validity of the data obtained from the individual aircraft maintenance personnel with respect to the details given of their work hours.

4.1.Aircraft Maintenance Companies

4.1.1. Questionnaire administration

This survey was sent to all 174 British aircraft maintenance companies licensed to maintain aircraft (JAR 145).

4.1.2. Responses

Completed questionnaires were returned by 39 companies of the initial 174 who received the survey, giving a response rate of 22.4% overall.

4.1.3. Details of Companies

Of the 39 companies who completed the questionnaire, 24 used only day shifts while the remaining 15 used a total of 43 different shift systems. The details of the numbers and types of employees, and the weights of the aircraft maintained are given in Table 23 below

Table 23. Details for the Companies

			No. Companies working on aircraft*:		
Companies using:	Mean No. Certifying	Mean No. Non-Certifying	Up to 2730 Kg.	2730 to 5700 Kg.	Over 5700 Kg.
Days only (N=24):	5.96	6.96	17	14	5
Shift systems (N=15):	63.13	107.47	5	5	8

* Note that many companies worked on more than one category

It is clear from Table 23 that those companies employing shift systems employed considerably more individuals and tended to work on larger aircraft.

4.1.4. Details of the Shift Systems

For the purpose of this analysis, those companies employing only day shifts were classified as using a permanent day shift. The number of companies using the five main types of shift system, and the most common exemplars, and the most common length of shifts are shown in Table 24.

Table 24. Number of Companies using the different types of Shift System

Shift System:	No. of Companies	Most common exemplar	Most common length
Rotating with Nights	10	2D2N4R	12 hours
Rotating without Nights	8	5M2R5A2R	7-9 hours
Permanent Mornings/Days	32	5D2R	12 hours
Permanent Afternoons	0	-	-
Permanent Nights	4	4N4R	12 hours

4.1.5. Conclusions

These most common exemplars of these shift systems correspond well with the results obtained from the individual aircraft maintenance personnel (see sections 3.3.1. to 3.3.5. above), as do the lengths of the shifts (section 3.5.2).

4.2. Aircraft Maintenance Contract Companies

4.2.1. Questionnaire administration

This survey was sent on an ad-hoc basis to a number of contract companies.

4.2.2. Response

Completed questionnaires were returned by 9 companies.

4.2.3. Details of Companies

Of the 9 companies who completed the questionnaire, all used some type of shift system. The details of the numbers and types of employees, and the weights of the aircraft maintained are given in Table 25 below

Table 25. Details for the Companies

Mean No. Certifying	Mean No. Non-Certifying	No. Companies working on aircraft*:		
		Up to 2730 Kg.	2730 to 5700 Kg.	Over 5700 Kg
81.78	395.78	3	4	8

* Note that many companies worked on more than one category

4.2.4. Details of the Shift Systems

The total number of individuals employed by these contract companies using the five main types of shift system are shown in table 26.

Table 26. The total number of personnel employed on the five main types of shift system

Type of System	**Certifying**	**Non-certifying**
Permanent Mornings/Days	503	2728
Permanent Afternoons	5	27
Permanent Nights	75	285
Rotating without nights	81	120
Rotating with nights	68	201

The total number of individuals employed on different lengths of shifts by these nine companies is shown in Table 27.

Table 27. The total number of personnel employed on different lengths of shifts

Length of Scheduled Shifts	Certifying	Non-certifying
Less than 7 hours	0	0
7.0-8.9 hours	71	639
9.0-10.9 hours	281	2273
11.0-12.9 hours	282	283
13 or more hours	53	218

The mean number of hours per week that the contract engineers/mechanics were normally contracted to work and the number of hours overtime they typically worked is shown in Table 28. This table also shows the contracted and "normally taken" annual leave. It should be noted that the annual leave data shown in this table should be treated with caution since some companies appear to have included weekends, and others to not do so, in calculating the number of days leave. Further, not all the companies supplied answers to all the questions so that it is not possible to add the contracted hours per week to the typical overtime hours to obtain an estimate of the actual hours worked per week.

Table 28. The mean weekly hours and annual leave days

	Certifying	Non-certifying
Contracted hours per week	45.94 hours	46.50 hours
Typical overtime	16.33 hours	16.28 hours
Contracted Annual Leave	28 days	28 days
Normal Annual Leave	25.83 days	25.83 days

4.2.5. Conclusions

The values obtained from this survey seem to agree fairly well with the results described in section 3.5 above.

4.3. Overall Conclusion

The results from these surveys of aircraft maintenance personnel employers give no reason to doubt the validity of the data obtained from the individual aircraft maintenance personnel with respect to the details given of their work hours.

