The role of expertise in dynamic risk assessment: a reflection of the problem solving strategies used by experienced fireground commanders

Although the concept of dynamic risk assessment has in recent times become more topical in the training manuals of most high risk domains, only a few empirical studies have reported how experts actually carry out this crucial task. The knowledge gap between research and practice in this area therefore calls for more empirical investigation within the naturalistic environment. In this paper, we present and discuss the problem solving strategies employed by sixteen experienced operational firefighters using a qualitative knowledge elicitation tool — the critical decision method. Findings revealed that dynamic risk assessment is not merely a process of weighing the risks of a proposed course of action against its benefits, but rather an experiential and pattern recognition process. The paper concludes by discussing the implications of designing training curriculum for the less experienced officers using the elicited expert knowledge.

Introduction

A building on fire poses a serious threat to human lives, properties, livestock, communities, local economies, natural resources and the environment at large (McLennan, Holgate, Omodei and Wearing, 2006). The dynamic and extremely dramatic environment where these events occur further increases the possibility of exposing firefighters to all sorts of risks and task constraints, most of which stem from the need to manage uncertainties, ensure the safety of crew members, rescue trapped victims, manage members of the public, adhere to statutory obligations binding fire fighters, and verify media perceptions (Burke and Hendry, 1997; Ingham, 2007; Grimwood, 2003; Lipshitz *et al,* 2001; Perry and Wiggins, 2008; Kahneman and Klein, 2009; Clancy, 2011). The nature of these environments also explain why firefighters sometimes encounter novel and difficult situations, despite being equipped with advanced equipment and gadgets such as breathing apparatus, fire resistant clothing and all sorts of hose-lines.

For instance, the excerpt below from the work of Flin (1996) illustrates a typical fireground scenario and highlights some of the complexities associated with fireground decision making mostly under time pressure:

> 'On arrival at the scene of a fire, officers are bombarded with a mass of visual and other information relating to the incident, its progress and its context. On a short time scale, often under great pressure, the officer in charge must grasp the situation, understand the problem being faced, prioritize fire service actions on the basis of reasonable strategy, deploy available resources, know when to ask for reinforcements and what these should be' (Flin, 1996:140)

To cope with these fast paced events, fireground commanders often employ an important cognitive task known as dynamic risk assessment which, as the term suggests, must be conducted rapidly. The concept of dynamic risk assessment (DRA) has thus proved of worth in promoting thinking about managing dynamic risks in the fire service, and its ability to closely link risk taking behaviour to decision making also implies there is now raised awareness about the cognitive architecture of incident commanders than ever before (Grimwood, 2003; Tissington and Flin, 2005; HM Government, 2008; Ingham, 2008; Klein *et al,* 2010; Clancy, 2011). But despite its growing awareness amongst scholars, the concept of dynamic risk assessment has been accused of being quite subjective and therefore difficult to measure as a scientific construct (see Tissington and Flin, 2005 for details). For instance, it is not yet entirely clear from the procedures binding most high risk domains the exact points where officers should follow the basic firefighting rules and where relying on previous knowledge would prove more appropriate (Burke, 1997; Goldstein and Gigerenzer, 2002; Klein, 2003; Lipshitz *et al,* 2007; Marewski, Gaissmaier and Gigerenzer, 2010).

Against the above background, the current paper therefore seeks to examine how expertise facilitates and informs the dynamic risk assessment process. By so doing, the dominant problem solving strategy employed by the sixteen fire ground incident commanders that

participated in the study will be assessed. The motivation for the study was partly hinged on the fact that only very few empirical studies have reported how experts actually carry out this crucial task of dynamic risk assessment, despite being an important theme in the incident command training manual (HM fire inspectorate, 1999; HM Government, 2008). This knowledge gap is perceived to have implications for research and practice and therefore requires more empirical investigation. It is hence believed that capturing the role of expertise in the dynamic risk assessment process is likely to enhance the design of training programmes for the less experienced fire officers, particularly at this present time where the frequency of occurrence of serious fire incidents has been on a decline.

Expertise and dynamic risk assessment

As with many other work practices, the firefighting domain is made up of several standard operating procedures (SOPs) that guide safe performances at the incident ground (Klein *et al*, 2010; Lamb *et al,* 2014). These SOPs are a combination of the technical procedures (e.g. using the right type of equipment such as hosereel, mainjet, ladder, fireman axe etc.) as well as the *modus operandi* of managing incidents (e.g. splitting crews between the front and back of a building). For example, one of the rule-based risk philosophies that have been widely accepted in the UK fire service states that:

- 'Firefighters will take 'some' risk to save saveable lives'
- 'Firefighters will take 'a little' risk to save saveable property'
- 'Firefighters will 'not take any risk at all' to try to save lives or property that are already lost' *(*HM Fire Service Inspectorate, 1999; HM Government, 2008)

But while it is worth acknowledging that rules and philosophical principles of these sorts are useful in most high risk domains as they help establish risk tolerance levels for operators, what remains a challenge is finding an appropriate way of evaluating phrases such as 'some risk', 'a little risk' and 'any risk at all'. A number of studies have suggested that experts often make decisions about what is risky/not in dynamic and time-pressured conditions mainly through experiential knowledge (Shanteau, 1992; Wong, 2000; Fessey, 2002; Adams, 2003; Grimwood, 2003; Perry and Wiggins, 2008; Rosen, Shuffler and Salas, 2010; Okoli *et al,* 2013). For instance, the fact that a particular procedure is labelled high risk in the fire manual does not necessarily always imply that incident commanders must take a defensive (or risk averse) position when such situations are encountered in real life; some level of risks must still be accepted and managed based on experience. So considering the huge expectations members of public usually hold for the response teams, it only becomes logical to expect that managing more dangerous and unpredictable fires will require the skills and knowledge of the more experienced officers.

