GDIA: a Cognitive Task Analysis Protocol to Capture the Information Requirements of Emergency First Responders

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ABSTRACT

As a partial requirement of the development of an information system for the UK fire and rescue services, this paper describes the development and application of a protocol capable of capturing the information requirements of fire and rescue first responders. After evaluating the existing techniques commonly used in difficult decision-making environments, a Goal Directed Information Analysis (GDIA) protocol is proposed. The clearly defined, repeatable steps of GDIA make it a requirements-gathering protocol which can be easily administered by an investigator without any prior knowledge or experience of the tool. This makes GDIA one of the very few information requirements-gathering protocols capable of capturing the requirements of the emergency-related domains.

Keywords

Emergency Response, Fire and Rescue, GDIA, CTA

INTRODUCTION

A proper design methodology is crucial in the development of systems for complex and difficult environments such as emergency response. Therefore, in such a domain, systems based on accurate design could prevent many disasters caused by decision-making failures. Decision-making failures in such domains commonly occur due to the information gap created in the minds of the system end-users (Endsley, 1995). Whether it be an information system or not, system failures are often due to the use of poorly designed methodologies, as most of the systems fail to capture the crucial Human Factors (HF) dimension of its end-users who operate in difficult environments (Bolstad, Costello, and Endsley, 2006). Therefore, consideration of the human role in the development of emergency response systems becomes of utmost importance in the development of such support systems (Walle and Turroff, 2007).

Investigation of the literature revealed two major schools of thought in the domain of HFs: the more traditional way of designing systems, which is the Technology Centred approach, and the more contemporary, called the User-Centred approach (Endsley, Bolte, and Jones, 2003).

User Centred Design (UCD) emerged as an interdisciplinary field of inquiry devoted to the methodology and sustainability of integrating user input into the design process (Beirne, Ramsay and Panteli,. 1998). Therefore, when it comes to the designing of systems, especially in complex and difficult domains, the UCD approach is preferred to the Technology Centred Design approach (Endsley et al., 2003).

Over the years, Cognitive Task Analysis (CTA) has become a popular methodology that supports systems design in various domains such as military & defence operations (Riley, Endsley, Bolstad, Cuevas,, 2006), aviation (Endsley and Robertson, 2002), air traffic control (Endsley and Rodgers, 1994), driving (Walker , Stanton and Young, 2001), nuclear and petro-chemical. Such widespread application indicates that the use of CTA is one of the most powerful methods available for the HF practitioners who promote the UCD approach (Diaper and Stanton, 2004). Stanton, Salmon, Walker, Baber and Jenkins (2005) also suggest that tools and protocols based on CTA methodology are of central importance to most of the instruments used to design a system and analyse its performance, especially as it affects the requirements-gathering and design concept phases of a system's development.

Since this particular research focuses on the fire and rescue service, a domain where system users experience high-level cognitive complexities, it is considered as a priority to identify a CTA-based protocol capable of understanding such complexities. Such protocol is expected to capture accurate and holistic end-user requirements, which lead to better systems design in the domain of fire emergency response. With the aim of proposing such a protocol, the rest of this paper is organised as follows. First, a brief introduction to CTA is provided. Then two selected CTA protocols assumed to be suitable for investigating the fire emergency domain are introduced and compared. Next, after considering the limitations of such identified protocols, the steps of a new CTA protocol, namely GDIA, are proposed. Thereafter, a case of the successful application of the proposed protocol is discussed. Finally, the work in this study is summarised and suggestions for possible future work set out.

COGNITIVE TASK ANALYSIS (CTA)

CTA is a methodology which comprises of a set of tools, techniques and protocols capable of identifying the cognitive skills, or mental demands, needed to perform a task efficiently. Compared to traditional task analysis, CTA methodology is identified to be most appropriate in exploring complex domains (Stannon et al., 2005).

