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A Framework for Qualitative Transportation Management Plan Assessment using Cognitive Task Analysis Methods

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A Framework for Qualitative Transportation Management Plan Assessment using Cognitive Task Analysis Methods

by

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Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 2014

Acknowledgements

First and foremost, I would like to thank Dr. William O'Brien for giving me the opportunity to work with him over the last two years on very interesting and exciting research problems. I have been fortunate to have his valuable guidance on academic and research matters alike. His encouragement motivated me to increase the breadth and depth of my knowledge.

I would also like to thank Dr. John Borcherding for agreeing to serve on my Masters Thesis Committee and providing his valuable comments on this thesis.

This thesis could not have been written without the assistance of Kristopher Pruner and Yetendra Jangid. I thank both of them for their patience in answering my questions on traffic planning and TMP strategies. The information they provided has been key to the conclusions in this thesis.

There are many individuals whose acquaintance over the last two years has enriched me in many ways. In particular, I would like to thank Yoganand Mandali for his support and guidance and Bharathwaj Sankaran for his keen research insights and support. Their hard work has been quite an inspiration indeed.

Last, but not least, I would like to thank Nabeel Khwaja for giving me the opportunity to work with CTR on interesting and more importantly, impactful research projects.

Abstract

A Framework for Qualitative Transportation Management Plan Assessment using Cognitive Task Analysis Methods

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The University of Texas at Austin, 2014

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Increasingly, highway transportation projects are tending to involve maintenance and rehabilitation work. The age and the condition of the transportation asset, in addition to funding constraints have been the key drivers of this trend. This implies that construction operations take place in the presence of traffic flows, leading to the creation of construction work zones. This has safety implications for the commuters and construction workers alike. In addition, construction operations also hamper mobility through the work zone. Effective management of the work zone is thus very important from the perspective of construction and mobility. The preferred and mandated method to manage the impacts of the work zone is the Transportation Management Plan, which prescribes a set of coordinated strategies for the same. The strategies used in a TMP range from enforcing lane closures to modifying the construction sequencing. As the choice of particular strategies or a combination of those affects the work zone, assessing TMP strategies is important to inform future decisions. This thesis proposes a framework for the qualitative assessment of TMP strategies and TMP processes using cognitive task analysis methods. The application of the proposed method is demonstrated through two case studies of large highway reconstruction projects, involving significant bridge reconstruction. The knowledge elicitation techniques are discussed and the obtained knowledge is represented using different knowledge representation structures. The benefits and the applicability of CTA methods are explored through the case studies of projects using different contracting strategies. Finally, recommendations are made for the design of decision support tools, based on the insights obtained through the analysis.

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List of Acronyms

CTA	Cognitive Task Analysis
DOT	Department of Transportation
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
MUTCD	Manual on the Uniform Traffic Control Devices
NHWZP	National Highway Work Zone Program
PI	Public Information
ROW	Right Of Way
STA	State Transportation Agency
TxDOT	Texas Department of Transportation
TMP	Transportation Management Plans
TTC	Temporary Traffic Control
TO	Transportation Operations
VPH	Vehicles Per Hour

Chapter 1: Introduction

Increasingly, highway infrastructure projects in the United States are tending to involve highway reconstruction/rehabilitation components. This trend is being driven by the age of the structure and deterioration in condition due to increasing traffic volumes. Another key factor is funding, as budget cuts have forced decision makers at DOTs to prioritize between new construction and rehabilitation of the existing asset before further deterioration occurs.

Highway reconstruction implies that construction often takes place in the presence of traffic flows, leading to the creation of construction work zones, defined as segments of roadways with “reduced lane widths, lane shifts and varying pavement surfaces” (Huebschman, et al, 2003). Due to the presence of traffic, there are safety issues to be considered for both motorists and construction workers alike. In addition, mobility considerations also have an impact on construction schedules and staging requirements in the work zone area. Thus, the construction work zone is characterized by multiple interdependent objectives of maintaining mobility, ensuring minimal disruption to construction schedules and ensuring the safety of construction workers and motorists.

Since 2004, the Transportation Management Plan (TMP) has been the preferred and mandated method to manage these objectives. According to the FHWA, (Jeannotte and Chandra, 2005, pg. 1-1)

> “A TMP lays out a set of coordinated transportation strategies and describes how they will be used to manage the work zone impacts of a road project.”

The strategies used in a TMP span different functional areas such as construction, traffic operations, maintenance and public information. Given that each project has its own unique challenges, choosing TMP strategies places significant cognitive demands on the practitioners involved in its development – an aspect that has largely been overlooked in existing literature.

This thesis aims to understand and analyze the cognitive demands placed on practitioners involved in the TMP development process through a combination of cognitive task analysis (CTA) methods. Cognitive Task Analysis is a set of methods that seek to understand why and how expert practitioners make decisions, with a focus on the information requirements and the sequence of tasks followed.

READERS GUIDE

This thesis consists of six chapters. The first chapter, i.e., the current chapter, provides an introduction to the research topic.

The second chapter provides an overview of TMP strategies with a concise introduction to the TMP development process and the different strategies used for managing the work zone impacts. An overview of the importance of TMPs to project performance is presented and existing research gaps are detailed.

The third chapter provides an introduction to the field of CTA with a discussion on the three stages of a CTA and the different methods involved in each stage. CTA studies in construction are also briefly discussed.

The fourth chapter recapitulates the gaps in existing literature, details the problem statement and outlines the proposed methodology to address the issues in the problem statement. The methodology and interview protocols developed for performing the CTA processes are described. Additionally, the scope of the proposed methodology is defined, with an explanation of the constraints of the method.

Chapter 5 presents the results and the analysis of the CTA methods. Relevant background information about the construction projects being studied is provided. The first construction project, the Dallas Horseshoe Project, concerns the development of the traffic control requirements and the monitoring of the TMP. The second construction project concerns the application of TMP strategies to the San Francisco - Oakland Bay Bridge rehabilitation project in California.

Chapter 6 provides the conclusion to the thesis, summarizing the results with concrete recommendations for further work.

Chapter 2: Literature Review

This chapter aims to provide a concise introduction to Transportation Management Plans. The history of TMPs is discussed, with the potential components of a TMP outlined. The TMP strategies of different state DOTs are discussed. In addition, literature pertaining to assessment of TMP strategies is also detailed.

BACKGROUND

The Federal Highway Authority (FHWA), in 2004, published updates to the rules concerning work zone safety on highway construction sites. In the update, the FHWA laid emphasis on the need to develop strategies for transportation management with a view towards safety and traffic control (23 CFR Part 630). The focus of the Rule is on providing "overall flexibility, scalability, and adaptability of the provisions, so as to customize the application of the regulations according to the needs of individual agency" (23 CFR Part 630).

Prior to the updates in the rule, the FHWA had established the National Highway Work Zone Safety Program (NHWZP), per the requirements in the Intermodal Surface Transportation Efficiency Act of 1991 (23 CFR Part 630). Through this update, the use of Transportation Management Plans was mandated on all highway projects receiving federal funding.

Prior to the update, agencies were required to use TCPs for managing the traffic flow around highway construction work zones. The updated rule required agencies to implement TMPs, which include, but are not restricted to TCPs. The number of components of a TMP can depend on the work zone impacts of the project (Jeannotte and Chandra, FHWA, 2005).

TMP DEFINITION

The Transportation Management Plan is a document that "lays down a set of coordinated transportation strategies and describes how they will be used to manage the work zone impacts of a road project" (Jeannotte and Chandra, pg. 1-1, 2005).

In order to understand the various components of a TMP, a discussion on the work zone impacts of a highway construction project is needed.

In the context of a highway construction process, the impacts of the work zone are primarily on safety and mobility. Safety impacts concern the safety of the motorists using the highway, as well as the construction workers in the work zone. Mobility impacts are those that reduce the ability of the motorist to travel through the work zone in a reasonable period of time and at satisfactory cost (Crawford, et al, 2011). Thus, managing the work zone involves, but is not restricted to, ensuring the safety of the entities using and working in the work zone and ensuring the performance of the highway to the satisfaction of road users. Additional entities impacted by construction work zones include businesses and communities that are located near the work zone or whose access requirements the construction work zones impinge upon. Considering the number and types of stakeholders impacted by the construction process, there is a need for a set of strategies that are coordinated, in order to best manage the work zone impacts.

TMP LITERATURE

Following the publication of the updated Rule, the FHWA published a series of technical reports, with the intent of providing guidance to State Transportation Agencies (STAs) regarding the development and implementation of TMPs. The following table, Table 2.1, lists the reports.

Title	Publication Year	Key features
Implementing the Rule on Work Zone Safety and Mobility	Sep 2005	This report provides a high level introduction to the TMP development process and strategies.
Work Zone Public Information and Outreach Strategies	Nov 2005	Provides information and guidance on public information campaigns for work zones.
Developing and Implementing Transportation Management Plans for Work Zones	Dec 2005	Provides a general overview and guidance to the development process of TMPs.
Work Zone Impacts Assessment: An Approach to Assess and Manage Work Zone Safety and Mobility Impacts of Road Projects	Aug 2006	This report provides general guidance to state DOTs on assessing the work zone impacts of construction projects.

Table 2.1 FHWA literature on Transportation Management Plans guidelines.

A Short Overview of the TMP Development Process

This section briefly describes the general development process of a TMP, with respect to different stages in the project delivery process – Planning, Design and Construction.

The development and consideration of TMPs begins in the Planning stage of a construction project. At this stage, information from various sources is compiled; typically, the information regarding the existing conditions, average daily traffic volumes, roadway conditions and relevant stakeholders is obtained. The information available at this stage is usually incomplete as the design process is not yet complete. Therefore, assessments of different construction strategies are largely preliminary and qualitative in nature.

The next stage in the TMP development process is developing the construction staging and phasing plans. Typically, according to the FHWA (Jeannotte and Chandra, 2005), the engineers develop the construction phasing plans which is then followed by a TTC plan. However, the FHWA recommends that inputs from the TTC should be used in the development of the staging and phasing plans.

After the TMP is finalized, the work zone impacts are monitored and compliance of the contractor's staging plans are checked against the requirements in the TMP. The FHWA (Jeannotte and Chandra, 2005) recommends that provisions for monitoring and assessing the TMP be included in the contract before the construction phase, rather than monitoring after the fact.

TMP STRATEGIES

The following discussion on the different TMP strategies is based on a review of the TMP guidelines published in the above reports, specifically the report by Jeannotte and Chandra (2005).