According to Shanteau (1992), experts are 'those who have been recognized within their profession as having the necessary skills and abilities to perform at the highest level'. Research on expertise has provided ample evidence to show that experts are able to use their

existing knowledge to facilitate situation assessment and gain perceptual advantage as events unfold (Chase and Simon, 1973; Calderwod *et al*, 1987; Endsley, 1995; Gobet and Simon, 1996; Dreyfus, 2004; Feldon, 2007; Dane and Pratt, 2009; Rosen, Shuffler and Salas, 2010). On this note, a number of authors have therefore suggested that experts are not necessarily better than novices because they think faster or possess a wider range of skills, but because they are able to organize and apply their knowledge and skills better — through a schema-based network. It is the operation of schemas that make the process of information retrieval from memory much easier and thus allow experts to see more easily what is invisible to novices, such as the identification of patterns, relationships and potential consequences of action (Sweller, 1994; Gobet, 2005; Hilbig, Scholl and Pohl, 2010).

But what is dynamic risk assessment? The DRA model (See for example Clancy, 2011; Tissington and Flin, 2005; HM Government, 2008) requires that fireground commanders:

- Continuously monitor and evaluate a situation, the tasks, the people and properties at risk
- Select the most appropriate systems of operation
- Assess and re-assess the chosen systems of operation
- Introduce additional controls if required
- Modify and implement action plans as events unfold

The strength of the DRA model is therefore evident from its flexibility, since it provides actors with an opportunity to make quick decisions e.g. whether to stick with the 'gold standard' ways of doing things or make some level of adjustments to existing rules. The model is thus unique in that it acknowledges that decision making on the fireground does not follow a static or linear model as often postulated by the classical theorists, but is rather dependent on various environmental and informational cues in the environment (Okoli *et al*, 2014; Ericsson *et al,* 2007; Harré, Bossomaier, and Synder, 2012).

Problem solving strategies on the fireground: Rule, skill and knowledge based decisions

The notion that experts are able to perform recurrent aspects of tasks using their extensive domain knowledge has been well reported in the literature (Sweller, 1994; Dreyfus, 2004; Hoffman *et al,* 1998; Paas, Renkl and Sweller, 2004; Pollock *et al,* 2002). These authors attributed this ability mainly to the efficient functioning of a powerful information processing tool known as schema. A schema contains rules and procedures that can systematically link particular features of a problem to its possible course of action (IF condition, THEN action). Without an adequate knowledge about a particular procedure, skills cannot be transferred for solving difficult problems (Feldon, 2007). Hence, one of the features of higher level competence is that knowledge becomes increasingly 'proceduralized' and readily converted into skills. Simply 'knowing that' (declarative knowledge) is not enough for most job tasks in high reliability organizations such as firefighting, but knowing what to do with what is already known, as well as knowing how to combine what is known differently have been

shown to be of greater importance in such domains (Wong, 2000). Experts often form their action plans and solve new problems using the general knowledge they have about a domain, or the knowledge they recall from concrete cases, or both. A direct relationship therefore seems to exist between the *skills* possessed by an expert, their *knowledge* of the domain and the domain *rules* that guide their actions. Ingham (2007) puts it this way:

> 'The application of standard rules does not mean that incident commanders are not creative. Working without rules is uninteresting, and absolute liberty is boring. The creation of innovative approaches does not happen in a vacuum; rather it is the result of playing with the rules, stretching them, moving and testing them. It is therefore essential to maintain common operating guidelines, or rules, because they form a stock body of common knowledge, but it is also essential to break the rules and play around with them because mastery reveals itself as breaking rules. The secret of creativity hinges on this insight: to know the right moment when one can go too far' (Ingham 2007: section 24)

Because it is not very clear how experts transit from one problem solving strategy to another and in what particular circumstance they make such transition, this paper also aims to examine the boundaries that exist between *formal* (rule based) and *dynamic* (adaptive or creative) risk assessment methods, and when experts are likely to apply which.

Methodology

The Critical Decision Method

This study hinges on the naturalistic decision making (NDM) paradigm which has been regarded as both a theoretical and methodological framework (Lipshitz *et al,* 2001). In the NDM community, researchers are mainly interested in capturing the cognitive strategies that aid experts' performance while managing real-life incidents. Studies in this domain are therefore specifically designed to examine how experts make decisions in the real world using their experience and domain knowledge (Kaempf *et al,* 1996; Zsambok, 1997; Hoffman, Crandall, and Shadbolt, 1998; Wong, 2004; Klein, 2008). As Kahneman and Klein (2009) put it:

> 'A central goal of NDM is to demystify intuition by identifying the cues that experts use to make their judgments, even if those cues involve tacit knowledge and are difficult for the expert to articulate. In this way, NDM researchers try to learn from expert professionals' (Kahneman and Klein, 2009:516)

Since firefighting is one of the domains that heavily rely on explanations from qualified experts in an attempt to better understand the cognitive rules and pre-requisite knowledge that aid optimum performance, it therefore became important to apply a knowledge elicitation tool in this study. Knowledge elicitation tools are structured protocols designed to assist experts to explain what they both know and do in their domains of practice. The study utilized the critical decision method (CDM) mainly because of its credibility and popularity

in the cognitive task analysis literature (for details of the CDM see Klein, Calderwood, and MacGregor, 1989; Hoffman *et al,* 1995; Wong, 2004). The CDM is a retrospective interview strategy that applies a set of cognitive probes to actual non-routine tasks (high-risk incidents). The CDM probes allow experts to be questioned in-depth as to how they were able to manage a particular incident (see 'procedure' section below). Through the CDM protocol we were able to capture interesting themes that underpin experts' competence, which includes the knowledge and skills used in making complex decisions, the types of information used and their sources, the cues sought at each decision point, the rules being followed (both cognitive and domain rules), the goals and sub-goals pursued, the amount of time spent on each decision, and the type of training that was most helpful in making each decision.

