Using Cognitive Work Analysis to analyse emergency responder team coordination at traffic incidents

ABSTRACT

Effective traffic incident management ensures the best possible road crash casualty outcomes while at the same time reducing the negative flow-on effects of incidents arising from congestion. Traffic incident scenes are complex, dynamic environments with distributed intra and inter-agency team functions and determining the best practices to employ is not always straight forward. Human factors models have been used to analyse complex socio-technical environments and these models may be useful for analysing emergency responder functions at traffic incidents. The aim was to investigate the applicability of Cognitive Work Analysis as a tool to analyse the traffic incident management workplace, with the goal of improving intra and inter-agency performance and collaboration at incidents. Results from two levels of Cognitive Work Analysis are presented – Work Domain Analysis and Strategies Analysis. Responders from Queensland Police Service, Queensland Fire and Emergency Services and the Royal Automotive Club Queensland’s Traffic Response Unit participated in a desktop exercise for the study. Cognitive Work Analysis successfully mapped the desktop exercise and identified agency functions, priorities, tasks, and resource requirements, intra and inter-agency collaboration requirements, different operational strategy requirements and produced useful recommendations to further improve traffic incident management.

Keywords: Cognitive Work Analysis, Work Domain Analysis, Strategies Analysis, Traffic incident management, emergency responder.
INTRODUCTION

Traffic Incident Management

The traffic incident management workplace is a dynamic, temporally challenged and high stakes environment. Good traffic incident management teams require a shared awareness of team goals, congruence between individual and team goals and coordination between team members conducting their separate tasks as part of the whole output (Charles, 2007). Within the overall traffic incident management system, the intra-agency teams are required to display these characteristics. Training within agencies is strict and professional development ongoing. However, at least in Queensland, aside from occasional joint exercises, there is currently no training to better understand inter-agency roles and responsibilities at incident scenes. Also, due to the distributed and hectic nature of traffic incident management systems, team awareness is reduced and this is an important factor for successful collaboration (Fiore & Salas, 2004; Gutwin & Greenberg, 2002). In a previous study team coordination and communication was cited as a primary safety concern by emergency responders (Cattermole, Horberry, Wallis & Cloete, 2014).

Traffic Incident Management as a Complex Sociotechnical System

Optimising the safety and effectiveness of traffic incident management will minimise the safety risks and concerns of responders at the scene and also ensure the best possible casualty outcomes. However, determining the best practices for teams in complex socio-technical systems such as traffic incident management workplaces is not straightforward. Theoretical models such as Cognitive Work Analysis can offer some guidance. There are five phases in Cognitive Work Analysis. Work domain analysis (WDA) focuses on physical and purposive environments within the work system. Control task analysis (ConTa) focuses on the decisions made and what needs to be done. Strategies analysis (StA) analyses strategies and processes needed to undertake work activities. Socio-organisational analysis (SA) investigates the coordination of workers. Worker competencies analysis (WCA) analyses the capabilities required by workers to perform the work required (Rasmussen, 1997; Rasmussen & Svedung, 2000).

Cognitive Work Analysis was developed to analyse complex systems where unanticipated events occur, an apt description of the traffic incident management environment. In several studies,
Cognitive Work Analysis has been modified to focus on team interactions (Ashoori & Burns, 2013; Naikar, Moylan, & Pearce, 2006; Naikar, Pearce, Drum & Sanderson, 2003). These researchers have indicated that Cognitive Work Analysis is a useful tool for analysing team collaboration and team cognition in complex socio-technical teams (Ashoori, Burns, d’Etremont & Momtahan, 2014; Naikar et al, 2006).