While traditional task analysis protocols are driven by the physical tasks, CTA protocols are driven by the operator goals identified as cognitive or mental demands (Kirwan and Ainsworth, 1992). Therefore, CTA is further defined as an extension of the traditional task analysis method as it is used to describe the knowledge, thought processes and goal structures underlying observable task performance (Schraagen, Chipman and Shalin, 2000). CTA techniques are essentially different from physical task analysis techniques as they attempt to describe and represent the cognitive elements that underlie the goal generation. (Militello and Hutton, 1998). As these are essentially independent from the technology or resources being used, compared to physical tasks, an understanding and analysis of operator goals allows analysts to capture a much more complete and accurate picture of the domain being investigated. Therefore, compared to its predecessor - traditional task analysis - CTA protocols have become a popular UCD approach. Thus, protocols based on CTA are recognized as essential for system designers in order to propose design concepts that allow the development of training procedures and work processes where analysis of the cognitive demands associated with the end-user operations becomes important (Stannon et al., 2005).

Since they are mostly accessed by knowledge engineers, cognitive psychologists and HF professionals, only a few CTA instruments have become accessible and therefore become popular among social researchers, training practitioners and information system designers (Militello and Hutton, 1998).

Although a protocol based on CTA methodology is considered to be appropriate, since this study specifically aims to acquire information requirements leading to better Situation Awareness (SA) of the fire fighters, the following considerations form an essential part of the process of recognising a suitable protocol.

- Analyzing only the physical tasks and practices may not discover the true and complete information requirements of a complex situation such as a fire emergency (Endsley et al, 2003).

- Analysis of Cognitive Demands (Goals) will help to reveal decisions made in complex situations similar to fire emergencies. Further discovery of decision requirements will lead to the dynamic information requirement needs during complex situations. Such information requirements are defined as requirements of the end user's SA (Endsley et al, 2003; Albers, 1998).

- Although there are many CTA protocols, the repeatability of most of them is identified as being increasingly difficult. Our investigations of the literature of many CTA protocols reveal that of most of them only describe results after their application or make comparisons against similar types of protocol.

Such literature barely describes a clear application guideline for the protocol. Therefore it makes the application of such protocols in a new context a challenge.

With careful consideration of the above concerns and after an in-depth study of many CTA protocols, Applied Cognitive Task Analysis (ACTA) (Militello and Hutton, 1998) and Goal Directed Cognitive Task Analysis (GDTA) (Endsley et al, 2003) are identified as being popular among systems designers in more dynamic and complex domains. Such popularity is gained mainly due to the fact that both these tools are recognised as feasible for a much larger population of researchers and system designers who are non-HF professionals and therefore not familiar with the incorporation of CTA methodology into their research or system development efforts. Considering the above factors and with the aim of further assessing the suitability of their application as a requirements-gathering and analysis protocol in the domain of emergency response, these two protocols were evaluated further.

GOAL DIRECTED COGNITIVE TASK ANALYSIS (GDTA)

As its name implies, GDTA is clearly driven by the operator goals or cognitive demands. GDTA is predominantly an unstructured interview-based protocol which essentially captures the information requirements leading to an operator's SA in a complex environment (Endsley et al, 2003).

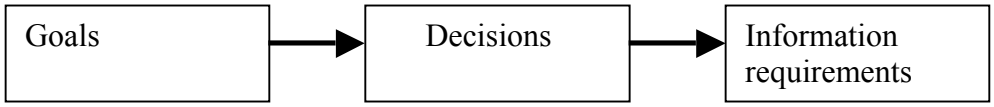

Figure 1: Relationship between Goal, Decisions and Information Requirements

According to the application guideline, starting from the first interview, users of this protocol should first visualise the goals followed by the decisions taken to achieve such goals and finally derive the information needed to make the decisions (Figure 1).

APPLIED COGNITIVE TASK ANALYSIS (ACTA)

Being a popular protocol under the CTA movement, a careful study of the ACTA (Militello and Hutton, 1998) literature reveals that it is also an instrument driven by the goals of the users.

In contrast to GDTA, ACTA steps are complex and highly subjective when it comes to integrating the findings of each step to obtain its final output. According to the ACTA literature, the findings of three different, semi-structured, interviewing steps: Task diagrams, Knowledge Audit and Simulation Interview (Figure 2), are integrated to achieve the final output in the form of a "Cognitive Demand Table. Although the theory of ACTA clearly defines its meta-methods and illustrates the detailed guidelines for carrying out its individual steps, the ACTA literature does not indicate any order or how to relate or combine the results of each step to obtain the final output. This can become a major obstacle in summarizing the outputs of the three steps: Task diagram, Knowledge Audit and Simulation Interview, into the Cognitive Demand Table. In the ACTA literature, the guidance given with regard to the above mapping of Cognitive Demands seems to be very vague and therefore likely to result in a confusing outcome.