TMP strategies can be divided into three general categories based on the functional area (Ref. Fig. 2.1):

1. Temporary Traffic Control
2. Transportation Operations
3. Public Information

Not all TMPs have the above components. For projects deemed to have a significant impact, all three components are required. Projects having minor impacts must have the Temporary Traffic Control Plan, with the other two components being optional. The Rule provides the STAs flexibility in determining the criteria to judge whether a project has minor or major impacts. Consequently, different STAs have developed different methodologies; for instance, CalTrans designates all projects, which result in a delay greater than 30 minutes as requiring major TMPs (Jeannotte and Chandra, 2005).

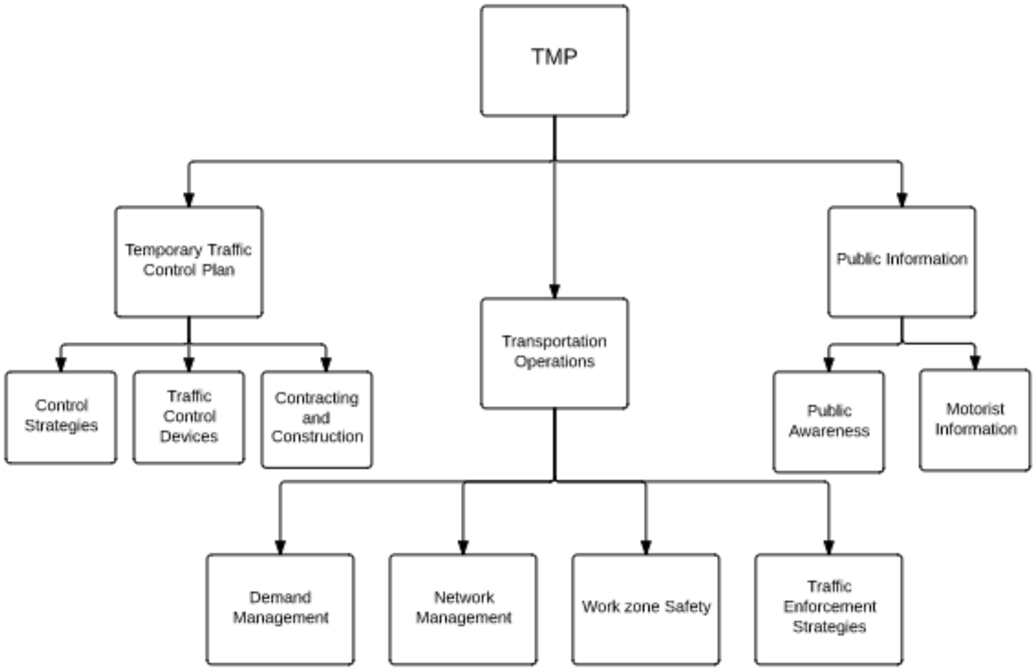

Fig. 2.1 Categories of TMP strategies

Temporary Traffic Control

Temporary Traffic Control (TTC) strategies aim to control the traffic flow in the immediate vicinity of the work zone. Strategies under this category can be further classified into three categories:

a. Control Strategies
b. Traffic Control Devices
c. Contracting and Construction Strategies

There are a number of strategies that fall under Control Strategies. They range from lane closures (full/partial) and ramp closures to meet safety and staging requirements to the provision of one-way lanes and nighttime construction work. Choice of the staging and phasing strategies has implications on the traffic flow through a work zone; for instance, a particular staging strategy may require more space, leading to a higher number of lanes being closed. Similarly, phasing strategies may result in full closures or partial closures, based on the control sections being built.

Traffic Control Devices, as the name implies, are devices that seek to regulate the flow of traffic through the transmission of messages/signals to the road users. Typical traffic control devices include Temporary Signs, Temporary Traffic Signals and Portable Changeable Message Signs. Temporary Signs are used to convey warning messages to road users; PCMS systems, too, serve the same purpose, but with the added advantages of portability and customizability. This makes them effective in communicating a great deal of information as well as informing the motorists of any abrupt changes in the work zone conditions, such as incidents etc.

Project Coordination, contracting and construction strategies deal with the presence of utilities, construction strategies such as the use of precast members and innovative contracting strategies such as A+B bidding etc.

Transportation Operations

The goal of these strategies is to reduce the work zone impacts by managing the transportation network infrastructure. Typical strategies involve demand management, corridor management, and safety management and traffic incident management and enforcement strategies (Jeannotte and Chandra, 2005).

Demand management

Demand management is essentially concerned with the reduction of demand through the work-zone by diverting traffic along alternative routes. This is an important part of TO, as reduced demand results in fewer traffic incidents and increased safety in the construction work zone. Provision of High Occupancy Vehicle (HOV) lanes is a typical strategy, incentivizing car-pooling among the commuters.

Corridor Management

Corridor management strategies focus on managing the transportation network around the construction work zone. Typical strategies include improvements in the intersections around the work-zone through the widening of shoulder lanes and addition of extra lanes.

Safety Management in Work Zone

Speed restrictions on vehicles and the placement of temporary barriers are two of the most common strategies used. Additionally, rumble strips are also placed to alert motorists of changes in the conditions of the roadway.

Public Information (PI)

This is one of the most cost-effective TMP strategies, according to the results obtained from several DOTs (Jeannotte and Chandra, 2005). The goal is to reduce work zone impacts by providing information to the travelling public, which results in increased awareness of work zone conditions as well as reduced demand. The information can be provided in various ways and at different stages in a project. The intended audience for the public information strategies is composed of:

1. Roadway users
2. Community in the area around the work zone
3. Businesses affected by the work zones

Based on the intended audience, the strategies can be classified into:

Public Awareness Strategies

The methods used to communicate range from advertisements in newspapers/media, project websites to maintaining public information centers and holding public meetings.

Motorist Information Strategies

The methods here involve the usage of PCMS and temporary signs to inform the motorists regarding the changes in the construction work zone. The intent is to rapidly disseminate information regarding any abrupt changes in the traffic conditions.

TMP EFFECTS ON PROJECT PERFORMANCE

There are a number of factors that have an impact on the success of a construction project. Indeed, the definition of success on a construction project and the factors that contribute to it has been changing and evolving (Chan, et al, 2004). In a review of seven major construction journals, Chan et al (2004) found that the factors impacting project success can be categorized as the following:

1. Project related factors
2. Procurement related factors
3. Project Management factors
4. Project-Participant related factors
5. External factors

Of particular interest to this thesis are the project participant related factors, such as the decision-making processes in the client organization, the contribution of the client to construction activities and the contribution of the client to design processes. From the discussion in the previous sections, it can be seen that strategies employed by TMP practitioners have an impact on the construction and design of the project. Thus, the choice of a particular strategy or a combination of the strategies can have a direct impact on the success of the project. Additionally, external factors also have a significant impact in the case of highway reconstruction; the concerns of external stakeholders such as businesses and governmental organizations must be taken into account.

Ellis and Thomas (2003) identified Maintenance of Traffic as a root cause of highway construction delays, noting the impact on construction sequencing and constructability. Similarly, Assaf and Hejji (2006) identified "traffic control at job sites" as a factor contributing to the delay of highway construction projects.

Therefore, from a construction engineering and project management perspective, it is important to study the factors that go into choosing different TMP strategies, in order to better understand the project risks, that is, in order to fully understand how the choice of the TMP strategies is made, it is necessary to understand how the experts consider the information available to them.

EFFECTIVENESS OF TMP STRATEGIES

In 2012, the FHWA published a report titled "Assessing the Effectiveness of Transportation Management Plan (TMP) Strategies: Feasibility, Usefulness, and Possible Approaches" (Scriba, et al, 2012). The objective of the report was to identify the different types of assessment approaches for TMP strategies that were being used by DOTs. The motivation behind this report was that, since the update to the Rule, many DOTs have been applying a variety of TMP strategies. However, the report noted that there was an element of uncertainty among practitioners as to the relative effectiveness of the TMP strategies. Moreover, quantifying the benefits of TMP strategies was a complex process as the observed improvements were not readily attributable to one strategy.

As discussed in the previous sections, different DOTs have customized the guidelines in the Rule to suit their objectives and constraints; indeed, this flexibility was provided in the language of the Rule itself. While DOTs have benefited from this flexibility, this has had the effect of differing terminologies, hampering the dissemination of knowledge, with regards to assessment of strategies. Moreover, assessment approaches vary across DOTs. They can be classified as below (Scriba, et al, 2012):

1. Qualitative approaches
2. Quantitative approaches
3. Hybrid approaches

According to the FHWA (2012), quantitative approaches to assessment are preferred. Indeed, as the report states: "Hard numbers provide value to practitioners that subjective opinions of TMP effectiveness lack" (Scriba et al, pg. 20, 2012). However, despite this, qualitative approaches are the most widely used. Qualitative approaches usually involve self-reports by field experts. These are usually carried out during and after the construction (Scriba et al, 2012). Quantitative approaches involve a pre and post construction comparison of relevant metrics such as traffic incidents, delays, queue lengths etc. Hybrid approaches are a combination of both qualitative and quantitative approaches, usually supplementing qualitative data with short-term easy-to-collect quantitative data. The following table, adapted from FHWA (2012) provides a concise comparison of the three approaches.

Approach	Advantages	Disadvantages
Qualitative	Richness of detail	Subjectivity may lead to inaccuracies Hampers ease of comparison across agencies
Quantitative	Provides objectivity and may be statistically analyzed.	Reduced detail: pre and post comparison masks the subtleties of the decision making process Data collection may not be possible or may lead to increased costs.
Hybrid	Combines the best of both worlds – subjectivity and hard numbers	Increased costs; difficult to manage both qualitative and quantitative approaches.

Table 2.2 Comparison of different assessment approaches, adapted from (Scriba et al, 2012)

The survey of practitioners revealed that informal qualitative approaches were more common (Scriba et al, 2012). Another factor in assessing TMP strategies is the scope of the assessment, which can range from full scale evaluation of all strategies on a project to the evaluation of a single TMP strategy to process reviews.

Fundamentally, the intended outcome of the assessment process is to share the received knowledge, both within the project organization and the larger agency. The need for a knowledge sharing mechanism was highlighted as a research gap by FHWA (Scriba, et al 2012). Indeed, experience in choosing TMP strategies is not uniformly distributed across state DOTs; some DOTs like California have more experience in the implementation of TMPs. All State DOTs surveyed by FHWA (Scriba, et al, 2012) requested improved knowledge transfer with respect to TMP strategy evaluation. Thus, based on the above discussion, the following observations can be made:

1. Choices of TMP strategies are made largely based on practitioner experience and experiential knowledge.
2. There is a large amount of variance in the experience level of different DOTs.
3. Communication of TMP processes and strategy choices is necessary for improving future TMPs.
4. Given the dynamic nature of work zones, the choice of a TMP strategy depends in large part on the context and the situation.
5. Qualitative approaches, in the form of self-reports, are currently being used convey the situational context.
6. The subjectivity of qualitative data is a drawback, hampering inter- and intra-agency communication.

