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Training for emergency management: tactical decision games

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Abstract

Training of the non-technical skills that are crucial to effective management of emergency situations is an issue that is currently receiving increasing emphasis in the petrochemical sector. A case study is presented of the explosion and fires at the Texaco Refinery, Milford Haven, UK, which occurred in July 1994 (HSE, The explosion and fires at the Texaco Refinery, Milford Haven, 24 July 1994. HSE: London, 1997), with particular focus on the human factors aspects of the event. A key issue identified by the official report into this incident was the importance of emergency management training. This paper outlines a novel, low-fidelity training intervention, the tactical decision game (TDG), which is designed to enhance the non-technical skills (decision making, situation awareness, communication and co-ordination, teamwork, and stress management) required for emergency management. It is proposed that enhanced learning of these non-technical skills, through experience and directed practice following repeated exposure to TDGs, will lead to more efficient emergency management, particularly when dealing with hazardous materials.

Keywords: Human factors; Training; Emergency management; Non-technical skills; Decision making

1. Introduction

The non-technical skills of an organisation's emergency response personnel are as important as their technical expertise and knowledge and application of emergency operating procedures. Relevant non-technical skills include co-ordination of actions, communications, and decision making, sometimes under pressure, by both individuals and teams. Within complex, large-scale organisations, such as petrochemical plants, the possibility of inadequate performance by incident management personnel, especially during the opening stages of the emergency, may indeed have a strong impact on the subsequent evolution of the event [2,3]. Other incidents involving high reliability organisations, for example, nuclear power

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installations [4] and Chernobyl [5], offshore oil production [6], and public transport [7], have demonstrated that non-technical skills such as situation assessment, decision making, and stress management, greatly influence incident management [8].

Industrial emergency planning identifies the most probable types of incident, their consequences, and the required emergency response procedures, based on hazard analysis and quantitative risk analysis [9]. In the UK, government regulations are outlined in the Control of Industrial Major Accident Hazards (CIMAH) [10], recently, updated to the Control of Major Accident Hazards (COMAH) HaHaz [11]. These latest regulations include changes that refer mainly to the chemical industry, but also some storage activities, explosives manufacture, nuclear sites and other types of industries, where threshold quantities of dangerous substances identified in the regulations are kept or used. Similarly, the nuclear industry is governed by regulations stipulated in the Nuclear Installations Act (1965), and the offshore oil and gas industry are covered by the Offshore Installations Safety Case regulations [12].

The purpose of these regulations is to ensure that such industries set up appropriate emergency response procedures and disaster management plans. These plans and procedures are subject to observation and assessment, often by independent scrutiny, however, this in itself does not necessarily ensure that the required human factors, or non-technical skills, are practised.

A number of incidents have occurred in the UK during the past decade involving hazardous materials at chemical plants (for example, the fire at Allied Colloids [13]; the fire at Hickson and Welch [14]). Due to the severity of the incident, the explosion and fire at the Texaco Refinery, Milford Haven, that occurred in 1994 [1], will be discussed in greater detail. The purpose of this article is to reflect upon the human factors aspects of this incident, to introduce the concept of TDG as a training intervention, and to consider how such supplementary training can lead to improved emergency management through increased knowledge and understanding of tactical concepts, techniques, and development of implicit understanding.

2. The explosion and fires at the Texaco Refinery, Milford Haven, 1994

The Texaco Refinery (as it was known locally), Pembroke, Wales, UK, was located on a site occupied by two companies, the Pembroke Cracking Company (PCC) which was jointly owned by Texaco Ltd and Gulf Oil (Great Britain) Ltd., and Texaco's Pembroke Refinery. The site covered 500 acres, and produced hydrocarbon fuels (such as gasoline, diesel, and kerosene), fuel oils and liquid petroleum gases (LPG) from crude oil. The facilities comprised a 190,000 barrels per day crude distillation unit, associated refining processes, and a blending and storage area, with deep water marine terminal. The process facilities, totalling 18 process units, were operated by the Pembroke Cracking Company (PCC) and the Pembroke Refinery (PR).