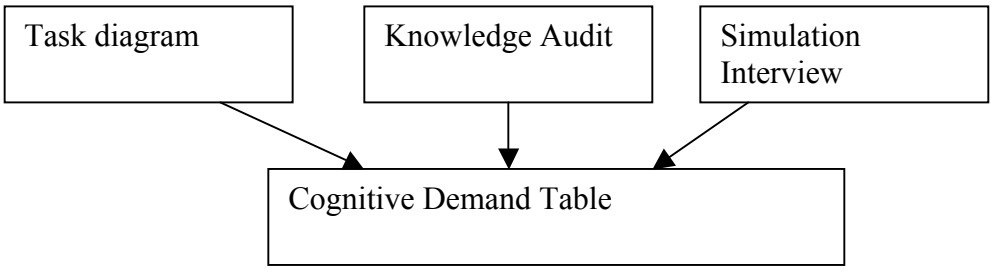

Figure 2: Development of Cognitive Demand Table

DIFFERENCE BETWEEN ACTA AND GDTA

As elaborated above, both ACTA and GDTA can be recognized as capable of analyzing the cognitive activities. The main difference is that in the ACTA protocol cognitive activities are being defined as cognitive demands whilst in GDTA they are defined as goals. Therefore, on careful investigation one can argue that the initial step (goals) of GDTA is the final step (cognitive demands) of ACTA.

Although it has been recognised by the authors of ACTA that it can be applied in the process of information systems design (Militello and Hutton, 1998), it is hard to find any written evidence indicating that ACTA has been applied with the aim of developing information systems. Predominantly, as a protocol it was utilized to design training programs and instructional material. In comparison, GDTA is exclusively based on gathering information requirements in complex environments with the aim of designing information system interfaces.

When comparing the information published; the ACTA literature explains its recommended meta-methods, such as simulations, interviews and observations, to carry out each of the three preliminary steps in a more elaborative and informative manner than GDTA. Therefore, in the implementation of the steps of the protocol, the user will find it much easier to administer the steps of ACTA than GDTA. As a researcher, this is considered to be important as it leads to improved accuracy of the findings since such flexibility of administration strengthens the guidance of each step of the data-gathering and analysis. Described as a core part of ACTA, the use of scenarios during the simulation interviews could become a much more appropriate interviewing technique with fire fighters than prompting them by only using the "why" and "how" probes which act as the main probes during the highly unstructured GDTA interviews. Therefore a properly developed scenario which is familiar to the fire fighters to be interviewed could become the ideal interview probe leading to better data-gathering.

LIMITATIONS AND CONSTRAINTS OF GDTA AND ACTA

Based on the considerations of the above differences, on careful perusal of the appropriateness of the steps of GDTA and ACTA protocols and their theoretical foundations, the following are identified as the constraints within the scope of this particular study.

1. With the use of unstructured interviews, ambiguity may creep in by asking the question "what are the goals?" to reveal the cognitive demands (goals), mainly due to the fact that SMEs in the FRS are more used to thinking of their tasks rather than their goals. GDTA theory describes and accepts this as a challenge, as in complex situations there is a greater risk that the answers of SMEs may end up only describing their physical tasks. Therefore, it may lead to a poorly-developed goal structure, causing a number of additional interviews before eliciting a satisfactory set of goals.

2. According to the current GDTA practice, information collected during the first interview session can be used to develop the goal & sub-goal structure along with the decision and information requirements. Investigating all three sectors during a single session of an unstructured interview may lead to the loss of vital data either related to goals, decisions or information.

3. According to GDTA, conducting unstructured interviews is recommended for data gathering. It is mainly guided by the use of weak interview probes such as "Why?" and "How?" By having such weak interview probes and keeping all interviews unstructured, GDTA allows interview sessions to float with the hope of discovering the goals after a maximum of 10 interviews.

4. According to ACTA, level of experience of the SME has a greater impact on the decision-making during emergency situations (Militello and Hutton, 1998). Therefore the level of information requirements of an experienced SME may be different to that of a novice. However, ignoring the above implication, GDTA does not indicate the necessary criteria for selecting the SMEs for the interview. This may lead to bias, causing major changes at the stage of validation, such as when results are discussed with a larger audience.

