The contribution of fatigue and shift-work to the Buncefield explosion and key lessons for the chemical and allied high hazard industries

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Although there have been multiple reports of the 2005 Buncefield explosion and fires, not all of the detailed underlying analysis has been fully published, particularly for the human contribution. In this paper, the original HSE investigation analysis of the fatigue and shift-work contribution to the incident is presented in more detail and set in the context of the full incident. The key lessons for the major hazard industries are identified e.g. provision of a workable, fair and safe shift system is a classic organisational factor - which the organisation needs to identify and address - but these can be overlooked in favour of managing symptoms instead. The authors' experience of being involved, as human factor professionals, in such a lengthy and demanding incident investigation is also addressed, and the key lessons learnt are identified for future investigators.

The current research and practitioner position on fatigue and shift-work is discussed with key lessons and issues identified for the chemical and allied major hazard industries. For example, there is an increasing trend for shift system problems to be presented as specific issues for management (such as overtime limits and management of return to work after exceptional hours) when the underlying cause is organisational and (usually) resource-linked. In other words when there are not enough people assigned to the shift system it cannot work as planned and can break down in a variety of less predictable ways.

Introduction

The two authors worked closely together as part of the human factors' strand of the HSE's Buncefield investigation. John Wilkinson led the human factors' part of the main investigation and looked at a wide range of performance shaping factors (PSFs) behind the incident and Julie Bell provided specific detailed analysis about the fatigue potential, a PSF that was identified as an important contributory cause. PSFs were investigated because these are the factors which make error more or less likely (in this case 'more'). And, while human error might be considered the default human condition e.g. it is one of the main ways in which we learn, as adults we humans normally get things right. PSFs help explain why we get it wrong on any particular occasion. Typically we tend to underestimate the impact of PSFs – especially external and environmental ones – when considering the actions of others, and over-estimate their contribution to our own. This is part of a natural cognitive bias called the Fundamental Attribution Error (FAE) in psychology (Reason 1997, p126) and of course the truth usually lies somewhere in-between. So after an incident it is important to understand what PSFs were prevailing, and after a major accident, there are invariably a large number of them to consider. Fatigue can be both a property of the individual (how tired they were at the time) and of the wider organisation and system which can set up individuals to 'fail' through tiredness on an acute e.g. within-shift, or chronic (cumulative) basis. It is important to understand both and their contribution but then to place them in context and balance so as to avoid the FAE. This is the systems' approach.

Fatigue and shift-work issues were identified as important contributory causes in the build-up to Buncefield and, in a general sense, on the night too. The complex and multi-faceted nature of fatigue means that it is not currently possible to take a 'measure' of an individual's fatigue level at any one point in time. Therefore, as investigators, we considered the elements that are known to influence fatigue such as sleep (quality and quantity), rest periods, workload and number of shifts to indicate whether supervisors were likely to be fatigued. This information was then used to assess whether the fatigue risk was being managed effectively. The fatigue issues associated with the Buncefield incident have since been identified in many other companies. While some are working to address the issues and minimise the risk to safety, others are failing to recognise the potential contribution that fatigue can have on decision making, situational awareness, verbal fluency, innovative and flexible thinking, monitoring and pattern recognition (e.g. during response to alarms).

The Background to the incident

This incident was Britain's largest peacetime explosion to date (HSE 2011 p11). Although no one died, there were substantial economic and community impacts e.g. the two major fuel pipelines to Heathrow and Gatwick airports were also controlled from an adjoining site. The investigation was lengthy and complex. Despite this, the incident was really very simple. At around 05.40 on Saturday 11th December 2005 one very large petrol storage tank at the Buncefield oil storage depot in Hemel Hempstead overfilled. The leak was not noticed in the control room or detected outside before a large petrol vapour cloud had formed. This ignited and exploded just after 06.00. All of the safety barriers failed on the night, including the tank level gauge which stuck so that the associated high-level alarm did not sound in the control room. The final independent high level switch (IHLS) on the tank had not been correctly set, and so also failed to work.