On 24th July 1994, following a fire caused by a lightening strike, all units (eight in total) on the PCC plant were shut down, with the exception of a Fluidised Catalytic Cracking Unit (FCCU). Later that same day, an explosion equivalent to at least four tonnes of high explosive occurred in vicinity of the FCCU. The explosion was triggered by a release of flammable hydrocarbons from an outlet pipe of the FCCU. A fire at the FCCU itself then ignited, as well as a number of secondary fires. Twenty-six people sustained injuries, although none serious. The situation was finally terminated on the evening of 26th July 1994, two and a half days later.

Although the lightening strike had resulted in plant disturbances and power interruptions affecting a number of PCC units, this was not the actual cause of the later release and explosion. The official investigation firmly indicates that the resultant situation occurred as a consequence of the subsequent failures to safely manage these plant upsets. A combination of events also exacerbated the situation, namely a control valve being shut when the control system indicated it was open; a modification which had been carried out without assessing all the consequences; control panel graphics that did not provide necessary process overviews; and attempts to keep the unit running when it should have been shut down.

An electrical storm in the Milford Haven area caused interruptions to the power supply prior to 9.00 a.m. on 24 July 1994. A fire on the crude distillation unit was caused by a lightening strike, and resulted in plant disturbances, including disruption to the vacuum gas oil feed. The fluctuations in the feed to the FCCU meant that the level of liquid in the high pressure separator had led to alarms being activated in the control room. Due to the low levels of feed, outlet valves on the process equipment had closed, trapping liquid hydrocarbons in a debutaniser, which was subjected to some heat. The liquid vaporised and increased in pressure such that pressure relief valves opened to vent the debutaniser. This occurred three times in total. The vented materials entered into the flare knock-out drum and then on to the flare.

Although one of the closed valves (valve A) later opened, another (valve B) remained shut, although indications received by operators in the control room wrongly showed that valve B was open. Due to their attention being focused on diagnosing one particular part of the problem, operators overlooked the anomalies with the situation as presented. Valve C was then opened resulting in large volumes of gas being vented to the flare stack to be burned off, causing high liquid levels in the flare knock-out drum. These levels were further increased by the operators' next actions where they tried to remove the flooding from the dry end of the interstage drum by draining the liquid directly to the flare line via an impromptu modification involving steam hoses which had been carried out some years earlier. Finally, as the flare knock-out drum was filled to capacity, liquid was forced into the drum discharge pipe. This pipe was corroded and the force of the liquid in the pipe caused it to break resulting in 20 tonnes of highly flammable hydrocarbon from which a vapour cloud formed and exploded. This cloud of vapour found a source of ignition about 110 m from the flare drum causing a fire at the flare drum outlet itself and a number of secondary fires.

Obvious problems with this situation included that within the control room, the display of system outputs was designed and configured such that it was difficult to obtain a complete picture of the whole process. The interface between the operators and control system did not provide a good overview, and discrepancies in the process went undetected. Once the plant upsets had occurred, the control room operators were overloaded with an increasing barrage of alarms, thus, decreasing the chances of control being restored by manual intervention, i.e. alarms were presented to operators at the rate of one every 2–3 s. In addition, following modifications to plant, the relevant technical procedures were not adequately altered to provide instructions for manual intervention in the event of plant disturbance, nor were any actions outlined that were to be taken in response to certain alarms. The failure to consider the safety consequences of a modification to plant further aggravated the situation.

Personnel on the FCCU comprised a multi-skilled, flexible team. In upset conditions, it was standard practice that all levels within the management structure assisted in the control room. However, this creates additional demands on teamwork, communication within the team, and coping under stressful conditions, as the report states “Where more than one operator is working, an increased emphasis on communication is required to ensure that each is working with the team, and contradictory operations are avoided” (p. 26). Furthermore, when, as in this situation, all personnel become involved at the tactical level of emergency management, strategic management suffers. During the incident, senior level personnel (e.g. supervisors and managers) “. . . helped out, they took on operating roles rather than taking an overview of the whole process” (p. 26). Decisions made and actions taken were, in this instance, too reactive and uncoordinated.

One of the key recommendations of the official report was that “training of staff should include an assessment of their knowledge and competence for their actual operational roles under high stress conditions” and “how to manage unplanned events including working effectively under the stress of an incident” (Recommendation 5, p. 4). Indeed, since this incident, the company have instigated training on the roles and responsibilities of operators, supervisors and managers, employing situational analysis techniques to assess managers’ ability to cope with upset conditions, as well as developing a training simulator to realistically reproduce the FCCU working conditions in both normal and upset situations.