5. As the final output of the ACTA is at the level of a cognitive demand table and this particular study specifically looks at the information requirements, it is essential to extend the findings of the cognitive demand table to the level of the information requirements. Unfortunately, the ACTA protocol does not provide guidance for such an extension.

Although both techniques are equipped with significant capabilities, in relation to this specific study, the limitations of both GDTA and ACTA lead to the conclusion that the independent use of either GDTA or ACTA is not appropriate and therefore is not recommended as a means of capturing the information requirements of fire fighters.

PROTOCOL GOAL DIRECTED INFORMATION ANALYSIS (GDIA)

GDIA Background

Considering the above limitations of the independent use of ACTA and GDTA, a proposal is made to develop an alternative protocol which is much more suitable to apply in emergency domains such as fire and rescue. In this exercise, the strengths of both ACTA and GDTA are adopted to form an appropriate tool rather than developing one from scratch. Therefore, amendments are proposed to combine the capabilities of both GDTA and ACTA so that in combination it can form a better tool to address the requirements-gathering for this particular type of study. After introducing such suitable amendments, a new protocol, GDIA, which embeds the combined strengths of both ACTA and GDTA, is developed.

Application Steps of GDIA

The following paragraphs discuss the key application steps of the proposed protocol, GDIA.

Step 1 – Context Discovery

Initial understanding of the context via a few face-to-face interviews with relevant SMEs, the observation of real time practices, formal and informal documentation such as procedure manuals and policy documents produced as part of the emergency response work, may also be investigated (Hammersley and Atkinson, 1995). It will create the opportunity and confidence to carry out the rest of the steps of the approach and finally to acquire information requirements. Especially, it will help to build up suitable fire scenarios which could be treated as a guideline for the second stage of the approach.

Step 2 – Scenario Development

ACTA incorporates clearly-defined interview probes during its application, the lack of which is a major limitation in GDTA. Among such probes "Simulation Interviews" are most significant. The Simulation Interview is a type of interview that is specifically based on the presentation of a challenging scenario to the SME. Although this study preferred GDTA to be the basis of its data-gathering technique, in order to overcome its limitation due to the unstructured nature of the interviews and thereby to improve its focus, it has been decided to introduce suitable scenarios to the interview sessions. Therefore, within the scope of the research, (Ex. Fire emergency of high risk structure) a suitable emergency scenario/s is introduced to illustrate the overall picture of such an emergency. With regard to an emergency, this will help to enhance the imagination of the SMEs during the interviews with a view to adding structure and focus.

Step 3 – Physical Task Identification

This involves the identification of SMEs from each job role, spending time with them and having a verbal discussion on each scenario to clarify any confusion. Each selected SME was asked to:

- Describe the possible activities they carry out (physical tasks) under each scenario.
- Among the activities set out above, request them to identify possible task groupings.

This is carried out by conducting face-to-face interviews with the selected SMEs. Depending on the resources and level of accessibility, an appropriate number and combination of SMEs can be selected. It is important to give equal opportunity to both experienced and novice SMEs to avoid any bias and capture complete and accurate requirements.

After collecting the task lists from several SMEs, the data is analysed to develop the task structure. The intention of this analysis is not to achieve greater precision but to identify tasks so that they can be used together with the previously designed scenarios, during the next step of the research approach as specific interview probes to acquire the cognitive demands of respective SMEs. During the application of this step, scenarios are expected to expand the

mental models during task identification so that SMEs may neither miss any important tasks nor describe irrelevant tasks.
In order to carry out the remaining steps of the process, the physical task structures for the job role are obtained as shown in Figure 3.