The CDM has been used in a wide range of studies (See Hoffman *et al,* 1995 for a review) and its strength lies in the fact that it is: (i) capable of demystifying the rationale behind experts' decision-making and problem solving strategies (ii) applicable under field conditions i.e. naturalistic settings (iii) useful for providing relevant information that can facilitate the design of instructional curricula for training novices e.g. less experienced firefighters could potentially be trained on how best to assess a situation based on the knowledge elicited from experts.
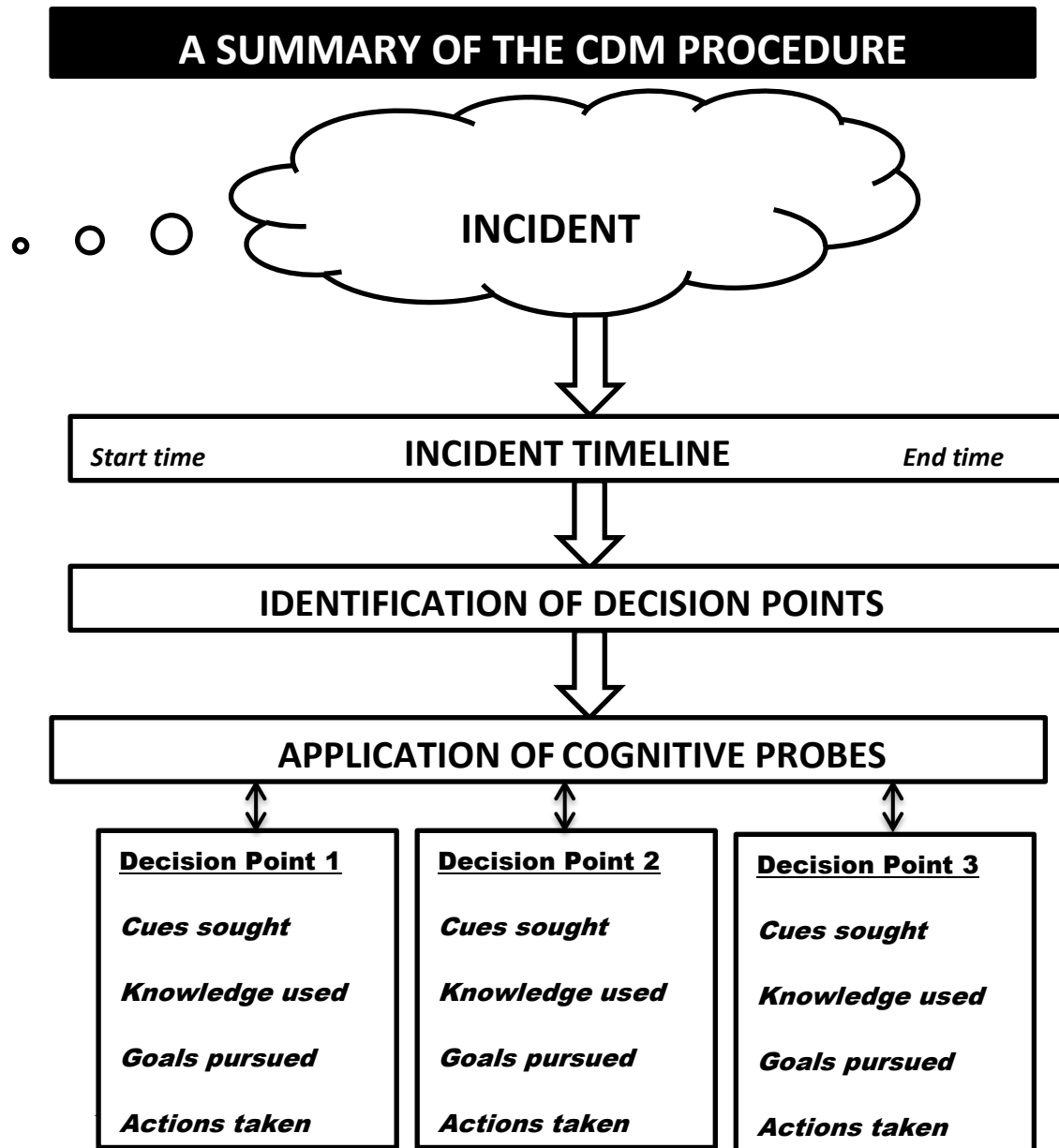
Although the CDM has gained dominance over the past few years as one of the most effective knowledge elicitation methods, its major criticism still remains that it cannot completely control the effect of memory limitations in human beings. Sceptics believe it is quite difficult to narrate a retrospective incident without either missing out some vital information or making up additional information. However, a number of empirical studies involving interview with experienced fire officers (e.g. Klein *et al,* 1988; McLennan *et al,* 2006; Burke and Hendry, 1997; Okoli *et al,* 2013) seemed to have challenged these claims. Despite some of the limitations that have been linked with retrospective verbal protocols, proponents of the critical decision method have demonstrated the effectiveness and reliability of the method for eliciting expert knowledge. This study provides additional evidence to substantiate existing belief that experienced officers do not easily forget non-routine incidents for which their skills and expertise were challenged; this includes incidents dated even as far back as 10 years.