The depot operation was essentially simple. Three large pipelines delivered a range of fuels to the site. The smaller one was dedicated to the site and mainly site-controlled and operated; the other two were larger and faster, and mainly controlled from elsewhere. These two delivered fuels to other sites as well and so could be 'on or off' with respect to Buncefield.

The human and organisational factors' contribution to the investigation

A human and organisational (HOF) specialist inspector (first author) was involved early on in helping assess documents and other evidence, and in preparing the questions for interviews. The investigating inspectors were HOF-trained and so identified emerging HOF issues quickly, allowing the relevant evidence to be captured and professionally assessed e.g. recovery of the shift schedule from the control room wall suggested that there could be an issue. The full evidence emerged, or was confirmed, through documents and interviews - these took over 6 months to set up and carry out; a long and painstaking process. The Health and Safety Laboratory (HSL – second author), which is the research agency for the Health and Safety Executive, provided deep topic expertise and scientific support.

The initial evidence included the fact that this incident happened at night and towards the end of a 12-hour shift - the classic 'small hours' period when accidents, due to fatigue, are more likely to occur (HSE 2006 p6). The pipeline supervisor was also focused on another pipeline task on the depot's 'own' pipeline immediately before the release and right at the end of his 12-hour shift; and the initial confusion for both supervisors arose at the end of shift / handover (HSE 2011). Fatigue can be acute e.g. within-shift, and 'chronic' (or cumulative) i.e. building up over a longer period – the latter was the main issue at Buncefield (see below). There was therefore good reason to investigate the fatigue and shift-work issues in more depth.

The HSL analysis of the evidence

The following sub-sections are taken – with minor amendments – from the original HSL report (HSL 2007) which helped inform the ongoing investigation and later supported the successful prosecution case.

The analysis of the shift schedule as planned and as worked

The interviews confirmed that the 8-week shift schedule was designed for 10 supervisors but was being worked by 8 because of on-going recruitment and retention difficulties. This resulted in supervisors working, for example, seven 12-hour shifts in a row (weeks 4-5), five successive 12-hour night shifts and increased overtime. They were left to arrange their own holiday and other relief cover. There were also no structured arrangements for within-shift rest and meal breaks. Supervisors would usually eat or take time out at their desk in the control room.

Table 1: Shift schedule worked by supervisors at the Buncefield Oil Depot

(N-Night; D-Day; T-terminal; P-Pipeline; RD-Rest day; S/By-Standby)

Shift	Mon	Tues	Weds	Thurs	Fri	Sat	Sun	Total Hours
1	N(T)	N(T)	N(T)	N(T)	N(T)	RD	RD	60
2	D(P)	D(P)	D(P)	D(P)	RD	RD	RD	48
3	S/BY	S/BY	S/BY	S/BY	N(P)	N(P)	N(P)	36
4	RD	RD	RD	RD	D(P)	D(P)	D(P)	36
5	N(P)	N(P)	N(P)	N(P)	RD	RD	RD	48
6	D(T)	D(T)	D(T)	D(T)	S/BY	S/BY	S/BY	48
7	RD	RD	RD	RD	D(T)	D(T)	D(T)	36
8	RD	RD	RD	RD	RD	RD	RD	0

The shift schedule was 0700-1900 / 1900- 0700, 26 work shifts over an 8 week cycle. There were 7 standby shifts and 23 rest days (RD). Staff worked on either the 'pipeline' or 'terminal' side of the operation. The total number of hours worked in any seven day period ranged from 0 hours to 60 hours. Over 17 weeks, the average was 40.2 hours. However, this planned schedule of work does not provide a complete picture: specifically, Shifts 4 and 5 combined to make a 7-day period where 84 hours are worked.

The overtime analysis

Overtime was also required over a sustained period for on-going project and (ironically) safety improvement work. While individual levels varied the following table (Table 2) shows the scale. The drop off towards December was largely due to an increasing reluctance by supervisors to continue to work these levels of overtime.

Table 2: Average overtime worked by the Buncefield supervisors in the 5 months before the incident (HSL 2007)

Time period (2005)	Minimum	Maximum	Average per person
14 Nov – 13 Dec	0	114	34.86
14 Oct – 13 Nov	0	127	60.35
14 Sept – 13 Oct	0	87	34.18
14 Aug – 13 Sept	10	92	53.36
14 Jul – 13 Aug	6	121	57.4

HSL also carried out an assessment of the shift schedule against the HSE shift-work guidance (HSE 2006). The original analysis follows and is based on the key dimensions of concern identified in the guidance for shift work.