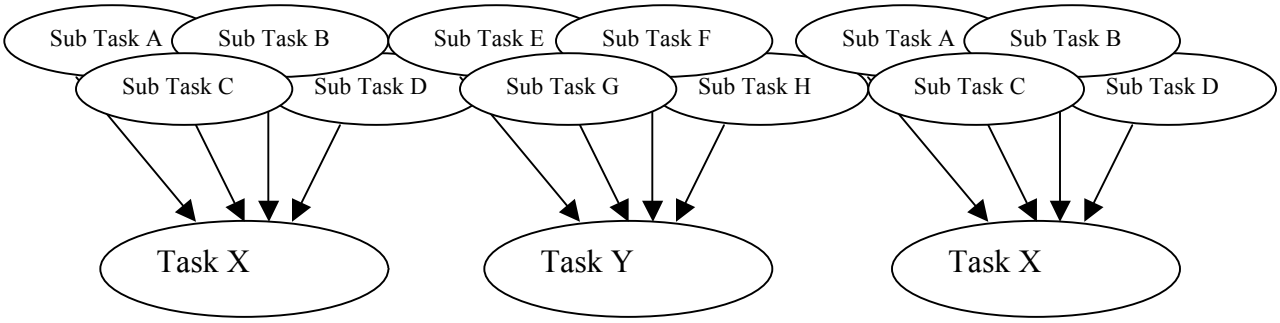

Figure 3: Tasks and Subtasks

Step 4 –Sub-goals and Goals Identification

Semi-structured interviews are conducted with the SMEs (preferably with the same SME who described the tasks) to identify the goals and sub-goals that are expected to be achieved during the situations under investigation. In this exercise, tasks identified earlier will be used as probes to unveil the cognitive demands or goals. With the task structures, the interviewer would now specifically ask *"Why do you want to carry out the task x, y,…?", "Why do you think tasks x, y……. are important?"*. Just before the start and in the middle of an interview, the scenarios described during the task identification can be used again to maintain the mental focus of the SMEs. A combination of both scenarios and tasks will improve the structure of the interview and therefore it will provide better guidance to explore the goals of respective SMEs. Specific tasks probes and scenarios are expected to control and guide the interviewing process, which is unlikely in GDTA goal-identifying interviews.

This session concentrates only on acquiring goals and sub-goals. As in the GDTA approach, there will be no attempt to overload the session by gathering information related to decisions and information requirements.

Based on the analysis of the above interviews and by summarizing the interviews of different SMEs, the goal and sub-goal structure representing that particular job role can be developed.

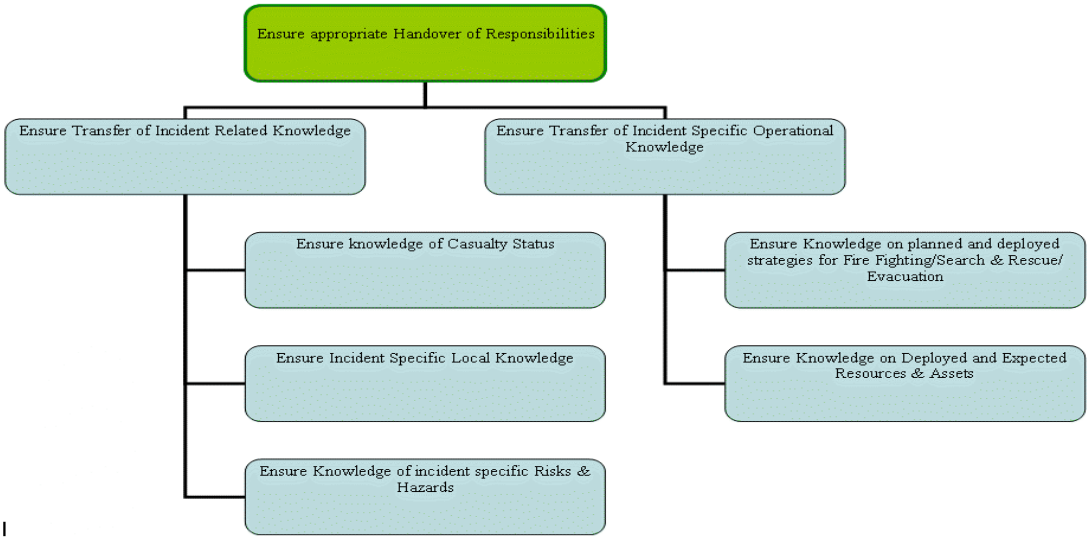

Figure 4: Representation of Incident Commander Goal Hierarchy for a Selected 2nd Level Goal

As an example of an application, an illustration of part of a goal structure belonging to an Incident Commander is elaborated in Figure 4. This particular figure is extracted from the goal structure diagrams developed after successful application of the steps of the protocol in the fire and rescue services of Derbyshire County Council, UK. This represents one of the second level goals; "*Ensure Handing Over of Responsibility"* and its subsequent level goals.