Participants and Procedure

The sample size for this study comprised sixteen experienced fire-fighters (n=16), selected across different major fire stations in the UK (n=6) and Nigeria (n=10). The sample was selected across the two countries in the wider study for the purpose of comparison, but also to identify common themes or similarities that might exist between the two groups with regards to fireground decision making. However, the scope of this paper is not to discuss cross-cultural differences between the UK and Nigerian fire services but to report the breakdown of the problem solving strategies that were utilized by both groups of firefighters. We have also developed a decision making model elsewhere that attempts to describe how both groups of experts make intuitive decisions on the fireground (Okoli *et al,* 2015)

The participants were carefully selected on the basis of their rank/position and also through peer nomination; this was to ensure that expertise is verified and not assumed (see Table 1). Since this study aims to elicit the knowledge and skills used by experienced fire commanders, it became crucial to ensure that only the most qualified experts were recruited. As a result, the authors ensured that all the participants that were interviewed had personally been involved in managing real-life fire incidents, which meant they had at least operated as incident commander (i.e. managing crews and leading one or more fire engines). In addition, all the participants recruited for the interview were supervisory managers (i.e. crew commanders, watch commanders and station managers), group commanders and flexi-duty officers; all ordinary fire-fighter were exempted from participating. One of the most important factors that differentiate supervisory managers from ordinary firefighters is the quality of training received by the former. The incident command and control training covers more advanced subjects in areas like decision making, personnel and resource management, breathing apparatus entry procedures, fire investigation, sectorization, team management, situation assessment and size up etc. Hence, it was important to ensure that all participants in this study had received incident command training and have managed a good number of complex incidents in the course of their firefighting career. The average length of experience for all the sixteen participants is 18.5 years (see Table 1). As shown in Figure 1, participants were first asked to recall and 'walk-through' a memorable fire incident that particularly challenged their expertise.

Fig 1. A visual presentation of the steps involved in the critical decision making process (Adapted from Klein, Calderwood, and MacGregor, 1989)

A SUMMARY OF THE CDM PROCEDURE

INCIDENT

| *Start time* | **INCIDENT TIMELINE** | *End time* |

IDENTIFICATION OF DECISION POINTS

APPLICATION OF COGNITIVE PROBES

Decision Point 1	**Decision Point 2**	**Decision Point 3**
Cues sought	*Cues sought*	*Cues sought*
Knowledge used	*Knowledge used*	*Knowledge used*
Goals pursued	*Goals pursued*	*Goals pursued*
Actions taken	*Actions taken*	*Actions taken*

Participants were informed in advance either through an email or a phone call about the nature of the interview and were told the type of incidents that were of interest to the study i.e. non-routine or atypical incidents. The rationale for limiting the choice of incidents to non-routine ones is because experts tend to rely more on their tacit knowledge when solving difficult tasks than they will normally do when performing routine tasks (Polanyi, 1962; Eraut, 2000).

After narrating the incident from start to finish, participants were asked to go over the incident again, but this time with the intention of constructing a timeline (i.e. making a summary of key decisions made from the start of the incident to when it was brought under control). During timeline construction, decision points were also identified: A decision point,

which is the basic unit of analysis in this study, is defined as the point where participants admitted choosing a specific course of action where other potential alternatives were available. Some examples of decision points include: 'I committed my crews with breathing apparatus into the building', 'I withdrew my crews from the building because it was too risky', 'I requested more appliances because I thought we didn't have enough at the time' (see Table 2). The timeline construction and decision point identification phases were then followed by probing each decision point using a set of cognitive probes. The CDM probes which were specifically structured to enhance the knowledge elicitation process contained a series of semi-structured interview questions covering some of the themes that were outlined earlier (see Hoffman, Crandall, and Shadbolt, 1998 for details of the CDM procedure).

Each interview lasted between 1hr-2.5hr and was tape recorded with the consent of each participant. A total of 65 decision points were obtained across the sixteen incidents. The interviews were transcribed verbatim and analysed using a combination of a qualitative coding process and the emergent themes analytical method developed by Wong (2004).

Results and findings

Table 1: Demographic characteristics of participants

Pseudonym	Years of experience	Position/rank	Nature of incident	Major task constraints
UK FIREFIGHTERS				
Adrian	17	Watch commander	House fire (Arson)	- Dealing with a victim who had mental health issues - Having to turn the incident to a welfare issue
Patrick	32	Asst. Fire chief	Petrol storage fire	- Difficulty in finding the seat of fire - Pollution of the water courses - Fire growing bigger after 4hrs of active firefighting
Dickson	23	Crew commander	Garage workshop fire	- A massive fire resulting from acetylene explosion - Having to fight the fire from a more defensive position
Brown	27	Crew commander	Garage workshop fire	- The need to simultaneously carry out firefighting and rescue operations - Multi-Agency coordination - Treating a victim with 30% burns - Managing public emotions
Lilian	15	Director in command	Bush fire	- The need to evacuate victims to a safe distance - Difficulty in providing shelter for evacuees - Heavy wind negatively affecting task performance