Suitability of the shift start times

Planned shifts started at 0700 and 1900. The start time of 0700 was considered adequate. HSE Guidance recommends avoiding start times before 0700 however consideration should be given to commuting times because time required to travel to work will reduce the rest period and the time available for sleep. Early morning starts can reduce sleep and increase the risk of fatigue. Based on current knowledge, a start time of 1900 is also adequate.

Consideration of shift duration

HSE Shift Work Guidance recommends that employers should avoid shifts that are longer than 8 hours, where work is demanding, safety critical or monotonous and/or there is exposure to work-related physical or chemical hazards. This is because, while research to compare the effects of 12-hour shifts with those of 8- hour shifts has produced equivocal findings, 12-hour shifts are related to greater subjective fatigue, insufficient sleep and performance decrements (HSG256 Table 5 p20). However, a number of advantages are claimed for 12-hour shift work, including the reduction in the number of handovers (but see Wilkinson & Lardner 2012) for a full discussion of the handover issues at Buncefield – same person handover can introduce other error potential). In essence though, whichever length is chosen it will need managing both to release the potential benefits and minimize the potential disadvantages. The working of 12-hour shifts is acceptable if it is managed correctly, for example if the following are taken into consideration:

- The employees are committed and motivated to work 12-hour shifts;
- Work is organised to minimise the risk of fatigue while undertaking tasks that are sensitive to the effects of fatigue;
- Breaks are taken at regular intervals throughout the shift;
- The number of consecutive shifts is minimised, particularly night shifts;
- Adequate rest days are taken following a period of 12-hour shifts;
- Methods for mediating the effects of fatigue are utilised.

The available evidence indicated that the working hours by supervisors at the Buncefield site were not managed to minimise the risk of fatigue.

Analysis of the number of consecutive shifts

When working 12-hour shifts it is important to limit the number of consecutive shifts, especially night shifts. The HSE guidance recommends, "in general, a limit of 5-7 consecutive working days should be set for standard (i.e. 7-8 hour) shifts. Where shifts are longer than this, for night shifts and for shifts with early morning starts it may be better to set a limit of 2-3 consecutive shifts, followed by 2-3 rest days to allow workers to recover" (HSE 2006 Table 7 p23). The number of consecutive shifts is closely linked to the subsequent number of rest days. However, if just the number of shifts is considered there were a number of issues of concern e.g. one shift comprised a block of five 12-hour night shifts; working this on a regular basis can increase the risk of fatigue. Another block of shifts ran into a second resulting in seven consecutive shifts (three 12-hour day shifts, followed by four 12 hour night shifts). This was not appropriate and increased the risk of fatigue.

Analysis of the rest periods – the number of days between shifts

The number of rest days after a series of consecutive shifts is important because it determines the amount of time the worker has to recover from work. The number of rest days included in the Buncefield shift schedule was variable but there were a number of occasions where fewer rest days were provided than would be recommended by guidance. For example, there was a planned period of seven, 12-hour shifts followed by only 3 rest days before recommencing work.

Consideration of the breaks provided

In order to mitigate the effects of fatigue during a 12-hour shift, regular breaks are required. Interview transcripts show that the workers took breaks when the work allowed and that these were not taken at fixed times or away from the control room.

Analysis of cumulative fatigue

Cumulative fatigue is the term used by some researchers to describe the accumulation of fatigue based on duty periods, the number of consecutive shifts before a rest period, and the duration of that rest period. There are uncertainties associated with the term but generally it relates to the increase in fatigue associated with working over a number of days or weeks. Supervisors at the Buncefield Oil Depot worked 12-hour shifts without regular planned breaks. At various points in the schedule the number of consecutive shifts was higher than recommended and the number of rest periods following a period of consecutive shifts was inadequate to allow sufficient recovery from work. Based on the evidence available and current knowledge and guidance, the basic, planned shift schedule worked by staff at the Buncefield Oil Depot was likely to have resulted in an accumulation of fatigue. This was of concern because fatigue can increase the risk of errors and accidents.