This incident has served to emphasise the importance of non-technical skills and the necessity for appropriate training for emergency management on industrial plant involving hazardous materials. Many of the lessons that became apparent following previous petrochemical explosions and fires, for example on the Piper Alpha in 1988, do not appear to be wholly learnt (see [15]). One of the criticisms made in the Official Inquiry [6] following the Piper Alpha disaster was “The strong impression with which I was left after hearing evidence. . . was that the type of emergency with which the senior personnel of each platform was confronted was something for which they had not been prepared” (7.52). Over 100 recommendations regarding the safe management of offshore installations were presented by Lord Cullen, many of which have since been incorporated into legislation, for example, the following guidance notes relating to emergency response [12]:

> 58. The organisation and arrangements should include adequate provision for: (a) establishing and maintaining a command structure by competent persons throughout an emergency. . . ;
>
> (i). . . . Among other matters, emergency exercises should provide the OIM (Offshore Installation Manager) and the command team with practice in decision-making in emergencies, including decisions on evacuation. All OIMs and deputies should participate regularly in such exercises. [12].

In addition, Regulation 7 of the Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations [16], referring to an identified person with responsibility for taking charge in an emergency on an installation, states that “The chain of command needs to be clear, and the duty holder should ensure that the person in charge and others in the chain are competent to manage emergencies” (p. 31).

The PCC site was subject to a variety of regulations and legislation, including the Health and Safety at Work Act (1974), the Factories Act (1961), and more specifically the Control of Industrial Major Accident Hazards Regulations (CIMAH) (1984). Under the terms of CIMAH, which are designed to prevent or mitigate the effects of major accidents, the site was required to submit safety reports to the HSE identifying the nature and use of dangerous substances at the site, and how major accidents could possibly occur, as well as describing the arrangements in place to prevent, control, or mitigate them. This further included the requirement to prepare on-site emergency plans. As the team on the FCCU was multi-skilled, a flexible approach to dealing with 'upset' conditions was in place, however, subsequent events indicated that training in the non-technical skills, such as communication and co-ordination, as well as decision making, required during serious upset conditions was lacking. Furthermore, the requirement for more senior personnel to stand back and take a more strategic stance, or 'hands off' role, was highlighted.

The criticisms and recommendations cited have indicated that effective emergency management relies upon the abilities and competence of the organisation's emergency management personnel. Moreover, such personnel should be trained to respond efficiently and decisively to novel incidents, on both an individual and team basis, particularly with respect to events that have the capacity to escalate into a severe incident. As a result, training interventions or mechanisms have been specifically designed to exercise the non-technical skills, e.g. decision making, communications, situation awareness, and stress management, required for effective individual and team performance.

3. Training for emergency management

Training interventions are required to improve teamwork skills, i.e. the skills necessary for team personnel, irrespective of role and task within the team, such as decision making, communications, shared situation awareness, leadership, and co-ordination, to ensure efficient team functioning [9,17]. Such training results in more effective and efficient decision making, accelerated proficiency and the development of expertise in individuals and teams, issues that are particularly crucial in complex, critical and hazardous real-life situations, such as emergencies.

Training methods and strategies that are specifically directed towards improving team performance, particularly during emergency response, include Crew Resource Management (CRM). Crew Resource Management is not only applicable in situations where teams are operational on a daily basis, but is a particularly effective type of training for teams which only come together in response to an incident or situation, as occurs in an industrial emergency management organisation. With its emphasis on non-technical training, focusing on leadership, command, decision making, communication and teamwork [18], CRM has been found to be particularly effective in improving team performance. There are dual benefits in CRM training — one is to improve human performance and teamwork in order to minimise the risk of emergencies or accidents occurring; the other is that CRM should help teams to perform more efficiently once an emergency has occurred. In conclusion, while CRM training was initially designed to reduce operational errors and improve emergency response performance in aircrews, there is increasing evidence that it can be adapted for other high reliability team settings such as offshore oil industry [19], aviation maintenance [20], and anaesthesia [21].

Training for emergency management, primarily for incident commanders, also tends to take the form of exercises or drills (see Flin [9] for a fuller description). Three main types of exercise exist, namely, seminar, tabletop and live exercise [22]. Whereas these types of exercises vary in terms of cost effectiveness, and generally test response organisation effectiveness and the application of procedures, they are limited in respect of their ability to promote the level of immediate tactical decision making required, primarily by incident commanders. Supplementary training in critical thinking, including anticipation and contingency planning, is required for decision makers, particularly for effective decision making in novel situations such as incidents or emergencies.