Jade	15	Crew Commander	Residential house fire	• Access difficulty • Limited work space making response effort difficult • Preventing the fire from spreading to other surrounding buildings (incident was at the heart of the city center)
NIGERIAN FIREFIGHTERS				
Young	8	Fire Supt officer	Road traffic explosion	• Loss of human lives • Managing the emotional outbursts of public members • Multi-Agency coordination • The need to carry out rescue and firefighting tasks simultaneously
Kevin	8	Watch commander	Residential house fire	• Heavy wind negatively affecting task performance • Preventing the fire from spreading to other surrounding buildings
Sammy	8	Fire supt. officer	Warehouse fire	• Difficulty in gaining access to the seat of fire • Thick and poisonous emissions from the smoke thereby making response effort difficult • Coping with public intrusion
Knight	8	Watch commander	School building fire	• Managing public emotions • The need to prevent the fire from spreading further
Adams	30	Chief fire supt.	School building fire	• Pressure to contain the fire and prevent further damage • Ensuring safety of crew members amidst uncertainty
Ryan	8	Fire supt. officer	Residential house fire	• Access difficulty to the seat of fire • Risk of electrocution resulting from direct firefighting on an electrical appliance
Marvin	30	Station Manager	Train explosion	• Novelty of the incident; never managed train fire before • The need to carry out rescue and firefighting tasks simultaneously • Carrying out rescue activities on a moving train
Atkinson	8	Watch commander	Petrol storage fire	• Massive fire due to petrol explosion • Pressure to avoid further explosion with combustible materials all around the vicinity • Managing public emotions • Managing media scrutiny
Jack	30	Chief fire supt.	Furniture factory fire	• Heavy wind negatively affecting task performance • Sourcing and managing water supply • Risk of electrical explosion in the area due to the effect of the

Sunny	29	Asst. Chief fire supt.	Office fire	• Difficulty in gaining access to the seat of fire
				• Presence of combustible materials in the building
				• Pressure to save valuable assets and important documents in the office

For the purpose of this study, the phrase 'problem solving strategy' refers to the behavior which fire ground commanders display while responding to complex fire ground tasks. In one of his early studies, Rasmussen (1983) developed a construct that outlined three types of such behaviours: rule based behaviour, skill based behaviour and knowledge based behaviour. Drawing on Rasmussen's idea, each decision point in this study was classified as any of standard, typical or creative as discussed below:

Standard decisions
These are decisions for which every officer would normally know what to do i.e. the standard way of doing things in the fire service. The decisions that fell within this category include points where experts were basically following fire-fighting rules, standard operating procedures or fire manuals. The fire-fighting profession, being a high risk job by its very nature, entails that officers follow some domain rules and procedures e.g. rules of communication between the operational team and the control room, rules for committing firemen into a building with breathing apparatus, rules for evacuating victims within certain distance away from the scene of incidents (see Table 2). Some of the participants emphasized the importance of following domain rules where possible, claiming those rules are actually there to ensure tasks are effectively carried out within the brackets of safety.

Participants were carefully probed regarding the standard rules they were following at each decision point, if any. Each decision point was carefully matched against both the incident timeline and cognitive probes, and then coded as 'standard' if any of the decisions was reported by experts as 'the normal way of doing things'. Care was taken to differentiate between decision points where experts were strictly adhering to standard rules (standard rules) and where they were making adaptations to the rules (typical rules). For example, recognizing the need to request additional resources on the fireground was coded under the standard (or rule based) category, but knowing the actual time to request the resources and/or providing an estimate of the amount of resources required was coded as typical since some modifications has now been made to the SOPs (see table 2 for examples). Hence, as shown in Fig 2 below, 24.6% of all decision points fell into the rule based category.

Table 2 Analysis of rule based, adaptive and creative decisions from selected decision points

Actions (Decision points)	Is this a Standard operational procedure in the fire service? (Y/N)	How participants approached each decision point		
		Standard (Knowing that)	Typical (Knowing when & Knowing how)	Creative (combining bits and pieces of information to form a story)
Assessing the situation upon arrival at the scene of incident	Y	X	X	
Ensuring that BA sets are well monitored upon committing crews into a building	Y	X		
Ensuring communication between operational team and control room i.e. every 10mins at the start of an incident, and then every 20 mins as the incident dies down	Y		X	
Evacuating the fire crews within a radius of 200m in the involvement of acetylene or LPG cylinders	Y	X		X
Requesting extra resources	Y	X	X	
Using the appropriate firefighting medium e.g. Hosereel or Mainjet	Y	X	X	
Requesting assistance from other emergency response organizations such as Police, Ambulance, Road safety, civil defence	Y		X	
Getting to the scene of an incident through the nearest route and as soon as possible	Y	X		
Ensuring firefighters are committed in pairs into a well-alight building	Y	X		
Climbing the ladder to the roof of the building, or breaking difficult walls to be able to gain access to the seat of fire	N		X	X
Notifying control room when switching from defensive to offensive strategy	Y		X	
Taking over from a less ranked commander at the scene of an incident	Y		X	
Sourcing for water in an area with low pressure or no hydrants	Y			X

- *Note: It should be noted that the categorization process was solely context-based, which explains why some decision points had the three problem solving strategies represented.*

The participants however reported that they are often forced to either neglect or adapt firefighting rules to suit current circumstances, especially if such rules have been judged less profitable, through dynamic risk assessment. This problem solving style is discussed next:

Adaptive (typical) decisions
These are decisions that required modifications or refinements to the standard way of doing things in solving a particular task. The CDM reports showed that one of the hallmarks of expertise is recognizing when and where following standard rules are likely to be flawed and adjusting response plans accordingly. Decisions that fell into this category include those for which experts showed a high level of flexibility and adaptivity in solving a particular problem.