Therefore, we state the following research need:

"An effective approach to eliciting and communicating expert information, retaining the contextual information and providing formalism."

The following chapters propose a solution, using the method of cognitive task analysis, to meet this research need.

Chapter 3: The Need for Cognitive Task Analysis

This chapter aims to explain why the technique of CTA has been chosen in this thesis to answer the research question raised in the previous chapter. It provides an introduction to the field of Cognitive Task Analysis (CTA) and describes the stages involved therein. Additionally, a review of existing literature of CTA applications to the field of construction is also performed.

INTRODUCTION

Cognitive Task Analysis is a set of methods that seek to capture the observable behaviors of experts engaged in cognitively challenging tasks as well as the unobservable cognitive processes employed by the expert to successfully complete the task (Chipman, Schraagen, & Shalin, 2000). It can be viewed as an extension of traditional task analysis techniques to encompass the cognitive processes of the expert.

Cognition and Cognitive Aspects

Before CTA techniques are described, it is helpful to understand cognition in greater detail, as well as to understand what aspects of cognition can be identified through a Cognitive Task Analysis.

Cognition is defined as comprising of "the activities of thinking, understanding, learning and remembering" (Merriam-Webster, 2014). By another definition, due to Hollnagel (2003), cognition is defined as "the ability to maintain control over a system's conditions". According to Crandall et al (2006), in order to understand cognition, one must fully understand the context in which the activity/task happens. The context of a task includes such elements as the purpose of the task, the information needed for the task and experience of the entity performing the task. Table 3.1 lists the complete set of contextual features identified in Crandall, et al (2006).

Features of cognition	
Purpose of the task	Goal of the task
The way prior experience is used	Contrast between expert and novice
Situation features	Information requirements and information availability
Nature of the cognitive challenge	Well defined vs. vague definition of the challenge
Available tools	Existing methods to complete task
Team members	Impact of team members (helpful/distracting)
Organizational constraints	Existing SOPs (Standard Operating Procedures)

Table 3.1 Features of cognition, adapted from Crandall, et al (2006)

CTA methods are typically applied to study individuals engaged in complex tasks, i.e., individuals handling significant cognitive demands to achieve specific outcomes. A characteristic of such tasks is decision making in the presence of multiple interacting and dynamic variables, the choice of a certain combination of which results in success or failure. Additionally, experts often internalize actions and decision-making abilities, which are not readily apparent from observations alone. In such cases, application of CTA methods can help uncover aspects of expertise, which may not be detected by traditional task analysis methods.

Applications of CTA methods

CTA methods have previously been applied to a wide variety of domains, ranging from nuclear power plant operations to air traffic control. Kaempf et al (1994) used a Cognitive Systems Engineering approach to identify the cognitive requirements of baggage screeners at airport security checkpoints. Seamster, et al (1993) performed a cognitive task analysis to understand the decision-making processes and mental models of air traffic controllers. Additionally, expert-novice contrasts were also highlighted.

CTA in construction

Increasingly, CTA methods are also being used in the field of construction engineering. Mondragon Solis (2013) detailed a list of studies utilizing CTA methods in the field of construction engineering. Distefano and O'Brien (2007) performed a comparative analysis of infrastructure assessment tools through the application of Applied Cognitive Task. The subjects in the analysis were soldiers with differing levels of infrastructure expertise. Through the ACTA technique, O'Brien and Distefano found that in contrast to expectation, soldiers preferred a complicated, yet feature-rich interface, as opposed to an easy to use interface. Saurin, et al (2008) examined the processes of safety management for construction workers in the context of Cognitive Systems Engineering (CSE) concepts and showed how improvements could be made to the chosen processes. Specifically, they observed five safety management processes and re-interpreted them in the context of three CSE concepts – flexibility, learning and awareness.

O'Brien, et al (2011) applied cognitive task analysis and an artefact-based analysis to construction superintendents with a view to inform the development of information technology (IT) systems for the purpose of jobsite management. The methodology used was from Potter et al (2002) and was composed of a Functional Abstraction Hierarchy (FAH) and a set of Decision Requirements, Information Requirements and Information Sources tables. Through the CTA, the authors developed representations of the logical inter-relationships between the cognitive tasks undergone by the construction superintendent while managing the jobsite.

Finally, Dissanayake and AbouRizk (2007) showed the application of fuzzy cognitive mapping to a construction scenario and observed that CTA methods could provide a basis for qualitative "what-if" scenarios in construction. In their paper, the authors developed a FCM based modeling methodology to model the performance of construction managers. A challenge identified by the authors was the identification of causal relationships, which could be obtained through knowledge elicitation techniques.

THE APPLICABILITY OF CTA

According to Clark et al (2006), Subject Matter Experts (SMEs) possess knowledge in the form of frameworks of abstract, schema-based representations. This feature of expert knowledge has implications on instructional transfer. Indeed, as Clark et al (2006) note, Hinds, Patterson and Pfeffer (2001) found a key aspect of knowledge transfer from experts to novices. During such knowledge transfer, experts were found to provide more abstract and theoretical explanations, which had insufficient detail and fewer statements. This lack of detail hampered the performance of novices attempting to learn from the experts (Clark, et al, 2006).

Moreover, Feldon and Stowe (2009) showed that experts are frequently inaccurate when describing processes that lie in their domain of expertise. Indeed, during self-reports, experts were found to frequently omit important steps in their accounts (Cooke and Breedin, 1994; Chao and Salvendy, 1994; Feldon and Stowe, 2009). For instance, Chao and Salvendy (1994) found that computer programmers were unable to explain more than 53% of the debugging steps they took while writing code.

Instead, instructional designers are increasingly using CTA methods to elicit knowledge as opposed to self-reports. Indeed, CTA methods perform well when compared against self-reports. Studies have shown that CTA can enhance by 12% the completeness of the information obtained when compared against unguided knowledge elicitation (Feldon and Stowe, 2009). Merrill (2002) compared CTA based instruction to other forms of instruction in the area of spreadsheet use. The other methods used were a direct instruction and discovery learning. It emerged that the participants who had CTA based instruction performed the best.

In a study of weapons engineers in the Royal Netherlands Navy Engineering Service, Schaafstal, et al (2000), found that CTA based training resulted in a significant improvement in the ability to troubleshoot, i.e., perform corrective maintenance tasks. Specifically, the authors found that CTA based training resulted in the technicians solving twice as many problems in lesser time as compared to the typical training method.

Through the literature review in the previous chapter, it emerged that state DOTs are considering or have already implemented self-reports as a part of their qualitative assessment approaches. Based on the above evidence from literature, it is recommended instead, that CTA methods be used. Thus, in order to close the research gap identified in the previous chapter, this thesis aims to use Cognitive Task Analysis techniques.

CTA METHODS AND THE STAGES IN THEIR APPLICATION

There are many CTA methods available in literature. Clark, et al (2006) note that researchers have identified over 100 different CTA methods. According to them, this proliferation in techniques is largely due to the origins of CTA – from military applications and specifying computer interfaces.

While there are a number of CTA methods available, most of them, generally, have a common structure. They are composed of the following stages (Crandall, et al, 2006):

1. Knowledge Elicitation
2. Data Analysis and Knowledge Representation

The stages are described below:

1. Knowledge Elicitation (KE)

As the name implies, this stage of the Cognitive Task Analysis is concerned with the elicitation of knowledge from the expert whose task is being studied. There are a number of methods of Knowledge Elicitation. Cooke (1994) conducted a review of knowledge elicitation techniques and introduced a classification scheme based on the mechanics of the methods. Cooke's analysis divided knowledge elicitation techniques into three categories (Cooke, 1994; Clark, et al, 2006) of Observations, Interviews and Task Analysis. More recently Crandall et al (2006), in their book *Working Minds*, mention a classification scheme adopted from the CTA Resource website (now defunct). The scheme introduced in their book is summarized below.

a. Interview

In this category, knowledge is elicited from the expert through interviews that may range from unstructured to structured. Crandall et al (2006) note that this method is popular among CTA analysts due to the flexibility it offers in terms of different probe questions. Common techniques include Applied Cognitive Task Analysis, Critical Decision Method, Questionnaires, PARI (Precursor, Action, Result, Interpretation) etc.

b. Observations

This category of KE methods includes strategies that rely on observations of the practitioner at work or on simulations. Such methods are typically used for tasks that are process based such as crane operators, air traffic controllers etc.

c. Textual

Textual KE methods rely on analysis of existing documentation and Standard Operating Procedures. Typical techniques include Content Analysis and MORT (Management Oversight Risk Tree) techniques.

2. Data Analysis and Knowledge Representation

The two stages of Data Analysis and Knowledge Representation involve a lot of overlap and are usually discussed together. Indeed, Mondragon Solis (2013) notes that the complexity of the data analysis phase is influenced majorly by the complexity of the Knowledge Representation phase. The input into this phase is the knowledge elicited from the KE phase.

According to Crandall et al (2006), data analysis typically occurs at two levels: at the level of each individual data record and at the higher level of the whole transcript.

They key here is to identify underlying themes in the interview notes that unite the individual data records. The output of unstructured and semi-structured knowledge elicitation methods typically needs to be coded, i.e., individual data records are tagged with the cognitive elements they represent. At a higher level, the analyst makes multiple passes through the data, seeking to uncover common themes in the data product. The outcome of the data analysis procedure is an annotated set of interview notes, which form the input into the Knowledge Representation phase.

The Knowledge Representation phase involves the representation of the analysis in different formats – graphical, textual and tables. The choice of the Knowledge Representation format depends on the objective of the CTA study and the inclinations of the analyst. Typically, for CTA studies, which seek to provide information for decision support systems, the Knowledge Representation form is of a Data Organizer (Crandall, et al 2006) – a table that usually lists the decision challenges, cognitive challenges and information requirements.

Crandall et al (2006) mention that treating each phase of a CTA as independent of the other, allows the analyst to take advantage of the most appropriate method in each category. As shall be described in the next chapter, different methods have been used for each phase of the CTA in this thesis.

Chapter 4. Research Methodology

This chapter brings together the two themes of TMP strategy assessment and Cognitive Task Analysis methods and explains why and how CTA is used in this thesis to answer the research questions. Specifically, this chapter details the framework developed to perform a cognitive task analysis of TMP practitioners. The protocols developed for semi-structured interviews are described and the methods of analysis and knowledge representation are discussed.