Step 5 – Validation of Goals

As described previously, the goal hierarchy forms the basis to obtaining information requirements. Thus, it is very important to make sure that the developed goal hierarchy is meaningful and accurate. At this level of the process it will be very useful to check the validity of the derived goal structures. The following steps illustrate this validation process:

- Distribute the developed goal structure among the interviewed SMEs.
- Carry out a brainstorming or focus group session with the previously interviewed SMEs or, if this is not possible, meet SMEs individually and revisit the developed goal and sub-goal diagrams to remove the doubtful elements.
- To improve the validity of the results so that they represent generic goals of the domain is being investigated, the results should be validated by having discussions with different fire fighters who represent other brigades of the same county where the interviews were conducted as well as the SMEs representing fire brigades in other counties.
- Accordingly, modify the goal and sub-goal diagrams based on the comments and suggestions.

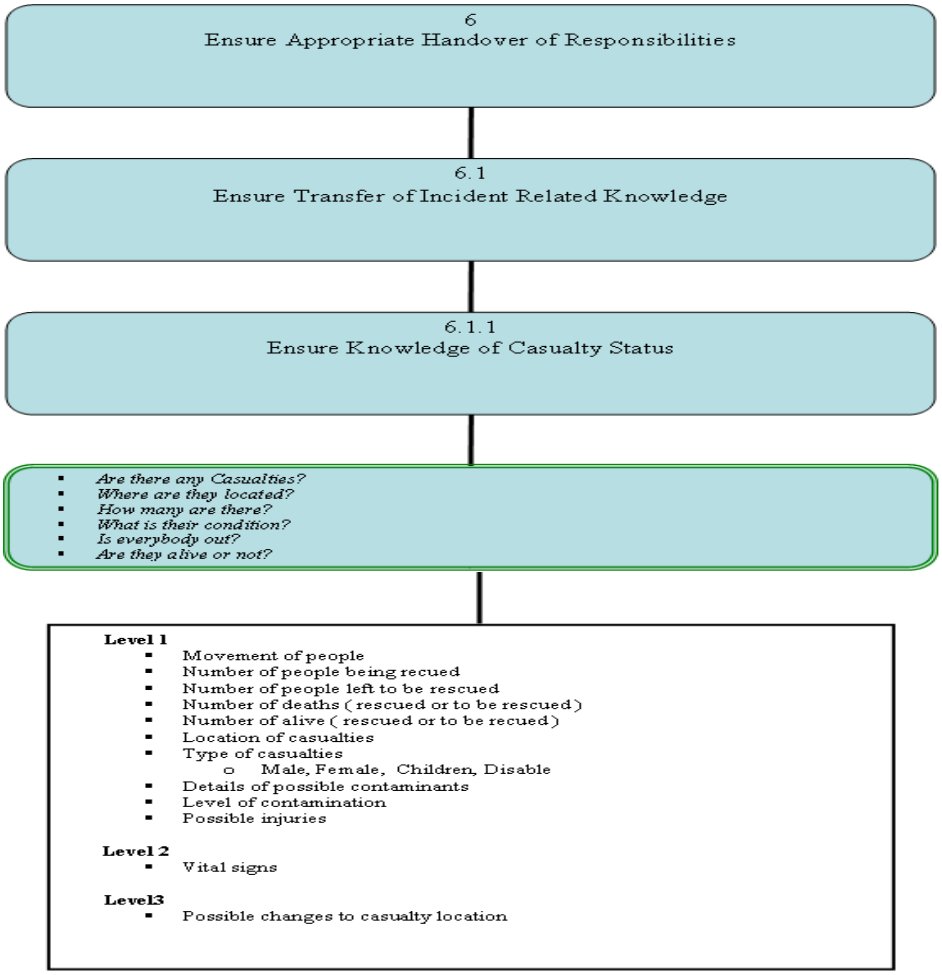

Figure 5: Representation of G-D-I Hierarchy of an Incident Commander

Step 6 –Information Requirements Identification

- Making use of the identified goals and the sub-goals as probes, semi-structured interviews would be carried out with the SMEs for the second time. This is expected to discover the decision-making requirements leading to achieving the goals/sub-goals and also the information requirements to make such decisions.
- Prepare the Goal – Decision – Information diagrams.