Study Aims

Cognitive Work Analysis has potential to offer valuable information regarding the required level of shared understanding, knowledge and collaboration at different traffic incident management scenes. The applicability of cognitive work analysis for traffic incident management was tested here using two of the five phases of Cognitive Work Analysis – WDA and StA. Decision makers from Queensland Police Service, Queensland Fire and Emergency Services and Royal Automotive Club Queensland’s Traffic Response Unit participated in a group exercise using a challenging incident scenario. Their results were analysed using modified forms of WDA and StA. It was anticipated that Cognitive Work Analysis may effectively determine collaboration points and offer insights to improve intra and inter-agency coordination, collaboration and interoperability for emergency responder agencies at traffic incidents.

METHOD

Participants

Participation in the group exercise was semi-selective in that stakeholders were requested to nominate senior decision makers for their agencies to participate. The group exercise of the desktop exercise included five participants - a senior traffic response officer), the officer in charge of the forensic crash unit for the Queensland Police Service, two Queensland Fire and Emergency Services inspectors and one Queensland Fire and Emergency Services assistant commissioner. The level of experience of the officers ranged from 15 years to 32 years with an average of just over 25 years’ experience (Mean = 25.8 years S.D. = 5.9) in the area of traffic incident management/emergency response.

Procedure
A Critical Decision Method interview procedure was altered to suit a group environment. The procedure was chosen as it aligned with and built upon a previous cognitive engineering study conducted by the authors (Cattermole, Horberry & Hassall, 2016). Participants were sent an incident scenario and map of the incident location two days prior to the interview and asked to consider their agency’s response to the given incident.

Participants attended interviews at the University of Queensland in a closed meeting room with access to a whiteboard. The interviews were conducted by a single interviewer (VC) who had considerable experience working in police and traffic incident environments. All interviewees gave informed consent to be interviewed and for interviews to be audio-recorded. The interview process took 3.5 hours.

A modification of the classic Critical Decision Method approach (from Klein, Calderwood & Macgregor, 1998), was utilised, applying four ‘sweeps’ of the incident. In Critical Decision Method, sweeps are described as:

- **Sweep 1: Incident identification**: The facilitator read through the incident details from beginning to end and then prompted each agency to begin with a description of what would happen from their agency’s point of view, from beginning to end of the incident. Responders were encouraged to interject when they considered their agency would take over functions or collaborate.

  Once the group finished, the interviewer retold the incident to the participants and wrote the details onto a whiteboard. At the end of this sweep, the interviewer and participants had a ‘shared view’ of the incident.

- **Sweep 2: Timeline verification and decision point identification**: The interviewer again retold the incident, encouraging the participants to organise the incident around a likely timeline. The interviewer then identified points where decisions would be made and actions taken. These ‘decision points’ formed the focus of the final two sweeps.

- **Sweep 3: Deep Probes** – Probe questions were used to focus the participant on particular aspects of the cognitive processes and context behind the hypothetical decisions made by
the experts at the incident. The questions included cue usage, prior knowledge, goals, expectations and options.

- **Sweep 4: Hypotheticals – What if…?** In the final sweep the participant was asked to shift their perspective to alternative views and outcomes. What if you were a novice in this situation? What if some particular aspect of the incident scene was different? This section examined the possibilities and consequences of other options, errors, and also extended the interviewer’s understanding of the activation points for expert decisions.

**Desktop Exercise**

The hypothetical incident scenario was set in Logan, South East Queensland, and based on a major incident on the Sydney F3 Sydney to Newcastle Freeway on 12 April 2010:

![Map of the incident area provided to participants at the exercise](image)

**Figure 1.** Map of the incident area provided to participants at the exercise

*At 1.45pm on the Thursday before Easter, a small truck travelling southbound carrying ‘canisters’ swerved erratically into the path of a B-double tanker carrying diesel fuel also travelling southbound on the Pacific Motorway just before the Logan River Bridge.*
The tanker swerved right to try and avoid the truck, clipped the back of the truck sending it towards the off-ramp at which point it rolled.