4. Tactical decision games (TDGs)

In complex, hazardous, real-world environments, particularly emergencies, decisions tend to be made by knowledgeable and experienced decision makers, and are embedded in larger dynamic tasks. The decision maker must balance personal choice with organisational norms and goals. Intuitive decision making, allowing quick and effective decisions to be made, is based on pattern recognition skills gained through experience [23]. However, as emergencies in many fields, especially the petrochemical sector, tend to be extremely rare, the opportunity to practise decision making in such situations seldom arises, and little actual experience is gained. Therefore the optimal manner to develop and improve intuitive decision making and related skills is through repeated decision making experiences in context. One possible novel intervention for crisis management training is that of TDGs [24]. TDGs act as a substitute for actual experience and provide a suitable, yet low-fidelity, opportunity to enhance skill development and expertise. Training in decision skills, through identification of the decision requirements, doing exercises with tactical decision games, and critiquing the exercises, has been found to boost expertise in decision making and judgement [23].

TDGs, predominantly based on scenarios ranging in complexity and technicalities, are designed to exercise decision making skills and to illustrate key operating principles. The objectives of TDGs can be summarised as follows [23,25,26]:

- To exercise and practise decision making skills and illustrate key operating principles
- To boost expertise in decision making and judgement
- To assist participants to develop a shared understanding and recognition of possible problems
- To build up a repertoire of patterns which can be quickly recognised and acted upon, particularly during emergency situations
- To practise non-technical skills such as decision making, communication, situation awareness, stress management, and teamwork

A prevailing principle of TDGs, however, is for all participants to develop a shared understanding and recognition of possible problems for emergency management.

4.1. Format of a TDG session

Typically, a TDG training session consists of at least one prepared scenario, either presented to participants in text form or read aloud by a Facilitator, and is roughly 2–3 paragraphs long. The purpose of the ‘story’ is to provide participants with a background to the situation, however, some of the information given may be inadequate, misleading, or extraneous, moreover, the scenario always culminates in a dilemma. This is accompanied by a ‘map’ (shown on an overhead) detailing the location, or suspected location, of the incident. Participants take on certain roles, and a limited amount of time and information is initially available. The requirement is that a plan to solve the incident is formulated. Participants are encouraged to illustrate their decisions about movements of personnel or materials on the overhead, and to provide realistic briefings as would be required.

To further illustrate the concept of TDGs, a generic example is shown below, however the ‘map’ can range from an entire site layout, to focusing on part of a site, for example, a turbine hall. The map should be schematic, mainly showing the key locations. The scenario will define the participants’ roles (either all taking the same role, or different roles), and describe the situation, culminating in the dilemma to be dealt with.

4.2. Tactical decision game — example: “Fire in the Storeroom”

You are (*emergency role(s) to be taken*), in the vicinity of the repack area next to the raw materials warehouse (Fig. 1). The Fire Alarm sounds, so you follow the emergency plan, and phone the emergency number. You are told to assume your emergency role. Your first briefing is that smoke has been seen billowing from the louvre windows of Oxystore No 1 (Fire Resistant Storeroom). You are aware that Oxy No 1 is used to store oxidising products, and is adjacent to the external chemical drum storage. Decide upon your actions following this information.