As an example, a GDI diagram representing the information requirements of a fire and rescue Incident Commander is elaborated in Figure 5. This particular figure represents one such GDI diagram developed after the successful application of the steps of the protocol. It represents the decision and information requirements leading to the achievement of the goal of "*Ensure Knowledge of Casualty Status"* where it acts as one of the many third level sub-goals of a superior goal of Incident Commanders during an operation, namely "*Ensure Appropriate Handover of Responsibilities"*.

Step 7 – Validation of Goal – Decision – Information Diagrams

To ensure that the obtained goal-decision-information diagrams are complete and accurate, they should be validated with a larger group of SMEs representing other similar organisations in the region where interviews were carried out and also organisations from other regions. With the instructions on how to interpret the diagrams, they would be deployed to a large number of SMEs (both interviewed and non-interviewed) along with a request for them to identify missing information or errors. Further, developed diagrams have to be distributed among suitable SMEs who work in organisations outside the county or the region being investigated, as such a validation is expected to improve the generalisation of the findings. In this manner the findings of the study become a much closer representation of the requirements of a much wider domain, such as a country, rather than one that is limited to a single county or a region. Later, the obtained feedback has to be integrated with the feedback of SMEs representing outside regions. Such integrated feedback could then be used to make the necessary corrections to the developed GDI diagrams. After embedding such integrated feedback, the resulting GDI diagrams are expected to be much more accurate and complete. As mentioned before, with regard to this particular study, it is expected to interpret the information requirements of the fire fighters across the UK and therefore not to be limited only to the requirements of the county or brigade where the basic data has been captured.

As described above, the graphical representation of the application flow of the GDIA steps is illustrated in Figure 6.