After skidding for a considerable distance, the B-double rolled onto its side blocking the southbound carriageway. The smaller truck rolled spilling its contents across an off-ramp. (Further details outlined specifics within traffic conditions, weather and other factors complicating the scene further)

The Cognitive Work Analysis consisted of:

• A model and description of the workflow at the scene.
• Modified WDA – including a work domain model, responsibility maps and collaboration tables.
• A hypothetical operational StA –to highlight to usefulness of the tool for traffic incident management an example was used comparing HAZMAT incidents to non-HAZMAT incidents to showcase the tool used for analysing operational strategies. Note: HAZMAT incidents are incidents where hazardous materials are present at the scene.

RESULTS

The participants identified the likely workflow for the scenario, depicted in Figure 2 (below). The workflow diagram outlines the scenario. Different roles and responsibilities are shown along the vertical axis and the horizontal axis shows the work progress over time
Figure 2. Workflow diagram of the hypothetical incident

Work Domain Analysis

Figure 3 (below) depicts the basic work domain model for the traffic incident scenario being analysed. Once developed, the model was subsequently verified by a subject matter expert. The five levels of abstraction are: functional purpose, abstract function, generalised function, physical function and physical form.
At the functional purpose level, the abstraction hierarchy corresponds to work domain purposes. Seven functions were identified for traffic incident management at this incident at the functional purpose level: initial assessment, emergency response, accident assessment, rescue operation, incident management, investigation, clearance and road assessment.

The abstract-function level relates to the values, priorities and principles of the teams at the incident. Eight processes were identified at this level: accurate incident assessment, timely response by appropriate groups, safe, effective and quick accident assessment, appropriate resources for timely rescue, safe and appropriate diversions minimising congestion, specialist teams arrive at appropriate times, effective investigations, quick clearance and road operational. The links between the abstract function level and the functional purpose level establish the why-how relation between the purposes of the work and the values and priorities.

**Figure 3. Work domain model for the incident**
Ten processes describe the generalised-function level of the work domain model. These are visual assessment, required information obtained, required crews at the site, consulting, incident command post managing operation, rescue conducted, traffic diverted, specialist teams operating, investigations conducted, and road cleared and assessed. This level identifies the main work processes at the incident and the links between generalised-function level and the abstract-function level identify the work domain processes that meet the values and priorities of the organisations at the scene.

The physical-function level identifies the physical work-domain resources. The eight resources identified were CCTV, witnesses, communication teams, policy teams, general responders, specialist teams, casualties and motorists. Links between this level and the generalised-function level identify the work-domain resources.

At the physical-form level the physical characteristics of work-domain resources are listed. The eight identified areas were computer screens and Traffic Management Centre screens, incident records (kept by each agency), procedural handbook (for each agency), policies, regulations and legislation (for each agency and overarching), responder placement (where, when, availability), responder equipment (time to use, type, location, availability), investigation records (Scenes of Crime, Forensic Crash Unit, coroner’s report, Environmental Protection Agency report, road assessment) and other equipment (for groups such as: environmental teams, local government, road assessors, tow truck operators). The links between physical-form and physical-function levels identify the attributes of work-domain resources.

The regular WDA identifies work-domain purpose, values, work processes, and the physical elements of the work domain. However, it does not identify shared values or work processes. To better understand the responsibilities for each agency, responsibility maps were developed. The maps were separated according to the seven functional purposes identified for the incident. Two responsibility maps are given as examples in this paper. In figure 4 (below), shared elements across all agencies for the purpose of ‘initial assessment’ include all priorities and generalised functions. Not shared elements are at the physical function and physical form level. Because higher level elements of this functional purpose are shared across all agencies, it is expected that inter-agency teams would work well together for this element. Given this information, it is interesting to note that initial assessments are conducted by each individual agency separately.
Figure 4. Responsibility map for initial assessment of the incident

In comparison to Figure 4, the responsibility map for the ‘emergency response’ function (see Figure 5 below) depicts not shared elements at all levels below the functional purpose. Where priorities differ, conflicts and counterproductive actions can occur. Differences at the process level relate to conducting the rescue and traffic diversion and highlight areas that can remain more intra-agency focused. The high level of shared elements at the lower level of this map highlight the need to ensure that boundary objects are designed to be compatible with needs and purposes of multiple operators for effective emergency response.
Collaboration Tables

To understand and analyse shared and individual purpose, values, processes, boundary objects, team structures and interactions in an intra as well as inter agency context, the next step was to build collaboration tables. These were divided into four levels – functional purpose, abstract function, generalised function and physical function. This paper will outline the collaboration table for the abstract function level only.