PROBLEM STATEMENT

In Chapter 2, the gaps in existing research were identified. The specific research need highlighted was the need for an assessment methodology that retained the contextual knowledge and detail of a qualitative approach and provided an efficient way to transfer knowledge across and within organizations.

Based on the analysis of existing literature, it is evident that while there exist many resources for developing and implementing TMP, the TMP strategy information consists of high-level descriptions and is largely general in nature (Scriba, et al, 2012). Moreover, it was found that TMP practitioners rely mostly on experiential knowledge to make decisions regarding the choice of TMP strategies. Therefore, in order to gain insight into the choice of TMP strategies, an understanding of how experts make decisions and judgments is important, that is, it is important to understand the *cognitive* demands placed on TMP practitioners. This insight into the decision making that TMP practitioners employ is largely unavailable in current literature.

Chapter 3 gave an overview of CTA methods and described existing literature that provides a comparison of CTA methods and unguided qualitative assessments, such as self-reports.

Thus, given that the focus is on the cognitive demands of practitioners, this thesis proposes to use Cognitive Task Analysis methods to better understand how experts involved in TMP development made decisions on past projects. Through a retrospective analysis of two major construction projects involving traffic planning, a demonstration of guided knowledge elicitation techniques and the associated knowledge representations shall be made.

STAGES OF COGNITIVE TASK ANALYSIS

As discussed in Chapter 3, CTA methods are composed of three stages:

i. Knowledge Elicitation

ii. Data Analysis

iii. Knowledge Representation

Choice of Knowledge Elicitation Methods

As described in Chapter 3, there are multitudes of methods available for conducting Cognitive Task Analysis. In order to choose particular methods, the author followed the classification made by Crandall et al, (2006), which classifies CTA methods on two criteria:

1. The type of data collection mechanism
2. The area of focus of a particular method

It must be noted that these two dimensions are used for classifying knowledge elicitation techniques; as discussed in the previous chapter, the three stages of CTA have been treated as independent of each other, allowing for greater flexibility.

Data Collection Mechanism

There are a wide variety of data collection techniques in CTA; the one used in this thesis is the interview, specifically, a series of semi-structured interviews. The interview method is among the most widely used methods in CTA methods as it is efficient and avoids logistical issues related to observations. (Crandall, et al, 2006). Also, given the retrospective nature of the analysis, it was not possible to conduct field observations. Finally, due to project confidentiality concerns, an analysis of reports of project data was also ruled out.

Area of Focus

The second criterion (or set of criteria) concerned where to look for the data, i.e., here we are concerned with the attributes of the data itself. The major criteria here are time, realism, generality and difficulty.

As discussed before, with regards to time, the data is located in the past. In terms of realism, the data is a real-world scenario as opposed to a simulation. In terms of generality, there are two levels of the data –

i. Specific incident

ii. Task

In the current analysis, it was noticed that while TMP development can be categorized as a task, a significant portion of the decisions made by practitioners also involved responding to changes in the TMP driven by unforeseen design/traffic conditions. Thus, there was much to be learnt from examining how practitioners respond to specific events, in addition to an examination of the overall sub-tasks.

Finally, in terms of difficulty too, there were two levels at which the data was observed to lie – routine events and challenging events. Here, how "routine" or challenging an event is, is measured by the impact the event has on the schedule and the overall lane closure strategy.

The different data target levels are shown in the following diagram:

Time	Past	Present	Future
	✔		
Realism	Real World	Simulation	Both
	✔		
Difficulty	Routine	Challenging	Anomalies
	✔	✔	
Generality	Abstract	Task	Incident
		✔	✔

Table 4.1 Classification of Data Target

Based on the above classification, two CTA methods were chosen for the first stage of knowledge elicitation:

1. Applied Cognitive Task Analysis
2. Critical Decision Method

The two CTA methods are described below:

Applied Cognitive Task Analysis

The Applied Cognitive Task Analysis (ACTA) (Militello and Hutton, 1998) is a streamlined CTA method that focuses on how experts accomplish certain tasks. The method involves three stages:

1. Task Diagram – In this stage, the interviewee is asked to decompose the task into sub-tasks, typically between three and six in number. The aim of this step is to achieve a high level understanding of the task and to zero-in on decision points.
2. Knowledge Audit – In this stage, the interviewee is asked about concrete examples in the job context. The aim is to obtain an inventory of task specific expertise.
3. Simulation Interview – In this stage, the interviewee is shown a training scenario and asked to identify major events. The intent is to probe the expert's assessment and critical cues.

The outcome of ACTA is a Cognitive Demands Table, which synthesizes the information obtained from the three tables. It identifies difficult cognitive elements and the cues and strategies used to address the issues.

Critical Decision Method

The Critical Decision Method is an incident based CTA method that seeks to uncover knowledge through probing an expert about difficult situations faced on the job. Based on the approach highlighted in Crandall and Klein (2006), a CDM was conducted by making four "sweeps" over the identified incident. The phases are as follows:

1. Incident Identification – This phase or sweep is concerned with the identification of a relevant incident to be studied in detail. The interviewee is asked to provide a general description of the incident.
2. Timeline Verification – The aim of this phase is to get a refined overview of the incident with key events in the incident process identified. The focus on the exact timeline is not too relevant in the case of TMP development; rather it is the sequence in which the events occurred that is more important.
3. Deepening – This phase is the most crucial of the three phases as the attempt here is to understand the cues that led the expert to make a particular decision. This phase results in an understanding of the interviewee's experience, skills and knowledge.
4. "What If" queries – In this phase, the interviewer performs a sweep of the entire incident, asking the interviewee how the decisions would have differed had some aspects of the incident changed. The intent here is to understand the contrasts between experts and novices and identifying if technological aids would have helped.

Modifications to the CTA methods

The current research problem is characterized by the following constraints:

1. Little expert base
2. Little availability of experts for extended interviews
3. Interviewer inexperience

4. Project confidentiality concerns

In light of these constraints, some modifications were made to the above two methods. Given the data driven nature of TMP decision-making, it was not possible to perform a simulation interview with a detailed example. Instead, "what-if" queries regarding past incidents were posed to the expert. The objective here was to elicit information about expert behavior in different conditions, thus approximating a simulation interview.

Concerns regarding validity of the ACTA were answered by the fact that the Knowledge Audit step is itself regarded as a CTA technique in its own right. Indeed, Hoffman, Coffey and Ford (2000) regard the Knowledge Audit as a shortened CDM (Crandall et al, 2006). Therefore, the current modification is still valid as a CTA technique. In addition, Simoes and Fonseca (2009) had demonstrated the use of a modified ACTA technique with the Simulation Interview phase removed.

More generally, Crandall et al (2006) note that there is no rigid definition of a CTA technique, nor are there prescription for their combinations. Indeed, Mondragon Solis (2013, pg. 36 2006), states, "it is up to the analyst to gather the necessary information, through any practical means, in order to complete the process of analysis." The value in identifying the two interview based techniques lies in the probe questions that each prescribes, which enhance the effectiveness of knowledge elicitation.

Having identified the two techniques to be combined, probes and questionnaires for the semi-structured interviews were prepared based on guidelines in literature. The major resources used for developing the probe questions were Millitelo and Hutton (1998), Crandall, et al (2006). The probe questions are included in the Appendix.

It is stressed that the probe questions included in the Appendix is not the complete set of questions asked; indeed, one advantage of a semi-structured interview is the flexibility of modifying future questions based on the answers to the previous questions.

Data Analysis and Knowledge Representation

Using the interview product obtained from the Knowledge Elicitation phase, an analysis was made and the results were represented in the form of:

1. Narrative content
2. Decision Requirements, Information Requirements and Information Sources
3. Process Diagrams

The narratives were used to provide the contextual information and the DR-IR-IS tables were used to provide specificity to the decisions made. The process diagrams showcased the overall process, highlighting cognitive elements wherever relevant.

The overall framework is shown below:

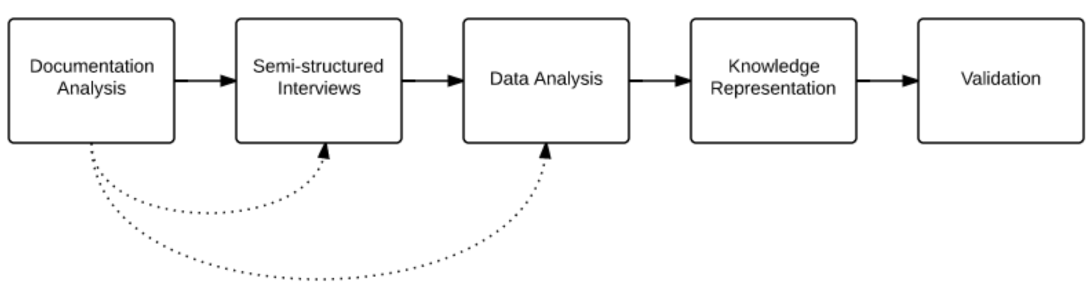

Fig. 4.1 Steps in the framework

SCOPE OF RESEARCH

This thesis is an exploration in the application of CTA techniques to TMP development. As such, to our knowledge, this is the first instance where CTA methods have been applied to practitioners involved in TMP planning. Therefore, one aim of this thesis is to examine whether CTA techniques yield useful information in the context of TMP development processes.

This thesis restricts the scope to analyzing major infrastructure projects; this is done so that projects with major TMPs can be analyzed. Specifically, two major construction projects were analyzed:

1. The Dallas Horseshoe Project in Dallas, Texas.
2. The Bay Bridge Rehabilitation in the Bay Area in California.

The practitioners who have been interviewed are involved in the following areas of TMP development.

1. Developing the traffic control requirements
2. Monitoring the TMP compliance with respect to the Traffic Control Plan
3. Developing construction strategies based on traffic control plans
4. Choosing Public Information (PI) strategies.

Chapter 5 – Data Analysis and Knowledge Representation

This chapter describes the results of the interviews and the analyses thereof. As mentioned in the previous chapter, two subject matter experts (SMEs) were interviewed, each with experience on major construction projects. For the purposes of the interview, the construction projects chosen were based on the most recent major project that the SME had worked on. The SMEs are referred to here as SME1 and SME2 respectively.