Analysis of the decision points showed that 63.1% of the overall decisions fell within this problem solving category, suggesting that the majority of decisions made by expert officers were skill-based and adaptive (see Fig 2). For example, one of the participants Patrick (32, Assistant Fire Chief, UK)[1] reported how he over-ruled the decision of a less experienced officer who was at the verge of requesting 12 additional pumps, asking him to increase the number of pumps 15 instead. Patrick reported making this intuitive decision after seeing the magnitude of the fire and its huge potential for spread. Another experienced participant, Adam (Chief Fire Superintendent, 30, Nigeria), also reported how he instructed his crew to utilize a hosereel (a type of hose that produces small quantity of water but with very high pressure) instead of a mainjet (a very big hose that produces large quantity of water but with less pressure). Adam explained that although using a mainjet would have probably been the most appropriate firefighting medium judging by the size of the fire, it could have in turn increased the possibility of the building to collapse, especially as cracks had already been spotted on walls. Therefore unlike the standard decision making strategy, adaptive decisions extend beyond merely "knowing that" to also include, more importantly, "knowing how" and/or "knowing when" (see decision points in Table 2).

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[1] Note that participants' rank and years of experience are displayed in parenthesis next to their names (pseudonyms) for ease of reference.
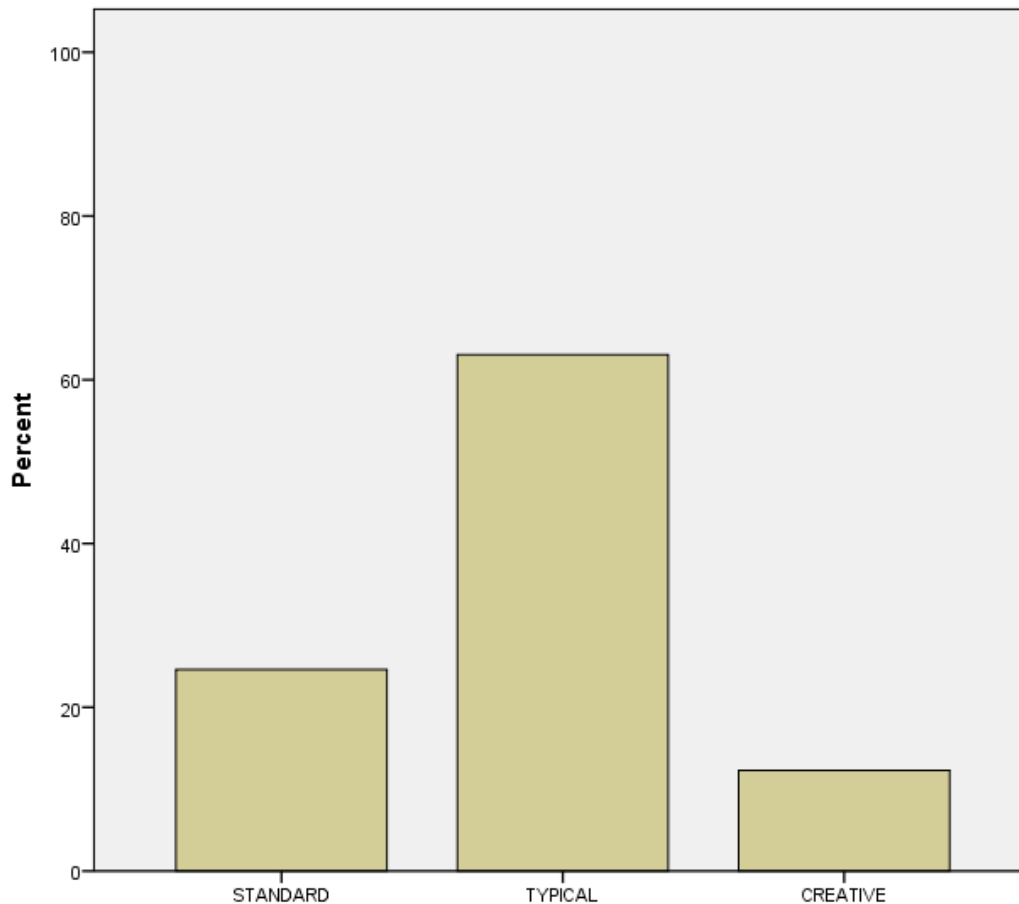
Figure 2: Frequency distribution of the problem solving strategies used by participants

Creative decisions
These are decisions which typically require creative problem solving strategies. In this problem solving category, no direct rules exist regarding how things should be done and pattern recognition is usually impossible because of the high level of novelty associated with the incident (see Cohen *et al,* 1998; Klein *et al*, 2010). In these circumstances, experts are obliged to make things work through improvisation, story building (combining bits of elements together to create a satisficing tactic) and creative insights.

As part of the cognitive probes, as with the other problem solving strategies, participants were asked to clarify at each decision point whether they were following any rules or whether they were being creative. They were also asked to explain why they think they were being creative i.e. if they admitted to being creative. Hence, a decision point is coded as creative if participants were able to demonstrate that they were making use of their 'out of the box' knowledge.   As shown in Figure 2, 12.3% of all decisions made by the experts were found to be creative

Although the perception and interpretation of what makes up a creative decision differed across the incidents and also amongst experts, three parameters were generally used by the experts to define what a creative decision is:

(i) Decisions that entailed making significant changes to an action plan i.e. moving from doing what is typical to expressing acts of "heroism". Heroic acts in this context means going the extra mile in finding alternative ways of doing things — even if it meant going beyond the boundaries of one's comfort zone in order to save lives and properties. Below are examples of creative decisions as reported by the participants:

- *Manually breaking of walls, doors and glasses so as to gain access to the seat of fire (Sammy, Fire Superintendent Officer, 8, Nigeria; Sunny, Assistant Chief Fire Superintendent, 29, Nigeria)*
- *Completely removing the roof of a building in order to gain access to the seat of fire (Patrick, Assistant Fire Chief, 32, Nigeria)*

The above two incidents were instances where the officers in charge could have easily admitted to defeat and withdraw their crews. But instead they chose to increase their risk appetite by going more offensive, which eventually proved more rewarding.