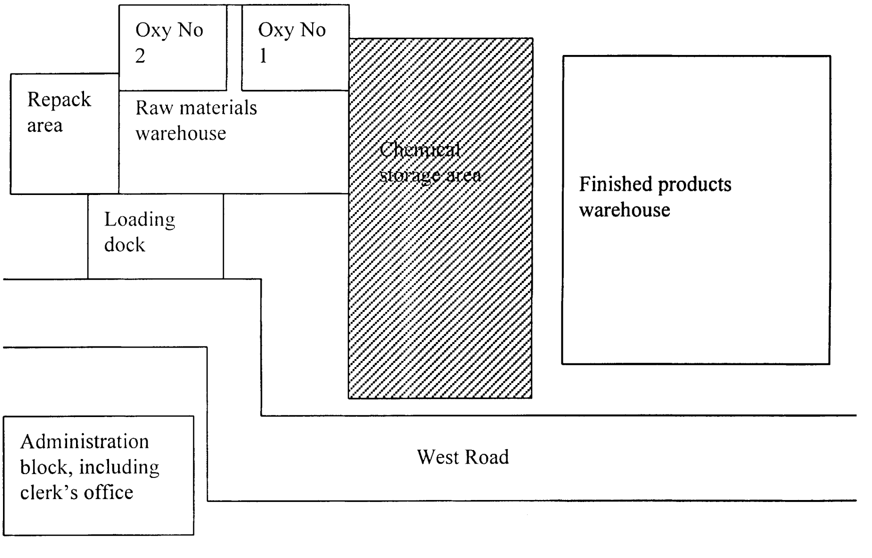

Fig. 1. “Fire in the Storeroom” diagram.

One member of the Fire Team raises the electric shutter door of the Warehouse and notices four kegs of AZDN lying on the warehouse floor, the contents of which are spilling out. You then receive word that at least three people were last seen in the Warehouse prior to the alarm being sounded, none of whom have reported in.

Your resources consist of the Fire Team (5 personnel), the Shift Chemist, and the local Fire Brigade.

What are you going to do? (1 minute is allowed for questions from participants).

Requirements

You have 3 minutes to decide what to do, prepare briefs for all relevant personnel, and dictate any radio messages, or provide briefings, about your decision. List any follow-on actions you are considering. Be prepared to brief your decisions to the group.

The emphasis for initial questioning and discussion is:

- What are you going to do?
- How are you going to do it?
- What are your main priorities and why?

During subsequent discussion, further questions include:

- What do you understand your focus to be?
- Prepare any briefing/message that might be required.
- Describe the make up of any team you might deploy.
- What special resources (e.g. equipment, materials, etc.) or arrangements (e.g. medical assistance, etc.) might be required?
- How would you deal with ‘X’ (e.g. representatives of external agencies) when he/she arrives on scene?

Facilitator’s notes include contingencies to be inserted during the discussion of solutions. For example:

- the AZDN explodes;
- fire team members complain of feeling unwell;
- lack of resources (personnel and materials); and
- the electric roller shutter to Oxy 2 has been left open, but the paperwork identifying the chemicals stored in Oxy 2 is unavailable.

The duration of each scenario exercise should be a maximum of 1 h and 30 min, involving both a discussion of the incident, feedback and debriefing. Heightened stress levels are imposed as the Facilitator, a key role in TDGs, uses a variety of distractions during the decision making period, reduces the decision making period, e.g. without warning, or introduces contingencies or “what if’s” during the presentation of individual solutions. Contingencies should be credible, but realistic. Participants should be given the opportunity to discuss what they would do in these various circumstances. Solutions reached and decisions made are discussed within the group, and any differences deliberated.

4.3. Benefits of tactical decision games

Communication improves as participants learn to recognise key words and phrases used, allowing more implicit and effective communication. Team performance improves as leaders learn to phrase their briefings and instructions more effectively and to describe their intent in a clearer and more concise manner. In addition, team members are given the opportunity to provide feedback about briefings and instructions given. Ultimately, however, by repeatedly working through such incidents, participants learn to make better decisions, i.e. quickly and efficiently, as well as gaining an increased knowledge base of the application and use of procedures, often through to the termination of the incident.

A great strength of TDGs is that the scenarios used allow participants to sample alternative task strategies, to compile an extensive experience bank, and to enrich experiences. TDGs then appear to assist participants in building up a repertoire of patterns of response, and provide the opportunity to practise recognition-primed, rule-based and knowledge-based decision making [27,28]. Furthermore, TDGs offer the opportunity to receive immediate feedback from peers about their solutions to the scenarios. Unlike full-scale emergency exercises or tabletop exercises, participants in a TDG session make decisions and in discussion “take their decision forward”, considering the consequences of a selected course of action, and have the opportunity to compare this with other possible courses of action. TDGs are not script-driven, in that no limits to the decisions that can be made exist. TDGs also allow decision makers to review the reasons behind why they made that decision, rather than only focusing on the decision made.

Practice gained through use of the TDGs should allow a repertoire of patterns to be built up. These patterns can then quickly be recognised and acted upon during an emergency situation. TDGs also provide the opportunity for vicarious learning as participants consider, discuss, and reflect upon the solutions presented by other, possibly more experienced, peers.