Expert	Project	Responsibilities
SME1	Dallas Horseshoe Project	• Developing traffic control requirements, • Monitoring implementation of TMP • Communicating with stakeholders
SME2	San Francisco-Oakland Bay Bridge Project	• Developing construction strategies and staging requirements • Performing constructability analyses • Designing public information strategies • Communicating with stakeholders

Table 5.1 Description of the areas of expertise of each practitioner

Each case study begins with a description of the project, illustration of the project area and relevant issues pertaining to the contract and traffic control constraints.

CASE STUDY 1: THE DALLAS HORSESHOE PROJECT

Description of the Project:

The Dallas Horseshoe Project is a major highway construction project located adjacent to the Central Business District of Dallas, Texas. It is a $800 million effort by the Texas Department of Transportation to reconstruct a series of bridges carrying I-30 and I-35E across the Trinity River (Dallas Horseshoe Project, 2014). It is among the most complex projects undertaken by the Dallas District of TxDOT (Khwaja and Pruner, 2014). A unique feature of this project is that it has been advanced through the Design-Build method, via legislation passed by the Texas State Legislature.

Need for the project

The project area ranks among the 17 most congested freeways in Texas (Dallas Horseshoe, 2014). Due to advanced age, the condition of the existing structures in the project area has deteriorated significantly. Currently, the roadways and bridges, mostly built in the 1960s, serve an estimated 460,000 vehicles on a typical weekday. In addition, two of the freeway-to-freeway movements require the use of a street connection (Khwaja and Pruner, 2014). As such, this is a classic case of an urban freeway reconstruction project.

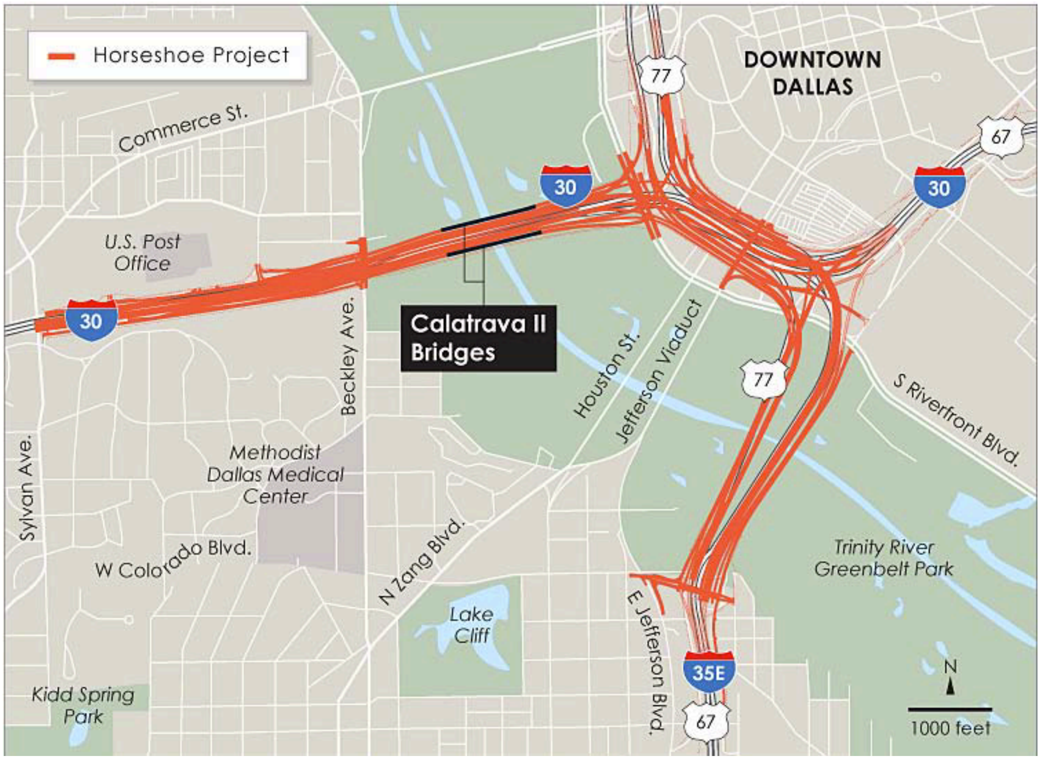

Fig 5.1 Location of the Dallas Horseshoe Project (from the Dallas Horseshoe website)

Fig 5.2. An example of the complex geometry of the Dallas Horseshoe Project (from the Dallas Horseshoe website)

Pegasus Link Constructors (PLC), an entity comprised of two contractors – Fluor Enterprises and Balfour Beatty Infrastructure - is managing the design and construction for this project. Post project completion – scheduled in summer 2017 - the freeways I-30 and I-35E will be widened to a total of 23 lanes. The project includes the expansion and repaving of new bridges and roadways along the two major freeways as well as the construction of two new pedestrian bridges along the IH30 frontage road bridges.

There are many challenges faced in project execution (Khwaja, and Pruner, 2014) such as:

1. Complicated traffic geometry
2. High traffic volumes in the project area
3. Spatial and staging constraints due to the levees of the Trinity River
4. Presence of multiple stakeholders in the project area, with differing levels of access requirements.

Under the specifications of the contract, the responsibility for developing the TMP rests with the contractor (Technical Provisions for the Horseshoe Contact, 2012). Additionally, the contractor must develop detailed traffic control plans (TCPs) in compliance with the Texas Manual on Uniform Traffic Control Devices (TMUTCD), Each TCP must be submitted to TxDOT for review a minimum of fourteen days prior to implementation. The TCP must include details for all detours, traffic control devices, striping and signage applicable to each phase of construction. Section 18 of the technical provisions for the Horseshoe Project also includes the allowable lane and roadway closures.

Data Analysis and Knowledge Representation

The interview process was conducted as described in the previous chapter. The ACTA method was followed by the CDM. Specific probes and questionnaires are as described in Appendix A.

According to SME1, the traffic planning process for the Dallas Horseshoe Project (DHS), at a high level, comprised of the following stages:

1. TxDOT developed the traffic control requirements for the technical provisions during the preliminary engineering phase, before the bid was assigned.
2. After the bidding process was complete, the contractor then began the design process, taking into consideration the constraints and lane closure strategies.
3. TxDOT reviews the design to ensure compliance with the traffic control requirements.
4. Additionally, through coordination meetings, a requirement under the contract, TxDOT and the contractor meet to resolve issues pertaining to changes in the lane closure strategies followed for construction.

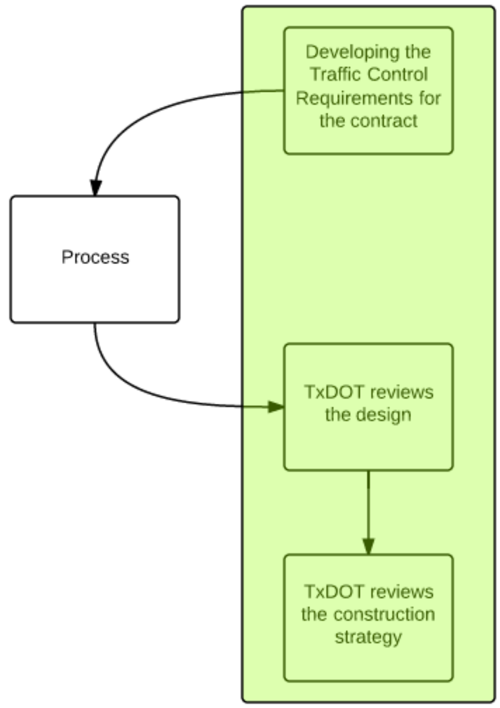

Fig. 5.3 An overall view of the traffic planning process on the DHS project

The stages that SME1 was involved in were Stages 1, 3 and 4, i.e., pertaining to the development of traffic control requirements and monitoring the compliance of the TMP. The relevant stages have been highlighted in green in Fig. 5.3.

Stage 1: Developing traffic control requirements

This phase is composed of two major tasks, which occur sequentially:

1. A qualitative assessment of project conditions
2. Developing the actual traffic control requirements

Task 1: A qualitative assessment of project conditions

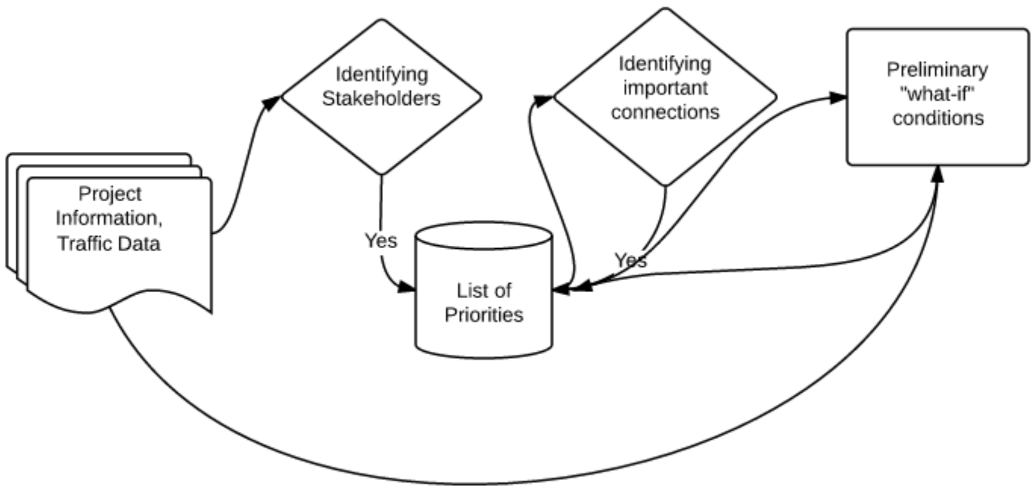

Fig. 5. 4 The decisions and processes in the Qualitative Assessment task

The goal of this task is to assess the project area and identify any obvious concerns. The outcome of this task is a rank-ordered list of priorities such as contacting stakeholders, identifying key connections that needed to remain open, identifying connections that can be closed. The identification of such links was performed over multiple passes over the project area, through preliminary "what-if" methods, i.e., the impact on the network if a particular link with high traffic volumes was closed. Alternative traffic links, in case of closures were identified based on experiential knowledge of the project conditions and traffic volumes. Then, in hypothetical situations, if a particular lane closure strategy was followed, the experts tried to visualize how the traffic would distribute itself. Judgments were made largely on the basis of preliminary calculations and experiential knowledge.

As illustrated in Fig.5.4, there are 4 key sub-tasks in this task.

1. Observing existing project conditions.
2. Identifying connections that needed to remain open.
3. Identifying connections that could be potentially closed.
4. Identifying stakeholders, both governmental organizations and entities in the project area, such as hospitals and schools.

Essentially, through this task, the team prioritized the different alternatives from the perspective of ensuring mobility as well as from a public information and outreach angle.