Consideration of workload

It is relevant to note that much of the work undertaken by supervisors at the Buncefield Oil Depot involved the monitoring of systems in the control room with periodic decision-making e.g. relating to tank filling. Performance on such tasks is susceptible to the effects of fatigue and errors are more likely. Another significant factor was the absence of a formal policy or procedure for managing fatigue and shift-work. As with looking for fatigue and shift-work in an investigation, if there is no safety management system focus then effective arrangements are unlikely to be in place and there is no baseline set.

Another strand of the HSL support for the investigation took this further and, using content analysis of the interview transcripts and other evidence produced a Hierarchical Timed Task Analysis (HTTA) to show peaks and troughs of activity in the workload across the preceding shifts. This was not pursued as part of the later investigation – it was not required for the prosecution case - but did show that there were peaks and troughs of activity for the supervisors and with some significant peaks e.g. at the final shift end. The coincident tasks concerned were also tasks that required significant attention by the supervisors. This evidence supported the view that as well as the fatigue and shift-work issues, the supervisors' attention was focused on other task e.g. dealing with significant changes of state to their 'own' pipeline during the final shift. This and other planned or unplanned tasks were likely to dilute their attention.

Key lessons for the major hazard industries

The investigation concluded that cumulative fatigue contributed significantly to the Buncefield event. However, many investigations do not adequately address fatigue issues. While fatigue is rarely the sole cause of an incident (especially in organisations with multiple layers of protection), it is pervasive and significant and requires good management like any other risk to safety. Whatever industry sector is involved, the human beings who work there are subject to the same mental, physical and emotional limitations as any other and so, will be affected in the same way by fatigue, whether from poorly designed or poorly controlled shift schedules, or from excessive working hours and workload.

The key message for the major hazard industries, on- and off-shore, is 'Keep it simple': design and manage shift schedules both to minimise fatigue and its effects, and to optimise manageability i.e. the ease with which any shift system can be run and worked, and its chosen shift schedule populated and managed in practice. A smooth-running shift system is good evidence that the shift schedule is reasonable. This means that for example, there are good arrangements to cover sickness / absence, and also training, optimisation and other demands on shift staff's time. It also means that safety critical communications are well thought through and established e.g. for shift handover, day / shift, operations / maintenance (and see Wilkinson and Lardner 2012 for a fuller discussion).

If people get it right most of the time what else went wrong on the night?

The fatigue and shift-work issues were important contributory causes at Buncefield but were not a 'smoking gun' – they rarely are. While organisational factors like these are often seen as just the 'wallpaper' by employees and others - 'the way things are around here' - in an organisation (Wilkinson & Rycraft 2014), they contribute to poor judgement, decision-making, behaviours, effectiveness, vigilance and much more over a sustained period. At Buncefield, many other HOF issues contributed too including shift handover, competency and training, procedures, the control room layout and the human-computer interface (see HSE 2011). So what went wrong on the night? There was one key error at the frontline: the supervisors' 'situational awareness' (their grasp of the bigger picture) was faulty as evidenced by their shared confusion about the pipeline-tank alignments immediately after the incident. What they said in their initial police statements later changed, though they still expressed surprise and disbelief at the outcome. Typically, where error is involved those concerned can usually describe what they have done and seen but cannot explain, or link it to, the result (HSE 1999).

Due to the poor shift handover arrangements, and a series of poor handovers leading up to the incident (the same two supervisors were involved from 9 December), they had confused which pipeline was filling which tank and this mistaken view had persisted through several handovers. Why? Put simply, they were not expecting to fill a petrol tank on that night shift (and in the incorrect configuration they shared, neither tank would have filled that night) and so have to switch tanks, and therefore the absence of an alarm was no cause for alarm. You don't look for something if you aren't expecting it and their focus was anyway elsewhere for key parts of the night. Consequently, with the serial failure of all the other barriers, the human – and last – barrier failed too.