TDGs have recently been developed and introduced as a training intervention in diverse organisations such as nuclear power plants and the Scottish Prison Service. Testing sessions conducted to date appear to support the effectiveness of TDGs in enhancing and fostering tactical decision making [29,30]. Participants have reported quicker and more efficient decision making, improvements in communication, and in planning. Benefits also include reports of increased confidence in personal abilities to manage emergency situations as a result of repeated participation. However, further empirical data require to be collected to allow TDGs to be fully evaluated as a training intervention.

4.4. Integrating tactical decision games into emergency training

As previously stated, TDGs form a supplementary training intervention. Across industries, training for emergency management generally consists of classroom-based training, manuals, and emergency exercises. Each of which can appear costly in terms of preparation and organisation. One of the advantages of TDGs, however, is that they are a low-fidelity training technique, requiring minimum preparation or any specific aids other than a prepared scenario, a room, and a group of participants (4–10). TDGs can therefore be conducted on-site, as and when a group of participants can meet. Moreover, they can be integrated into classroom-based training modules to allow trainees to increase familiarity with and to practise non-technical skills. Although the emphasis is on non-technical skill development, TDGs also allow technical or procedural aspects of emergency management to be covered during discussion.

A further advantage of TDGs is the opportunity to discuss emergency response, principles and procedures. A note of any unclear issues raised during discussion can be taken, and further clarification can be sought and disseminated throughout the emergency response organisation. Such discussion can have a long-term positive effect on emergency preparedness and planning, as matters that may have previously been overlooked or misrepresented can be resolved.

5. Conclusion

The official report into the explosion and fires at the Texaco Refinery, Milford Haven, in 1994, recognised and commented on the need for personnel to manage unplanned incidents, and in particular, to work effectively under stress. As effective emergency management not only relies upon the application of technical expertise and emergency operating procedures, but also depends upon the non-technical skills of the teams involved in accident management, TDGs would appear to offer a useful supplementary intervention in such a high reliability organisation. Response to emergencies by complex, large-scale organisations demands co-ordination of actions, efficient communication within, between and across teams, and a high level of decision making both by individuals and teams, sometimes under pressure.

In terms of the events described in the case study discussed in this article, evidence of failures in communication between the operators in the control room emerged as well as confirmation bias, whereby confirming as opposed to disconfirming evidence is considered when evaluating working hypotheses [31]. It was further noted, in the official report, that decisions made tended to be reactive and uncoordinated. TDGs as a training intervention are designed to practise communication. Indeed, additional TDG learning tools such as Commander's Intent, where leaders can practise giving briefings or instructions, and team members can provide feedback regarding their interpretation of the briefing or instruction, have been specifically developed to exercise communication between leaders and teams.

It is generally accepted that critical decisions and actions often need to be taken during emergency situations under stress [32,33]. Task demands can not only have a crucial effect on decision making by the individual, but can also constrain the behaviour of teams, forcing them to change their pattern of communication, distribution of tasks, and style of decision making, which can give rise to serious errors [34]. On an individual basis, errors can be prevented by knowledge of procedures and training in decision making skills to master, reduce or tolerate the demands of stressful situations, and to ensure that problems can be managed before critical consequences ensue. TDGs help train individual skills such as situation awareness, pattern matching and cue learning, as well as the recognition of typical cases and patterns through experience. Mental models can be built up, and a greater degree of expertise in managing uncertainty and dealing with time pressures acquired.

Furthermore, group or team participation in TDGs fosters the development of shared or compatible mental models of the task and the roles of each team member, and, ultimately, teamwork skills such as situation awareness and leadership. By tailoring training to the needs and requirements of each of role within a team, building on a foundation of generic training in terms of the relevant industry base, team members will be trained to carry out their individual roles within the team and the organisation as a whole in a more effective and efficient manner. TDGs also provide the opportunity to clarify the duties and responsibilities of different roles in the emergency response organisation. In terms of the incident at PCC, senior manager participation in TDGs could have provided experience of coping with a serious upset condition, for example, taking an overview of the situation (the 'big picture'), maintaining hands-on detachment (working at a strategic as opposed to tactical level), and making decisions under stress (both time and risk).

By learning through experience and directed practice the necessary non-technical skills, both for teams and individuals, personnel involved in an emergency management organisation will be better prepared, more equipped, and more able to deal with the demands endemic in any accident response situation.

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