Based on this decomposition of the task, a set of Decision Requirements for this task is obtained, represented in the Decision Requirements Table, as shown below:

Decision Requirements
DR1. Identifying important connections
DR2. Identifying stakeholders
DR3. Making preliminary "what-if" queries

Table 5.2 Decision Requirements for Task 1

Each Decision Requirement can further be represented as having Information Requirements (IRs), each of which has Information Sources (IS).

Information Requirement	Information Source(s)
IR 1.1 What are the facilities in the project area that have stringent access requirements?	This information is gained from knowledge of the project area. This information can also be obtained through a survey of aerial photography.
IR 1.2 What are the businesses that will be impacted?	This information can be obtained from aerial photography. Parking requirements and access considerations of businesses in the area of the work zone. Social considerations can also play a role.
IR 1.3 Where are facilities like schools located?	This information can be obtained from aerial photography. Additionally, the Central school district can also be contacted.
IR 1.4 What are the community organizations that must be contacted?	City Council members who know the main organizations like neighborhood associations.

Table 5.3 Information requirements for identifying stakeholders

The next table lists the Information Requirements and Information Sources for the Decision Requirement of identifying important connections.

Information Requirements	Information Source(s)
IR 2.1 Identifying connections that are to be classified	This information can be obtained from the Origin-Destination tables that have been developed using travel demand modeling.
IR 2.2 Determine the values of the attributes of each connection (attributes here are the stakeholders associated with a connection and traffic counts)	Stakeholders associated with a connection can be identified through a survey of aerial photography of the project area Traffic counts are obtained from the Dallas District of TxDOT
IR 2.3 Make a binary classification of the identified connections	Based on the attributes of each connection, make a classification by considering how many lanes need to be open in either direction.

Table 5.4 Information Requirements for classifying connections

Table 5.5 lists the Information Requirements and Information Sources for the Decision Requirement of performing preliminary "what-if" queries on the chosen lanes.

Information Requirements	Information Source(s)
IR 3.1 What are the speed limits for a particular connection?	Project Information 2D plan sheets
IR 3.2 What are the incidents counts on this particular connection?	Traffic data
IR 3.3 What is the traffic volume per lane per hour on this connection?	Traffic data – archived freeway detectors and ramp volumes
IR 3.4 Which stakeholders are affected by this lane closure strategy?	Aerial photography Project Data

Table 5.5 Information Requirements for "what-if" queries

Task 2: Developing the traffic control requirements

This task is concerned with the development of the actual traffic control requirements for the technical provisions under the DHS contract. The input into this task is the output of the previous task, namely the rank-ordered list of identified connections and stakeholders. At this stage in the Project Delivery Process, the bid was not assigned yet and the design was 30% complete.

The major sub-tasks identified in this task are:

1. Using the identified links and connections from Task 1, examine traffic volumes to decide
    a. What links qualify as busy and which links don't.
    b. Identify slack in roadway capacity at specific times
    c. Visualize the traffic conditions in the future

2. Develop a rationale for lane closure strategies with a view to providing the contractor flexibility. This flexibility is important, as the final design is unknown at this point of time.
3. Identification of facilities that involve complex construction strategies due to particular clearance/staging issues.
4. Consideration of constructability strategies to inform lane closure strategies.

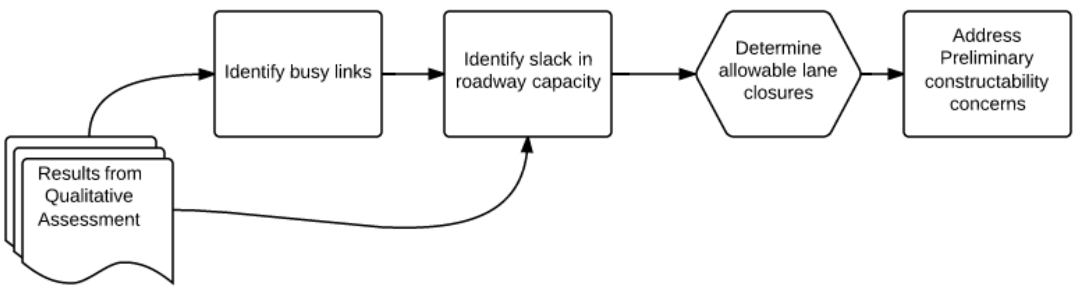

Fig. 5.5. Developing traffic control requirements

As for the previous task, a list of Decision Requirements is made as follows:

Decision Requirements
DR4. Determine if and when a connection is busy
DR5. Determine if there is a slack in the roadway capacity
DR6. Determine allowable lane closure durations

Table 5.6 Decision Requirements for Task 2

The Information Requirements and Information Sources tables for each of the Decision Requirements are as follows:

Information Requirements	Information Source(s)
IR1. Identify the traffic volumes on the connection	Traffic volumes from TxDOT
IR2. Identify the peak hour traffic volumes	Distributions of traffic volumes obtained from TxDOT
IR3. Configuration of lanes	Lane widths and lane configurations, choke points etc. identified from aerial photography and traffic data and project design data
IR4. Identify threshold for designating a lane as busy	Experiential knowledge (2000 VPH) Highway Capacity Manual

Table 5.7 Information Requirements for determining if a connection is busy

Information Requirements	Information Source(s)
IR1. Identify the roadway location and lane configuration	2D Plan Sheets Aerial Photography
IR2. Identify the traffic volumes on the connection	Traffic volumes from TxDOT
IR3. Identify threshold for designating a lane as busy	Experiential knowledge (2000 VPH) Highway Capacity Manual

Table 5.8 Information Requirements for identifying slack in roadway capacity

The heuristic used to develop and evaluate lane closure strategies is identified. The steps are:

1. Consider the number of lanes that are open before construction begins.
2. Consider the number of lanes that are open after construction.
3. Take the minimum of the two
4. This is the number of lanes that has to be kept open at all times during peak hours.

The rationale for this heuristic is as follows:

For the most part, the DHS project is concerned with road widening; narrowing the width of the roadway occurs only at a few places. Thus the contractor is given the benefit of the narrowest configuration that will exist between the start and finish dates of construction.

The following table lists the Information Requirements and Information Sources required to make a decision regarding the allowable lane closure durations for specific connections.

Information Requirements	Information Source(s)
What is the number of lanes in the existing design for this connection?	2D Plan sheets
What is the proposed number of lanes for the same connection, post construction?	Project Information Schematic Design
What are the dimensions of the specific structure?	Project Information Schematic Design
What are the spatial constraints that the contractor might face?	Aerial photography Experiential knowledge of project area
What are the traffic conditions in the proposed work zone?	ADT volumes Archived freeway detector data
What problems would the contractor face in construction of the particular structure?	Construction Engineering knowledge Experiential knowledge of similar construction efforts on previous projects

Table 5.9. IRs for determining allowable lane closure durations.

Stages 3 and 4: Review of Contractor's design and construction strategy with respect to the traffic control requirements

Over a period of one year, after the bid was assigned, the contractor and representatives from the state DOTs met weekly to ensure the compliance of the design and construction strategies with respect to the traffic control requirements.

The knowledge representation of this process is shown below, in the form a process diagram with cognitive elements highlighted. As the process spanned a year, a task diagram was not thought to be appropriate. The following process diagram is adapted from a CTA study of aviation professionals by Hutton, et al (2000). The cognitive processes are depicted in green.

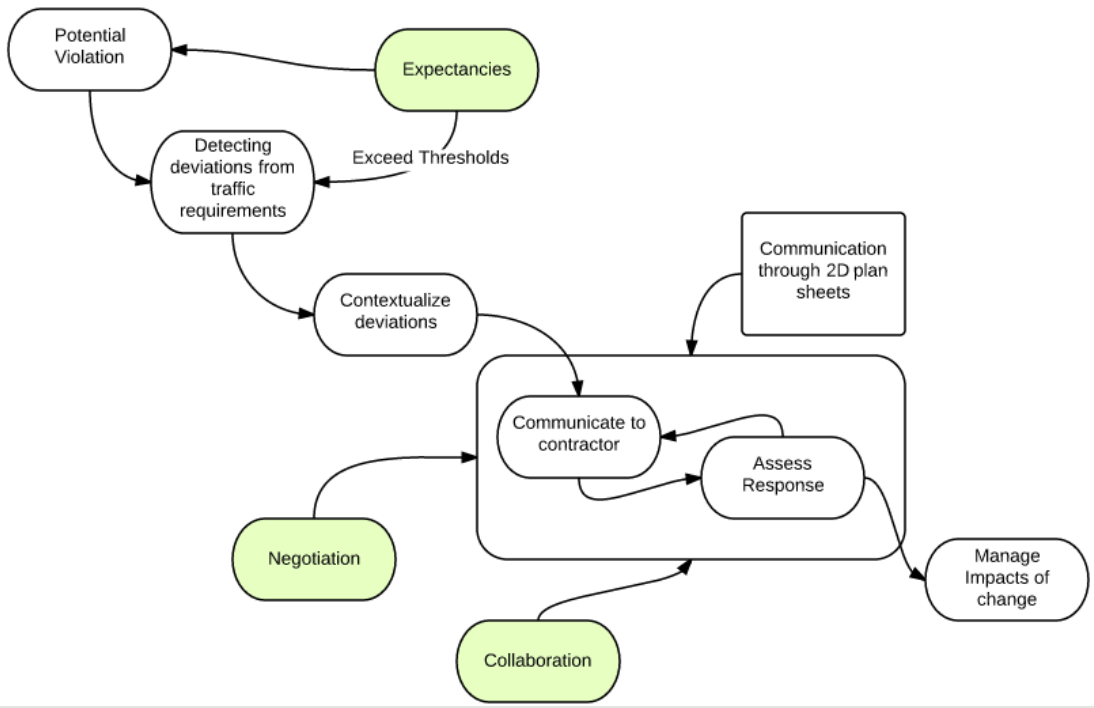

Fig. 5.6. Process Diagram of the review process

From a cognitive perspective, the initial meetings in the series of coordination meetings involved aspects of negotiation and collaboration. From a project management perspective, the purpose of the initial meetings was largely for alignment of project objectives, i.e., the agency and the contractor arrived at a mutually acceptable understanding of the traffic control requirements. SME1 remarked that designing according to the traffic control requirements was a challenging task, one that involved extensive communication between the agency and the contractor.

The means of communication was through notes on 2D plan sheets. The challenges to the decision included visualization of the site based on the 2D sheets, which inhibited “what-if” queries by the participants in the meetings. Some decisions spanned multiple meetings, in part, due to the time consuming nature of performing “what-if” queries using traditional paper tools.