A collaboration table at the abstract-function level outlines shared/not shared values, principles and priorities. Table 1 (below) identifies that all communication teams across the agencies share priorities of accurately assessing the incident and facilitating timely response by the appropriate
responders. However, only Queensland Fire and Emergency Services and Queensland Ambulance Service communication teams are concerned about providing resources for a timely rescue and casualty treatment, only Queensland Police Service and Queensland Fire and Emergency Services communication teams are concerned about specialist teams arriving at appropriate times and the Brisbane Metro Traffic Management Centre (BMTMC) is the only communications team focused on safe and appropriate diversions minimising congestion, quick clearance and getting the road operational. All the responder agencies except Queensland Ambulance Service are concerned about providing safe, effective and quick accident assessment. The separation of responder agencies into inner cordon roles and outer cordon roles is evident in this table as Queensland Fire and Emergency Services and Queensland Ambulance Service prioritise providing appropriate resources for a timely rescue and casualty treatment, whereas Queensland Police Service and Traffic Response Unit focus on providing safe and appropriate diversions minimising congestion.

Queensland Police Service often play an individual agency role in conducting investigations at the scene, but due to the extensive nature of the incident, in this scenario they would be assisted by specialist teams from Queensland Police Service (for example: Forensic Crash Unit, Scenes of Crime), Queensland Fire and Emergency Services (for example: scientific unit), and other specialist teams (for example: Environmental Protection Agency, coroner). Teams sharing the priority to quickly clear the incident and make the road operational are the BMTMC, Queensland Police Service, Traffic Response Unit, tow truck companies and Queensland’s Department of Transport and Main Roads.
Table 1 Traffic incident management collaboration table at the abstract-function level

<table>
<thead>
<tr>
<th>Abstract Function</th>
<th>QPS Communications Teams</th>
<th>QFES Communications team</th>
<th>QAS Communications team</th>
<th>BMIMC</th>
<th>QPS</th>
<th>QFES</th>
<th>QAS</th>
<th>TRU</th>
<th>Specialist teams QPS</th>
<th>Specialist teams QFES</th>
<th>Specialist teams (other)</th>
<th>Tow Trucks</th>
<th>DTMR/Road assessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate incident assessment</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>Timely response by appropriate groups</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>Safe, effective, quick accident assessment</td>
<td></td>
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<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Appropriate resources for timely rescue and casualty treatment</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Specialist teams arrive at appropriate times</td>
<td>X</td>
<td>X</td>
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<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td></td>
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<tr>
<td>Safe and appropriate diversions minimising congestion</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Effective investigation</td>
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<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Quick clearance and road operational</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
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</tbody>
</table>

Team Strategies Analysis

In team strategies analysis, how tasks are performed at incidents is investigated across four categories: operational, coordination, team development and structural strategies. Due to the hypothetical nature of the current scenario it was impossible to investigate team strategy analysis in detail, however the analysis would be useful for traffic incident management training and policy development as it can identify team structures and interaction patterns under different circumstances. An example situation has therefore been identified for an operational strategy to test the suitability of team strategies analysis for traffic incident management.
In Figure 7 (below) the operational strategy for normal visual assessments by responder agencies is compared with the operational strategy for incidents where there is HAZMAT (i.e. an incident involving hazardous materials).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Team Function: Visual Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team structure</td>
<td>Resource access</td>
</tr>
<tr>
<td>HAZMAT</td>
<td>QFES</td>
</tr>
<tr>
<td>NORMAL</td>
<td>QFES</td>
</tr>
</tbody>
</table>

Information flow map:

- Start: Normal
- HAZMAT:
  - QFES: Identify points to communicate to firecomm & organise team to conduct tasks
  - QPS: Identify points to communicate to QPS comms & organise team to conduct tasks
  - QAS: Identify main points and communicate to QAS comms & begin treatment
  - TRU: Identify main points to communicate to BMTMC & begin tasks
  - Take incident command. Communicate with all agencies and Firecomm as required by guidelines for HAZMAT

- Liaise with other agencies as required
- End

**Figure 7. Operational strategies table for visual assessment at traffic incident**

**DISCUSSION**

This study examined the applicability of cognitive work analysis for traffic incident management using two of the five phases of cognitive work analysis – WDA and StA. Cognitive Work Analysis effectively determined intra and inter agency collaboration points and coordination requirements.
The findings support and build upon the previous study conducted by the authors (Cattermole, Horberry & Hassall, 2016).

WDA was conducted in the first part of the analysis. The purpose of this section was to identify shared/not shared purposes, values, priorities and principles. The analysis found that the initial assessment of incidents is conducted by communications teams for each agency. All teams shared function, priorities and purpose for this part of traffic incident management, indicating that team collaboration and coordination should be high. It is notable that this function is carried out separately by all agencies.

The emergency response function is again carried out by all responder agencies but some have different priorities and processes in their response. This indicates that these should be areas of focus to increase understanding across agencies regarding differences of purpose and priorities.

It was also identified that the agencies share many of the same boundary objects in order to achieve their tasks. Shared boundary objects need to be adaptable to all traffic incident management requirements and seamless across agencies. For example, policies written for one agency should not impede the work of other agencies working in the traffic incident management environment. Consideration needs to be given to the adaptability of all boundary objects across the traffic incident management environment.

Overall, the WDA section of the analysis identified shared aspects of the incident and highlighted aspects of the scene that required coordination as well as identifying scene tasks that were individual functions of agencies. This information is useful in determining focus of effort for inter-agency coordination. As an example, the responsibility map for the ‘emergency response’ function outlined that all agencies conducted emergency response, but that their priorities were not necessarily aligned. It is important for optimal interagency coordination that responders from each agency understand the priorities of other agencies so they can ensure they don’t impede the work of other responders and to improve inter-agency understanding at the scene. This issue can be exacerbated at incidents where specialist groups from agencies are required at the scene as responders from other agencies may not have had exposure to them. A recommendation from this study would therefore be to review agency training to include inter-agency roles and priorities at the scene and/or consider developing inter-agency training packages.
Team StA used an example to showcase the usability of the analysis for traffic incident management. Operational strategies for a normal incident versus a HAZMAT incident were quite different. The HAZMAT incident was far more streamlined. This type of analysis would be useful in the traffic incident management environment to map real versus ideal operational strategies of incidents. For example, the participants in this exercise identified that the rules for HAZMAT coordination are strictly followed in the urban environment but less so in the regional/rural environment, largely due to the reduced resources and officer experience in regional/rural areas. This analysis could be used to verify the comments of the group and also to identify if any of the incident outcomes differ as a result of differences.

Limitations in this study include the fact that the scenario was a desktop exercise rather than a real environment. It is possible that processes identified in an office would not occur in real incident situations. The team coordination and collaboration requirements identified for the incident might be specific to the incident rather than generalised. The group were all officers from an urban centre. Differences between urban and regional/rural responses were discussed in the exercise and it is likely the analysis could not be generalised to regional/rural incidents.

Nevertheless, the potential of team Cognitive Work Analysis as a tool to analyse the traffic incident management environment is evident. Cognitive Work Analysis in this exercise clearly identified the overlap and temporal variation of agency responsibilities at traffic incident scenes and sub-optimal inter-agency coordination. Future analyses could conduct studies interviewing decision makers from attending agencies at real incidents, in urban, regional and rural environments. Information from this type of analysis would inform optimal processes and practices in the traffic incident management environment.

References


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