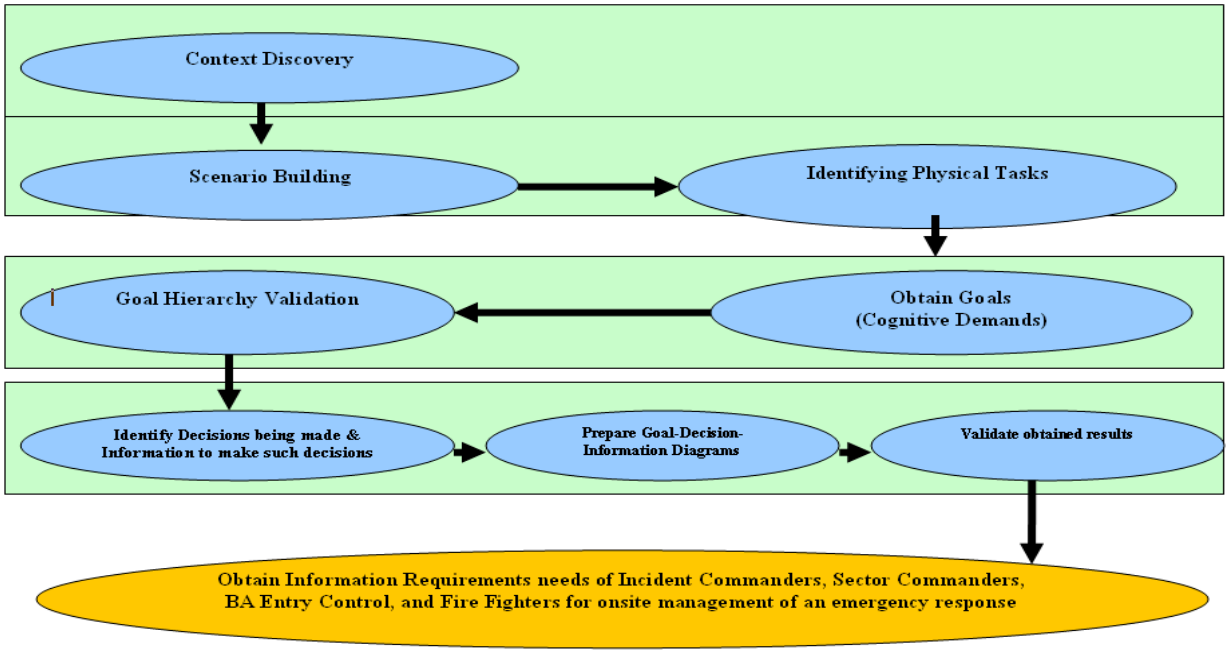

Figure 6: GDIA Application Flow

APPLICATION OF GDIA TO CAPTURE INFORMATION REQUIREMENTS OF UK FIRE AND RESCUE

Since this protocol was developed with the aim of capturing information requirements of the fire fighters in the UK, it was applied and administered in the fire and rescue service of the midland county of Derbyshire. During this exercise, information requirements of four fire fighter job roles: incident commanders, sector commanders, entry control officers and front line fire fighters, which are considered to bare critical operational responsibilities during large scale fires are extracted (Prasanna, Yang, and King, 2008). This information capturing exercise was carried out in six fire stations of the county of Derbyshire where more than 40 fire fighters representing experienced, novice, full time and retain were selected in such away to avoid unnecessary bias during the information gathering. According to the defined GDIA steps, semi-structured interviews were carried out with above selected SMEs in three separate interviewing phases and four fire scenarios: fire in a large and one of the most popular high rise shopping malls in the region, fire in high rise hospital building, fire in high rise community housing and fire in a nuclear reactor, representing the highest risk fires expected in the county were used as the main interview probes. Thereafter, as described in the application process of GDIA, for each job role, captured information was mapped to form the goal-decision-information (G-D-I) hierarchies. Finally for the purpose of improvement of the captured results as well as to validate the appropriateness of the steps of the GDIA, hierarchies were sent back to the interviewed fire fighters and requested them to comment on the accuracy and the appropriateness of the findings. In addition 16 experts in the Derbyshire fire and rescue, representing fire fighting training staff and experts who had real life experiences in fighting fires similar to the incidents described in the above scenarios were requested to comment on the findings. Apart from its validation in the county of Derbyshire, the obtained GDI hierarchies were later re-validated in two other counties, namely Leicestershire and Nottinghamshire. This third party validation was carried out across 8 fire stations where similar to the case of Derbyshire nearly 20 experts representing fire fighter training staff and fire fighters experienced in high risk fires have given their feedback and suggestions on the findings. Such extended validation is expected to elaborate the efficacy of the GDIA as well as elicit generalised findings which represent the nationwide information requirements of fire fighters in the UK. In this study, as it is often criticised and considered as misleading to interpret the findings of a qualitative study as quantified results (Pope, Ziebland, and Mays, 2000), summarisation of received qualitative feedback during the validation phase of the study with the aim of quantification to use it as a measure of accuracy and appropriateness of the GDIA protocol is avoided. Although it is beyond the scope of this study to carryout such a survey with the aim of quantifying the viability of GDIA protocol as a tool of information capturing, as a clear indicator of efficacy of the GDIA protocol, feedback during the validation sessions and later during the presentations conducted at various fire brigades with regard the results obtained for all four job roles have shown greater satisfaction and enthusiasm among the fire fighters. Most of them agreed and believed these findings to be comprehensive and accurate enough to represent the information requirements which are considered as essential to support their highly dynamic and complex cognitive decision-making during any large-scale fire emergency.

CONCLUSIONS AND FUTURE WORK

This paper has elaborated clearly the defined steps of a CTA protocol which is specifically suitable for capturing information requirements in complex domains such as fire emergencies. Because the issues of capturing the right information, sharing it with the right people and presenting it in the right format are essentially common to the success of any emergency information system, the protocol presented in this paper is expected to be suitable for a wide range of emergency response domains. Unlike previous similar attempts, it is specifically designed to support system designers and analysts who intend to develop systems for dynamic environments but who are non-HF practitioners and therefore not familiar with administering CTA protocols which are complex and difficult. Further, it has managed to remove some of the application constraints and ambiguities of two popular CTA tools in the context of information-gathering requirements in the domain of emergencies.

Since this particular protocol is developed with the aim capturing the information requirements of the fire fighters leading to the development of an information system Safety Net (Yang and Frederick, 2004), the obtained information requirements are currently being used by the Safety Net development team as the primary input in developing its user interfaces (Yang, Prasanna, and King,, 2009), database structures and the systems architecture. In addition, both the Leicestershire and Derbyshire fire and rescue services have requested permission to use the obtained goal-decisions-information hierarchies and deploy them into the computer terminals of their newly-acquired command support vehicles. The command support teams of these two counties have shown great enthusiasm for deploying these hierarchies as they expect that they could become vital operational prompts to be used by the respective job roles, especially the incident commanders during their response work. Therefore, as the

next step, efforts will be made to deploy the identified Goal – Decision – Information hierarchies onto the computers of command support vehicles of both Derbyshire and Leicestershire.

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