A retrospective analysis of the incidents encountered in the TMP review process revealed that incidents fell into one of two categories – minor and major violations to the traffic control requirements. The decision to designate a violation as minor/major largely depended on the mobility impacts of the proposed change in the lane closure strategy.

There were a number of factors considered by the expert in deciding the appropriate course of action to deal with the proposed change, such as, impact on traffic, queue formation and queuing characteristics, safety implications for motorists and construction workers, benefits of the change in other areas/phases of the project. As described in the introductory chapter, TMP planning is characterized by the presence of multiple interdependent goals. The choice of a strategy has implications on other goals and sub-goals.

Major issues typically arose as a result of one of two things:

1. An infeasible lane closure condition

This happened on the DHS project, in large part due to the constraints of the contracting strategy. Due to the DHS being a D-B project, the agency would have to develop the traffic control requirements in Stage 1 with incomplete data on the final design. This could result in an infeasible lane closure condition. Thus, in such cases the TMP was not enforced rigidly.

2. Allowing a violation could result in improved project delivery

In some incidents, the contractor would propose a novel solution that would result in the simplification of the TCP in the area around the work zone and would ultimately enhance safety.

Incident 1:

One particular incident of a major change to the lane closure strategy was deciding whether to close a particular ramp. Under the original strategy, the ramp would be open, resulting in the presence of four traffic switches. A traffic switch here implies a shift in traffic flow from an old pavement to a new pavement. Enforcing a ramp closure would have allowed construction to be done with one traffic switch. The decision is shown below in Fig. 5.7:

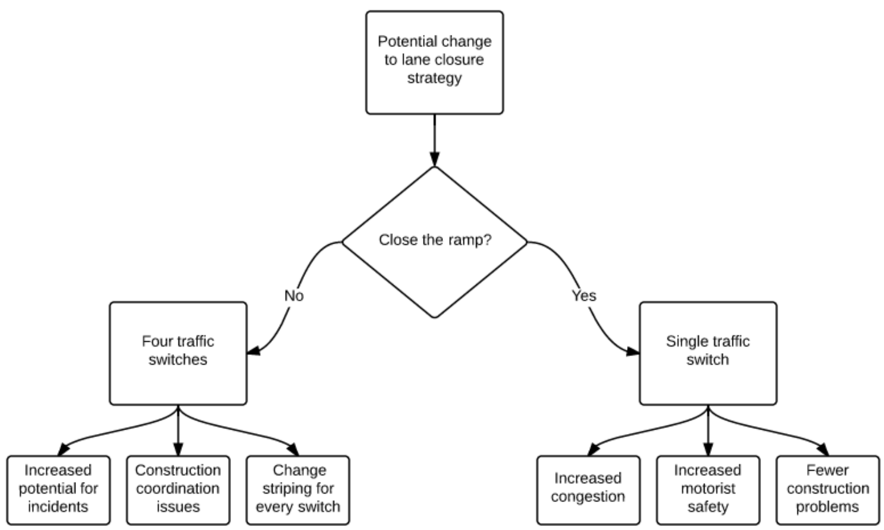

Fig. 5.7 Decision for a ramp closure on the Dallas Horseshoe Project

Incident 2:

The incident in question was regarding construction near the Colorado Blvd, where it goes under I35E. This is near to where the existing structure and the proposed roadway intersect. The contract provisions had originally included an allowable lane closure for that particular intersection, foreseeing problems. However, after the project was let, the contractor provided a solution that involved the construction of a temporary alignment for Colorado. Thus, a closure of 90 days in the short term would result in savings of 9 months on another part of the project.

The table on the following page represents the cognitive demands on the TMP practitioner through the development process

The following table summarizes the decision challenges, cognitive demands and strategies used by the expert over the entire traffic planning process.

Phase	Decision Challenge	Cognitive Demands	Cue/ Information	Strategies used
Qualitative Assessment	Managing the complexity of O-D tables under sever time pressures	Sense-making, decision making, memory, spotting anomalies, communicating/coordinating	Travel demand modeling to determine origins and destinations, historical traffic volumes of each O-D pair	Satisficing: restricted number of connections considered, with the understanding that flexibility would be provided to make changes later.
Qualitative Assessment	Making preliminary "what-if" queries in the absence of complete design information, under time pressures	Sense- making, visualization, memory, problem detection, communicating/coordinating	Experiential knowledge regarding traffic impacts of certain lane closures; proximity of stakeholders such as hospitals, schools; design information and spatial constraints	Identify the major connections, which would face problems if closed.
Developing the traffic control requirements	Developing a prescriptive lane closure strategy with insufficient information and time pressures	Decision making, communicating/coordinating, visualization of consequences	Hourly volumes obtained from freeway detector data and microsimulation models	Provide the contractor flexibility within the constraints by giving the benefit of the narrowest lane configuration
Monitoring compliance of design and construction strategies with traffic control requirements	Communicating the agency's view of traffic control to the contractor using 2D plan sheets	Communication/coordination, negotiation, visualization of consequences	2D design sheets, traffic volumes, ROW data	Understand the contractor's point of view, avoid confirmation bias, encourage the generation of a number of alternatives

Table. 5.10 Summary of Cognitive Demands and Decision Challenges

CASE STUDY 2: SAN FRANCISCO-OAKLAND BAY BRIDGE REHABILITATION

This set of interviews took place with a subject matter expert (SME2), who had experience in developing TMPs for CalTrans. Table 4.1 describes the roles and responsibilities held by SME2. The construction project in question is the San Francisco – Oakland Bay Bridge Project (SFOBB).

Background

With a span of 8 miles, the SFOBB is a important part of the transportation infrastructure in the Bay Area of California. The bridge services an approximate 285,000 vehicles per day on trips between San Francisco and Oakland, CA. The need for the project arose due to wear and tear and reduced safety with respect to seismic considerations. Thus, CalTrans commenced the bridge retrofit in summer 1998, with an expected date of completion to be winter 2014 (Ng, 2008).

There were a number of challenges encountered in the construction:

1. Traffic concerns – due to the high traffic volumes throughout the day, it was not possible to have frequent closures. Moreover, if the bridge was closed, the traffic volumes on other, already busy transportation links would be greatly increased.
2. Multiple stakeholders – The presence of multiple stakeholders such as the Bay Area Toll Authority, City of Oakland etc. added complexity to the project.

3. Environmental concerns – Environmental concerns put additional constraints on construction in terms of material handling.

The TMP for this project therefore was classified as major TMP and was used to manage the work zone as well as the system wide effects of lane closures.

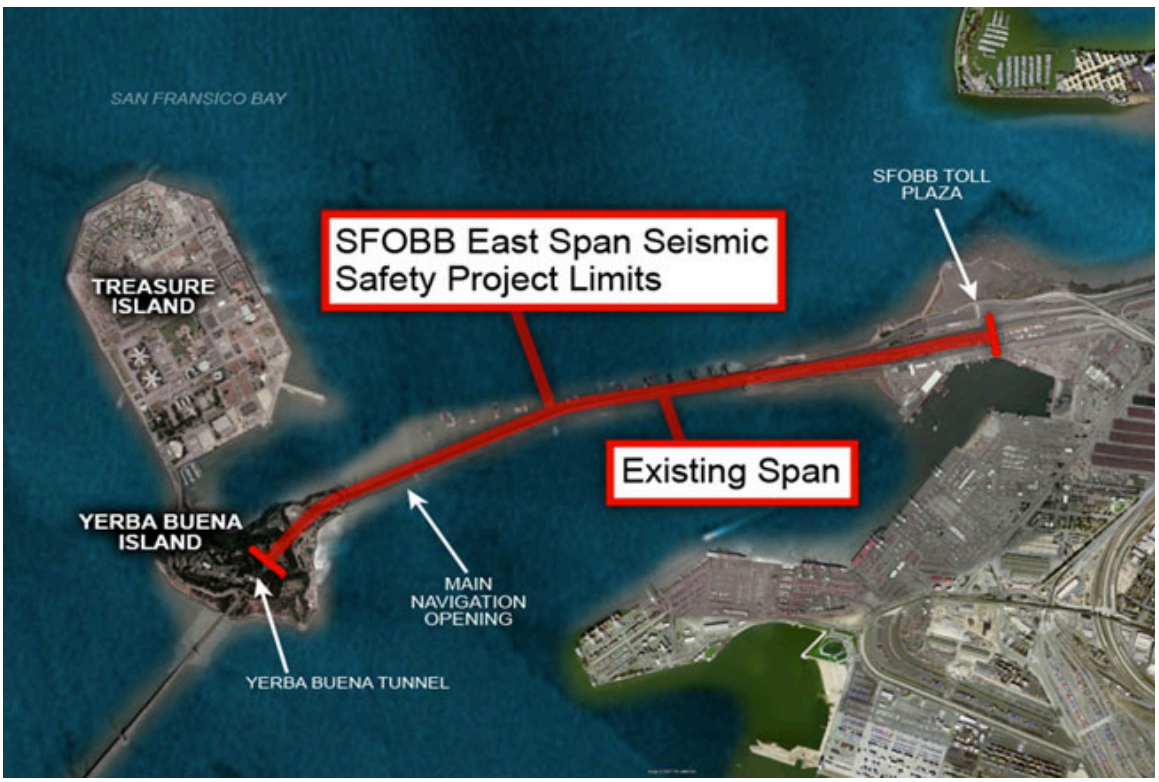

Fig. 5. 8. The existing span of the SFOBB (taken from SFOBB TMP, 2008)

Fig. 5. 9. The new proposed span of the SFOBB (SFOBB TMP, 2008)

The interviews with SME2 consisted of semi-structured interviews about the overall project and TMP decisions and the discussion of a specific incident. The analysis of both sets of discussions is summarized below. The analysis of the specific incident is presented in the form of a process diagram with the cognitive demands outlined

Data Analysis and Knowledge Representation

The following process diagram explains the process that the expert employed to handle the traffic and construction impacts of a major design change that occurred on the SFOBB.