Getting shift-work right

The published literature shows that over the last 10 years, there has been a move toward the use of fatigue risk management systems (FRMS), especially for more complex organisations where fatigue is likely to be one of a number of factors that combine rather than the single cause of an accident. The increasing pressure on staffing levels, lack of experienced staff and reliance on overtime, increases fatigue risk. While limits on working hours have a role to play it is equally important to follow good practice guidance, using fatigue models, collecting and analysing safety data, subjective reports, and education and training. A risk assessment approach should be taken and there is simple and accessible guidance (HSE 2006). Avoid over-complicating things though. It is vital to gather feedback from the real operating experience through auditing and monitoring, and from those involved in managing, supervising and working the shift system. It is essential to be able to record and analyse the actual individual hours and shifts worked, not just the averages or the planned shifts.

A policy and procedure are necessary but keep them short and accept they will develop through experience. Equally a shift system needs managing – it is no good leaving those working in it (or an overloaded supervisor) to deal with planned and unplanned absences on an ad-hoc basis. While inevitably there will be exceptions (but they should be just that, exceptions, not the norm), it is how these are managed afterwards that really matters to avoid tired people returning to work without effective mitigation.

There is absolutely no point in tinkering with an existing shift schedule if it is not being worked as planned. The underlying organisational factors are usually simple e.g. not enough staff to work the rota, or not enough people in some roles, or insufficient flexibility in the schedule to cope with real work demands. Workloads and work planning may also need fixing. So these factors need to be addressed first, then check out the shift schedule and review it once there is experience of it working as planned.

Finding a reasonable and workable shift schedule also requires early, active and informed user involvement i.e. those who work the shifts, supervise and manage them. There is no magic or perfect shift system; they are all a compromise because humans have a biological drive to be awake during the day and to sleep at the night. The range of shift schedule choices is in practice small because of simple arithmetical facts about dividing the available time and days into workable and fair arrangements over a calendar year e.g. maximising and fairly sharing out the weekends off within a schedule to make the most of the diminished social opportunities created by shift-working. The practical options are set out very clearly in Miller (2006).

Training and awareness play a part, particularly in focusing manager and supervisor attention on what matters in operating the shift system, and in helping users and their significant others to understand the likely impacts on health, safety and their social and domestic lives, and how best to mitigate this.

Finally, considering the social and domestic side of working shifts is a vital (HSE 2006; Miller 2006). A predictable shift schedule (Miller 2006) allows those working it, and their families, to make plans to mitigate the inevitable reduction in normal social and domestic contact. Schedules that result in ad-hoc working to fill gaps, cover overtime and other emergent work are inherently unpredictable.

A good shift system and shift schedule will be one that is characterised by (reasonably) smooth running i.e. it will work away quietly and not create undue management, supervisory or user difficulties. However, as with all things, change is inevitable, so fatigue management will need effective monitoring and auditing, and regular review against operating experience, improving standards and knowledge, and changing business needs.

What could have been done differently at Buncefield to reduce the risk from fatigue?

Hypotheticals are always dangerous but - in a nutshell, the larger organisation could have helped the site to recruit and train sufficient supervisors to work the original or new shift pattern, and to provide the necessary oversight for ongoing improvement work. In either case the fatigue situation would have likely improved significantly and this would have likely impacted positively on some of the other contributing factors to the incident. What can be said is that better attention to this key organisational factor ***could*** have made a difference by changing some of the 'wallpaper'.

Lessons for investigators

Fatigue is recognised as a contributing factor for accidents, injuries and deaths in a wide range of settings. Published literature supports a positive association between long work hours, risk of attentional errors, accidents and/or injury occurrence, sleepiness and fatigue. While fatigue is acknowledged as a contributing factor for accidents, the evidence for a causal link is more complex. Errors which initially may seem to be about, for example, procedural violation or lack of situational awareness can, when explored in more depth, have fatigue as an underlying factor. Fatigue is insidious and, while it may rarely be a 'smoking gun' after an incident, it can set the scene for a making a wide range of failures more likely, but unpredictably. Investigators tend to find what they look for though, and even basic recording of timings, previous shift history and hours, and shift system performance e.g. overtime levels, actual shifts worked vs planned, are often neglected. A good investigation system will look for fatigue and shift-work issues among a wide range of other performance shaping factors.

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