5. Recommendations for "Good Practice"

5.1. Background

5.1.1. The International Context

There is widespread international concern over the safety implications of the work schedules of aircraft maintenance engineers. Studies of these schedules have been conducted, or are underway, in Australia, Canada, France, Japan, New Zealand, and the U.S.A. and it is probable that this list is by no means exhaustive. For example, a Canadian study has found that aircraft maintenance engineers typically sleep for between 6 and 7.1 hours only on workdays between long or extended shifts and it is noteworthy that this finding is in agreement with the results of this study, in which the normal sleep durations between morning/day and night shifts were found to average 6.8 and 6.5 hours respectively.

Likewise, the finding of over 100 different shift systems in the present study is similar to the French results obtained for Air France aircraft maintenance engineers. In New Zealand, the introduction of a 12-hour shift system (2D2N4R) has proved highly successful and popular with those concerned, but in Japan changes to the shift systems involving greater numbers of successive work-days have given rise to considerable concern over safety. The FAA has supported a number of research studies, and reports based on these are available from their website (http://hfskyway.faa.gov). The FAA's overall aim, is to identify risk factors and avoidance techniques with a view to alleviating errors or incidents that could lead to an accident.

5.1.2. Risk and Fatigue

The basic aim of any set of guidelines for "good practice" must clearly be to minimise the risk of an error or mistake being made. There is very good evidence that the likelihood of mistakes or errors increases when individuals are fatigued. However, the objective scientific evidence on trends in risk reviewed in Section 1 and 2 indicates that these do not necessarily show the same trends as those in fatigue, and indeed may sometimes show a very different trend. This is despite the fact that many objective measures of performance, such as reaction time, have been shown to parallel subjective fatigue measures very closely. Thus models based on subjective estimates of fatigue, while clearly a potentially extremely useful tool, may thus sometimes result in spurious conclusions or recommendations. Further, it should be emphasised that individuals' perceptions of risk do not always show the same pattern as objectively assessed risk. The approach adopted here is thus to base recommendations on the objective trends in risk where these are available, and to supplement this with evidence from studies of fatigue or sleep duration where objective risk data is unavailable.

5.1.3. Risk Management Programmes

Concern over risk is not confined to the aircraft maintenance industry and it would be foolish to ignore approaches to risk management that have proved successful in other sectors. Such approaches range from a relatively simple set of limitations on the work hours of a particular occupational group, such as the CAA's own "Scheme for the Regulation of Air Traffic Controller's Hours" to more general schemes such as Western Australia's scheme for "Fatigue Management" in commercial vehicle drivers. These more general schemes include recommendations for the scheduling of work hours, but also cover wider ranging issues such as the individual's readiness to work, workplace conditions, training and education, documentation and records, and the management of incidents.

The current project was primarily concerned with issues relating to work schedules and any associated flight safety risk, and the recommendations made for best practice must thus necessarily be confined to this aspect of a risk management programme. However, it should be emphasised that although these recommendations could be implemented by themselves, they should ideally form part of a wider ranging risk management programme.

5.2. Guidelines for "Good Practice"

5.2.1. Underlying Principles

Wherever possible, the guidelines proposed here are based on established trends in risk. These were derived from reviewing large-scale studies of accidents and/or injuries in many different types of industry and country. However, there are many features of work schedules that may give rise to concern with respect to their impact on sleep and/or fatigue, but for which there are, as yet, no good studies showing their impact on risk. In these cases, and in the absence of objective risk data, the guidelines have been based on the available evidence relating these features to sleep and/or fatigue. The aims in these cases have been threefold, namely to:

1. Minimise the build up of fatigue over periods of work
2. Maximise the dissipation of fatigue over periods of rest
3. Minimise sleep problems and circadian disruption

5.2.2. Daily limits

There is good evidence that risk increases over the course of a shift in an approximately exponential manner such that shifts longer than about 8 hours are associated with a substantially increased risk. Thus, for example, it has been estimated that, all other factors being equal, the risk on a 12-hour shift system is some 27.6% higher than that on an 8-hour system. Shifts longer than 12-hours should thus clearly be considered as undesirable. For the same reason, it would seem wise to limit the extent to which a shift can be lengthened by overtime to 13 hours. Likewise, it would seem prudent to ensure that the break between two successive shifts is sufficient to allow the individual concerned to travel home, wind-down sufficiently to sleep, have a full 8-hour sleep, have at least one meal, and travel back to work. The EU's Working Time Directive sets this limit at 11 hours, and this would be consistent with a maximum work duration, including overtime, of 13 hours. Three daily limits are thus recommended, namely:

1. *No scheduled shift should exceed 12 hours.*

2. *No shift should be extended beyond a total of 13 hours by overtime.*

3. *A minimum rest period of 11 hours should be allowed between the end of shift and the beginning of the next, and this should not be compromised by overtime.*

5.2.3. Breaks

There is surprisingly little evidence on the beneficial effects of breaks on risk. However, there is evidence that fatigue builds up over a period of work, and that this can be, at least partially, ameliorated by the provision of breaks. There is also recent, and as yet unpublished, evidence that risk behaves in a similar manner, increasing in an approximately linear fashion between breaks. It would thus seem prudent to recommend limits on the duration of work without a break, and on the minimum length of breaks. It should be emphasised here that there is some evidence to suggest that frequent short breaks are more beneficial than less frequent longer ones. However, it is recognised that work demands may prevent the taking of frequent short breaks. In the light of this, and of the findings from the survey regarding the provision of breaks, two limits are thus recommended, namely:

4. *A maximum of fours hours work before a break.*

5. *A minimum break period of ten minutes plus five minutes for each hour worked since the start of the work period or the last break.*

5.2.4. Weekly Limits

Fatigue accumulates over successive work periods and it is thus necessary to limit not only the daily work hours, but also the amount of work that can be undertaken over longer periods of time. The aim here is to ensure that any accumulation of residual fatigue is kept within acceptable limits, and can be dissipated over a period of rest days. However, if these limits are simply related to the calendar week this can result in unacceptably high numbers of shifts or work-hours between successive periods of rest days. It is thus necessary to express the limits with respect to any period of seven successive days. In the light of this, and the findings from the survey, the following recommendations are made:

6. *Scheduled work hours should not exceed 48 hours in any period of seven successive days.*

7. *Total work , including overtime, should not exceed 60 hours or seven successive work days before a period of rest days.*

8. *A period of rest days should include a minimum of two successive rest days continuous with the 11 hours off between shifts (i.e. a minimum of 59 hours off). This limit should not be compromised by overtime.*

5.2.5. Annual Limits

Some residual fatigue may accumulate over weeks and months despite the provision of rest days, therefore annual leave is important. There is, however, little evidence to indicate what might be considered an ideal number of days annual leave. Accordingly, based on the survey results it is suggested that 28 days annual leave would be appropriate. This aligns with the EU working time directive. 21 days annual leave should be the minimum. In the light of this the following recommendation is made:

9. *Wherever possible, a total of 28 days annual leave should be aimed for and this should not be reduced to less than 21 days leave by overtime.*

5.2.6. Limits on Night Shifts

There is good objective evidence that risk is increased at night by about 30% relative to the morning/day shift. There is also good evidence indicating that risk increases in an approximately linear fashion over at least four successive night shifts, such that it is about 45% higher on the fourth night shift than on the first night shift. However, given the increased risk on 12-hour shifts relative to 8-hour shifts, it would seem prudent to take account of shift duration in recommendations for limiting successive night work. It is also the case that a single night's sleep following a span of night shifts may not fully dissipate the fatigue that may accumulate over a span of night shifts. Finally, there is published evidence that later finish times to the night shift can result in shorter day sleeps between successive night shifts, and there was some support for this finding in the current survey. In the light of these considerations and the findings from the survey, the following recommendations are made:

10. *A span of successive night shifts involving 12 or more hours of work should be limited to 6 for shifts of up to 8 hours long, 4 for shifts of 8.1 to 10 hours long, and 2 for shifts of 10.1 hours or longer. These limits should not be exceeded by overtime.*

11. *A span of night shifts should be immediately followed by a minimum of two successive rest days continuous with the 11 hours off between shifts (i.e. a minimum of 59 hours off) and this should be increased to three successive rest days (i.e. 83 hours off) if the preceding span of night shifts exceeds three or 36 hours of work. These limits should not be compromised by overtime.*

12. *The finish time of the night shift should not be later than 08:00.*

5.2.7. Limits on Morning/Day shifts

There is good objective evidence that an early start to the morning/day shift can result in a substantial truncation of sleep. The extent of this truncation depends on the time at which the individual has to leave home which in turn is largely determined by the start time of the shift. Indeed, it has been reported that for each hour earlier that individuals have to leave home to travel to their morning/day shift they sleep for 46 minutes less. However, operational and local factors sometimes necessitate early start times. It is also the case that a balance needs to be achieved between later starts to the morning/day shift and earlier finishes to the night shift with a view to maximising the sleep duration between both types of shift. In the light of this and the findings from the survey, the following recommendations are made:

13. *A morning or day shift should not be scheduled to start before 06:00, and wherever possible should be delayed to start between 07:00 and 08:00.*

14. *A span of successive morning or day shifts including 32? Or more hours of work that start before 07:00 should be limited to four, immediately following which there should be a minimum of two successive rest days continuous with the 11 hours off between shifts (i.e. a minimum of 59 hours off).. This limit should not be compromised by overtime.*

5.2.8. Days notice of Schedule

There is no objective evidence that the number of days notice given of a schedule effects risk or fatigue, but it was perceived as influencing risk in the survey. In the light of this finding from the survey, the following recommendation is made:

15. *Wherever possible aircraft maintenance engineers should be given at least 28 days notice of their work schedule.*

5.3. Further Recommendations for "Good Practice"

The following recommendations are not specifically concerned with the scheduling of work hours and fall outside the area of expertise of the author. Nevertheless, it is clear that recommendations for the features of work schedules form only one part, albeit a major one, of a comprehensive risk management programme.

16. *Employers of aircraft maintenance personnel should consider developing risk management systems similar to those required by Western Australia's Code of Practice for commercial vehicle drivers.*

17. *Educational programmes should be developed to increase aircraft maintenance engineers' awareness of the problems associated with shiftwork. In particular, it is important to draw their attention to the objective trends in risk with a view to increasing their vigilance at points when risk may be high despite the fact that fatigue may not be. It is also important to provide information on how to plan for nightwork, and to give guidance on the health risks which seem to be associated with shift work, particularly at night.*

18. *Aircraft maintenance personnel should be required to report for duty adequately rested.*

19. *Aircraft maintenance personnel should be discouraged or prevented from working for other organisations on their rest days, and hence from exceeding the proposed recommendations on work schedules despite their implementation by their main employer.*

5.4. Summary of Recommendations

1. *No scheduled shift should exceed 12 hours.*

2. *No shift should be extended beyond a total of 13 hours by overtime.*

3. *A minimum rest period of 11 hours should be allowed between the end of shift and the beginning of the next, and this should not be compromised by overtime.*

4. *A maximum of fours hours work before a break.*

5. *A minimum break period of ten minutes plus five minutes for each hour worked since the start of the work period or the last break.*

6. *Scheduled work hours should not exceed 48 hours in any period of seven successive days.*

7. *Total work , including overtime, should not exceed 60 hours or seven successive work days before a period of rest days.*

8. *A period of rest days should include a minimum of two successive rest days continuous with the 11 hours off between shifts (i.e. a minimum of 59 hours off). This limit should not be compromised by overtime.*

9. *Wherever possible, a total of 28 days annual leave should be aimed for and this should not be reduced to less than 21 days leave by overtime.*

10. *A span of successive night shifts should be limited to 6 for shifts of up to 8 hours long, 4 for shifts of 8.1 to 10 hours long, and 2 for shifts of 10.1 hours or longer. These limits should not be exceeded by overtime.*

11. *A span of nights shifts involving 12 or more hours of work should be immediately followed by a minimum of two successive rest days continuous with the 11 hours off between shifts (i.e. a minimum of 59 hours off) and this should be increased to three successive rest days (i.e. 83 hours off) if the preceding span of night shifts exceeds three or 36 hours of work. These limits should not be compromised by overtime.*

12. *The finish time of the night shift should not be later than 08:00.*

13. *A morning or day shift should not be scheduled to start before 06:00, and wherever possible should be delayed to start between 07:00 and 08:00.*

14. *A span of successive morning or day shifts that start before 07:00 should be limited to four, immediately following which there should be a minimum of two successive rest days continuous with the 11 hours off between shifts (i.e. a minimum of 59 hours off). This limit should not be compromised by overtime.*

15. *Wherever possible aircraft maintenance engineers should be given at least 28 days notice of their work schedule.*

16. *Employers of aircraft maintenance personnel should consider developing risk management systems similar to those required by Western Australia's Code of Practice for commercial vehicle drivers.*

17. *Educational programmes should be developed to increase aircraft maintenance engineers' awareness of the problems associated with shiftwork. In particular, it is important to draw their attention to the objective trends in risk with a view to increasing their vigilance at points when risk may be high despite the fact that fatigue may not be. It is also important to provide information on how to plan for nightwork, and to give guidance on the health risks which seem to be associated with shift work, particularly at night.*

18. *Aircraft maintenance personnel should be required to report for duty adequately rested.*

19. *Aircraft maintenance personnel should be discouraged or prevented from working for other organisations on their rest days, and hence from exceeding the proposed recommendations on work schedules despite their implementation by their main employer.*

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