(ii) Decisions that were almost completely opposite some of the stipulations in the standard operational procedures of the fire service (albeit for a just cause).

- *decision not to withdraw the fire crews to a distance of 200m in an incident involving LPG and acetylene cylinders against what was stipulated in firefighting manuals (Dickson, crew commander, 27, UK)*

(iii) Decisions that required creating new ideas through improvisation, especially in novel circumstances

- *Creatively fastening a mainjet water supply to a wall in order to keep attacking the fire while fire crews are safely withdrawn from the immediate environment (Brown, 23, Crew commander, UK)*
- *Digging a temporary dam for storing water and also liaising with water carriers to ensure a steady supply of water in a rural area with extremely low pressured hydrants (Darren, station manager, 17, UK)*

The role of experience in dynamic risk assessment: Evidence from experts' qualitative report

One of the most important objectives of the study was to identify where and how the knowledge for making fireground decisions was obtained. The excerpts in table 3 demonstrate how participants reported this experience-based prototypical decision making strategy:

Table 3: Excerpts showing participants' responses to the sources of information on the fireground

Participants' answers to the question: where and how was the information for making fireground decisions obtained from?	Key phrase
The only way I can describe it is that those incidents contribute to a template, and those templates are in your head; just a framework for thinking that you call upon instinctively. You may only have 5 or 6 templates perhaps, but most of the incidents you go to will fit into one of those templates (Patrick, Assistant Fire Chief, 32, UK)	Insights gained from previous incidents
It was an unusual incident, but something inside you takes over, where you go into a mode of professionalism. And it comes because you've been doing it for that long, and through the training and the knowledge and experience you are able to go into a firefighter mode (Brown, Crew Commander, 27, UK)	Experiential knowledge
I didn't look at that incident and think this is like any other incident that I went to. I take learning points from all the incidents I go to and that, I believe, produces an ability to then make decisions (Jade, Crew Commander, 15, UK)	Lessons learnt from past incidents
There are some [incidents] that are similar, and some that are not similar, but you must remember. Like today, if we attended the same scene and we noticed the same building, about 5-7 rooms, and two rooms were not affected, we can apply the same method we used there (Adams, 30, CFS, Nigeria)	Lessons learnt from past incidents
Yes, [you are reminded of previous incidents] but I think it is more of a collection of experiences as opposed to a particular incident (Sunny, 29. ACFS, Nigeria)	Experiential knowledge
…..but with 8 years' experience that I have, following tankers, fighting fires everywhere, entering well, entering rivers to rescue, fighting fire, gas fire, petrol fire, free burning fire, oil fire. I have attended all. So with those experiences not once, not twice, not thrice (Kevin, Watch commander, 8, Nigeria)	Experiential knowledge

As shown in Table 3 all the expert participants agreed that dealing with a current problem often requires making use of previous knowledge and experiences, mainly by matching cues from the environment to the numerous patterns that have been pre-stored in the memory. Prior research has evidenced how experienced commanders develop domain knowledge from the consistent and repeated experiences they have linked together unconsciously to form a pattern (Crandall and Gretchell-Leiter, 1993; Fessey, 2002; Hogarth, 2003; Klein, 2003; Perry and Wiggins, 2008). A pattern therefore represents a set of "action scripts" that is chunked together and often triggered by one or more internal or external cues. The authors have published this cue-action relationship on the fireground elsewhere (see Okoli *et al,* 2014)

Discussion and conclusion

Findings from figure 2 showed that experts utilized the three problem solving strategies (i.e. standard, adaptive and creative decisions) when solving complex firefighting tasks, of course depending on the nature of the incident. Further analysis of the various decision points also generated insights regarding the sequence of this arrangement i.e. the conversion that exists between the application of rule, skill and knowledge based decisions. For example, Table 2 showed that rules and procedures seemed to be invoked when performing recurrent or routine aspects of tasks (e.g. requesting additional resources), since expected outcomes are mostly similar from problem to problem. But in situations where expected outcomes varied from problem to problem (non-routine tasks such as carrying out firefighting and rescue tasks on a moving train), the experts tended to depend less on rules/procedures and rely more on their prototypical and creative ability. These findings therefore give credence to existing beliefs that experts seem to understand the boundaries of their skills and when to apply or switch between the three strategies as events unfold (Rasmussen, 1983; Goldstein and Gigerenzer, 2002; Kahneman and Klein, 2009).

Specifically, the early research of Polanyi, who has been regarded as the father of tacit knowledge provides further explanation to the relationship that exists between rule based, adaptive and creative decisions (Polanyi, 1962). Polanyi's main line of thought was that creative acts (or acts of discovery) are imbued with strong personal feelings and commitments, and that knowledge is highly dependent on human action — what we termed experiential knowledge in this study. In one of his famous books titled *Personal Knowledge*, Polanyi (1958, pp.3) refuted the then dominant belief that science was value-free, arguing instead that the informed guesses, gut-feelings and intuitions which are part of exploratory acts are motivated by what he called 'passions'. The assumption that codified or theoretical knowledge (in our case rule-based knowledge) is totally objective was therefore the major bone of contention for Polanyi. Taking a closer look at how the so called codified knowledge is used in practice, he argued that such knowledge is grounded on 'personal judgments' and 'tacit commitments'. Since the majority of the decisions experts made were adaptive (63.1%), meaning that the standard ways of doing things were in most cases refined and adjusted to

suit current goals, it therefore becomes logical to infer that dynamic risk assessment requires making adjustments to domain rules, and in some cases making creative decisions through experience.

Furthermore, the qualitative reports in Table 3 provided additional evidence regarding the relationship between dynamic risk assessment and experiential knowledge. We strongly believe that adaptive decisions reflect both the level of experience and the quality of training that officers have been exposed to over the course of their firefighting career. This therefore explains, to a large extent, why the experienced fire commanders were able to look at a burning building, envision the stairways, elevator shafts and roof supports and then intuitively predict what was happening inside, making sense of their implications for task performance. Experience was also found to be vital in making critical fire ground decisions such as whether to employ an offensive attack or to go defensive, whether to commit crews into a building or become more precautionary, whether to allocate more resources at the beginning of an incident or wait till a later stage when more information must have been obtained.

Since commanders are aware that generating and/or evaluating a large set of options will likely cause the fire to span out of control and then become impossible to manage, some authors have shown that they rely instead on their experience to generate a workable option, which is usually the first, and possibly the only option they would have to consider (Burke, 1997; Johnson and Raab, 2003). Thankfully, a number of scholars have attempted to demystify, through the concept of pattern recognition, how experts are able to utilize previous knowledge in solving current tasks (Gobet, 2005; McLennan *et al*, 2006; Lipshitz *et al*, 2007; Perry and Wiggins, 2008; Klein, 2008; Harré, Bossomaier, and Snyder, 2012; Klein, 2008). This concept has thus been widely utilized in the field of cognitive psychology to explain how professionals are able to carry out a quick scan across the large repertoire of patterns in their memory, from which they are then able to select the most appropriate 'action scripts' that best suit a current situation. The expert reports presented in the various sections above and also in Table 3 thus provided a useful explanation as to how and why domain experts — even under intense time-pressure, shifting goals and incomplete information — are still able to conduct dynamic risk assessments rapidly and yet accurately. Experienced firefighters often strive to draw from their rich mental model through which they can then describe, explain and predict events better.

The above findings support two of the most prominent theories in the expertise literature: the chunking theory (Chase and Simon, 1973) and the template theory (Gobet and Simon, 1996). Just as proposed in these theories we found that the amount of templates chunked into an expert's memory is a function of the amount of incidents they have attended in the past, their years of experience and their level of exposure to difficult tasks — through which they are then able to build up a reservoir of recognized pattern (see Table 1). Previous studies have shown that the more patterns people are able to acquire over their years of practice, the more they are able to match a new situation to one of the patterns stored in their reservoir of knowledge (Shanteau, 1992; Zsambok, 1997; Eraut, 2000; Fessey, 2002; Rosen, Shuffler, and

Salas, 2010). This explains why fire fighters, in real life, could see the colour of a smoke and intuitively know that toxic chemicals and other combustible materials are involved.

Despite evidence from the current study to substantiate existing claims underpinning experts' competence in managing complex incidents, prior research has shown that experts' judgments are not always accurate. For example, Kahneman and Klein (2009) revealed certain conditions in which experts might also be as vulnerable to the same mistakes as novices, implying therefore that trusting experts' judgement solely on the basis of their years of experience or subjective confidence could be misleading. The extensive knowledge and skill sets possessed by experts can also serve as a potential source of overconfidence if not harnessed with prudence. When experts attain certain level of competence they tend to rely more on automated (tacit) knowledge, which sometimes result in ignoring certain cues they feel unfamiliar with. Hence the danger of expertise in this regard lies in missing out, explaining away or ignoring some important cues (Okoli *et al*, 2015). Klein (2003) used the term *fixation* to explain how actors sometimes choose a particular course of action and tenaciously cling to it without the willingness to compromise. We therefore acknowledge that expertise can somewhat affect the quality of generated knowledge outputs in studies involving knowledge elicitation. For instance, when interviewees fail to acknowledge the link between automaticity and expertise, they often tend to unintentionally fabricate *consciously* reasoned explanations for their *unconscious* actions during knowledge elicitation (Ericsson and Simon, 1993; Wiley, 1998).

Although the critical decision method utilized in this study has proved of worth in overcoming most of the effects of expertise during knowledge elicitation, we hope that mentioning these potential downsides of expertise will create awareness amongst scholars who have interest in recruiting experts for research purposes.

Finally, since the ability to effectively conduct dynamic risk assessments on the fireground lies in utilizing existing knowledge, which is largely rooted in experience and deliberate practice, we therefore recommend that standard operational procedures should be treated as a tool for informing rather than one for dictating. The less experienced officers should be made to explore various scenarios e.g. training facilitators could design learning tasks for which novices are only required to apply basic firefighting rules and those where applying such rules could appear counter-productive. It is believed that a training procedure that is heavily focused on making rule-based decisions could apparently jeopardize the creative power of professionals, thereby slowing down their learning curve.

Future research is needed in this area to investigate the mode of conversion between the rule based, adaptive and creative decision styles across a wider domain of practice. In addition, future research involving expert studies or knowledge elicitation may benefit from a more robust knowledge output by utilizing two or more knowledge elicitation tools that will not only aid the expert knowledge elicitation process but also help to compare various aspects of expert knowledge.

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