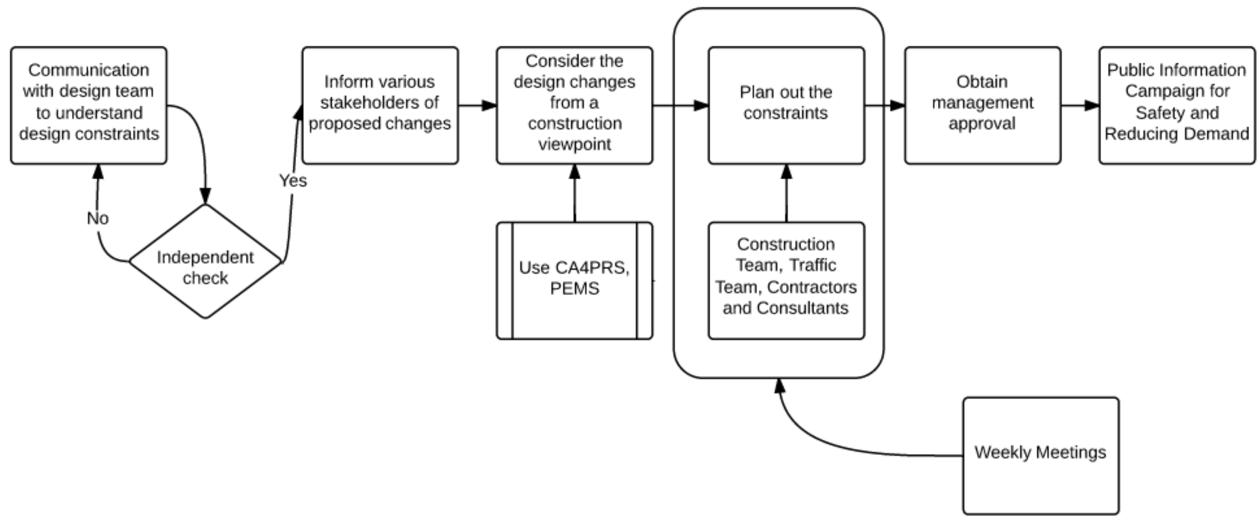

Fig. 5. 10 Process diagram to handle design changes

Based on the identified process, the major Decision Requirements were identified as below:

Decision Requirements
DR1. Alignment of various stakeholders
DR2. Planning the closures
DR3. Planning the construction schedule
DR4. Choosing between different TMP strategies
DR5. Choosing different Public Information strategies

Table 5. 11 Decision Requirements for handling design changes on the SFOBB

The corresponding Information Requirements and Information Sources are listed below for each DR.

DR1. Alignment of various stakeholders

Information Requirements	Information Sources
Who are the necessary stakeholders impacted by this change?	Project information Stakeholders located near the work zone Stakeholders with jurisdiction over the work zone Utilities near the work zone
What information must be communicated?	Design changes – 2D design sheets
What are the potential traffic impacts on the work zone?	Preliminary analysis of design changes
What are the potential concerns of the stakeholders?	Stakeholders representatives Organization mission statement

Table 5.12 IRs and ISs for alignment of various stakeholders

DR2. Planning out the closures

Information Requirements	Information Sources
What are the design changes?	2D plan sheets issued from the design division
What are the spatial constraints faced?	2D plan sheets and knowledge of the jobsite
Can construction be done without closing the bridge?	Spatial constraints, traffic volumes, impacts on the overall network
What is the impact of reducing lane widths?	Highway Capacity Manual CalTrans documents Experiential knowledge Knowledge of experts from Transportation Operations (TO)

Table 5.13 continued next page

What are the staging requirements?	Constructability analysis received from construction division (also from own constructability analysis)
What does the traffic look like on the particular connection?	PEMS, historical traffic numbers

Table 5.13 IRs and ISs for planning out the closures

DR3. Planning the construction schedule

Information Requirements	Information Sources
What are the allowable closure durations?	Planned lane closures
Constructability analysis	CA4PRS Construction knowledge of construction personnel
Staging requirements	Design data (rule of thumb: try not to use the freeway; maintain at least 3 lanes in each direction)
What is construction material being used?	Construction documents Design data
What is the setting time of the concrete?	Construction personnel
How much buffer must be provided?	Rule of thumb: 10%. Based on construction knowledge
What is the weather going to be like?	Weather forecasts Known seasonal variations
Are there environmental issues to be considered?	Seasonal migration patterns of protected species in the area

Table 5.14 IRs and ISs for planning the construction schedule

DR4. Choosing different TMP strategies

Information Requirements	Information Sources
What are the constraints on the work zone?	Design data
What are the traffic mobility impacts?	Transportation Operations division CA4PRS
What are the road user costs?	CA4PRS
What are the construction costs?	Construction division
What are the enforcement costs?	COZEEP/MAZEEP

Table 5.15 IRs and ISs for choosing different strategies

DR5. Choosing Public Information Strategies

Information Requirements	Information Sources
What is the minimum reduction in demand desired?	Experiential knowledge Impact of closure (major/minor)
What type of outreach must be done?	Impact of closure (major/minor)
Where must PCMS signs be placed?	MUTCD, experiential knowledge
What will be the cost of the Public Information campaign?	Cost for physical locations, media outreach, signs etc.

Table 5.16 IRs and ISs for choosing public information strategies

It must be noted that the San Francisco-Oakland Bay Bridge Project is a Design-Bid-Build project. This has implications on the TMP strategy as well. Typically, in a design bid build project, the design changes received are complete and 100% before the start of construction. The TMP process followed is similar to the one prescribed by the FHWA guidelines.

After receiving the changed design specifications from the design team, the TMP practitioner communicates the same to the various stakeholders in the project. These include administrative stakeholders such as the Bay Area Toll Authority as well intra-organizational stakeholders such as the Transportation Operations officials. From a cognitive perspective this stage is largely concerned with collaboration and negotiation among the stakeholders for achieving alignment regarding the design changes.

Having received the approved design changes, various construction scenarios with different lane configurations are planned. Tools such as CA4PRS and PEMS are used; CA4PRS provides constructability guidance and PEMS provides traffic information. Over an extended period of time, through multiple meetings between the construction team from the agency, the transportation operations group and the contractor's representative, schedules are planned in detail. At this stage, considerations such as the type of concrete, the setting time etc. are taken into account to estimate the required lane closure durations.

A key cognitive demand placed on the TMP practitioner is that of predicting schedule performance having taken into account disruptions such as weather and the environment. Lane closures are typically planned well in advance of the actual construction (2 – 4 months). This allows for effective public information campaigns; however, this comes at a loss of flexibility. In case of disruptions due to weather or environmental issues, the schedule is disrupted. Experts typically build in buffers to prevent this from happening.

Thus, for a DBB project, the practitioner with adequate design and traffic data makes the choice of TMP strategies. In this particular project, given that this is a case of bridge construction, spatial considerations also played a part. While the general rule of thumb is to maintain at least 3 lanes in each direction, a full lane closure was implemented in one direction. In addition, the presence of seismic activity also played a role in the choice between recurring lane closures, nighttime construction and full lane closures. Strategies that resulted in faster bridge construction were emphasized.

DISCUSSION

From a review of the IR tables, it can be observed that the TMP development process places high data processing demands on experts. Based on the information requirements and information sources identified through the analysis, we arrive at the following classification of information sources:

1. Project Information

In this category, we have information regarding the design of the project, the existing conditions, the relevant stakeholders, design data, location of utilities in the project area, right-of-way information as well as information about the surface characteristics of the project area.

2. Traffic data

All data related to the traffic characteristics of the project, such as the average daily traffic counts, the traffic volumes on specific links, the O-D tables for simulation models, freeway detector data etc. is placed in this category.

3. Contextual data

The geo-spatial location of stakeholders such as hospitals, important businesses and schools is classified as contextual data.

This classification is not meant to be rigid, i.e., for instance ROW data is project specific as well as contextual. An observation is made that the sources of data are disparate and located in different information systems, which range from paper-based systems to web-based systems. In a CTA of construction superintendents, Mondragon Solis (2013) found that information disaggregation among a number of sources posed a hindrance to the ability of superintendents to make decisions. Through the analysis of results of obtained, a similar phenomenon can be spotted for TMP practitioners. Indeed, the number of data sources was found to add to the cognitive demands imposed on the SMEs.

Liston et al (2000) denoted techniques such as highlighting documents and overlaying different documents as visualization techniques. More recently, O'Brien et al (2011), in a study of construction superintendents have shown that construction superintendents, through drawing and taking notes on project documents are attempting to process information quickly in a visual manner. In the Knowledge Elicitation phase of this thesis, both SMEs in conversation mentioned that they would write on 2D plan sheets. A further investigation revealed that the lack of vertical profile information placed additional cognitive demands on the experts. This is especially important during the review of the design and construction strategies; the lack of vertical profile information was found to hinder the decision making process, resulting in decisions spanning multiple meetings.

As described in literature and as shown in the Information Sources in the tables in the previous chapter, practitioners rely on their experience and intuition to make decisions regarding the choice of TMP strategies. One of the major cognitive demands of experts is hypothesis generations and rapid validation of lane closure strategies. Given the interdependent goals, a change in the lane closure strategy could have impacts on the safety, construction schedule and mobility. Based on the above observations and the responses of the practitioners to the CDM probe question "What tools or technologies would have helped?" the high level requirements for a decision support tool can be described as follows:

1. Support visualization of existing and proposed project geometry
2. Support the simulation of construction strategies
3. Support the use of traffic data in microsimulation models for "what-if" queries
4. Support experts to rapidly validate their hypotheses, i.e., the tool must allow the experts to interact and model what-if scenarios rapidly.

A Comparison between DB and DBB projects

The two sets of interviews, described above, were regarding projects of different contract types, namely Design Build and Design Bid Build. It is interesting to compare and contrast the traffic planning processes on the two projects.

From the perspective of cognitive demands placed on the practitioners, we see that developing the traffic requirements for the Horseshoe project was a process that had severe time pressures and more importantly, lack of sufficient design information. The practitioners dealt with this challenge by iteratively reducing the search space, to focus only on the regions of the project that were deemed important. This strategy had an effect on the later stage of TMP review, as some lane closure durations were found to be infeasible for certain construction situations. The practitioners accounted for this by providing flexibility for the contractor through the technical provisions of the contract. In the second case study, the choice between TMP strategies was made with adequate information about design and the work zone area.

Another key difference between the two projects is the level of contractor involvement and input in the development and choice of the TMP strategies. In the Horseshoe project, the contractor was heavily involved in the TMP process. Moreover, as the time from TMP approval to actual construction was very less, this allowed the project team greater flexibility in responding to disruptions such as weather/incidents. From a cognitive perspective, the cognitive demand on the TMP practitioners of generating different alternatives for TMP strategies was reduced, as the contractor took a greater role in developing innovative construction strategies.

While there are differences between the two projects in terms of their contracting strategies, the choice of the TMP strategies is similar, i.e., the characteristic of interdependent goals still holds. This allows the use of a common knowledge representation to represent the various strategies using the following image:

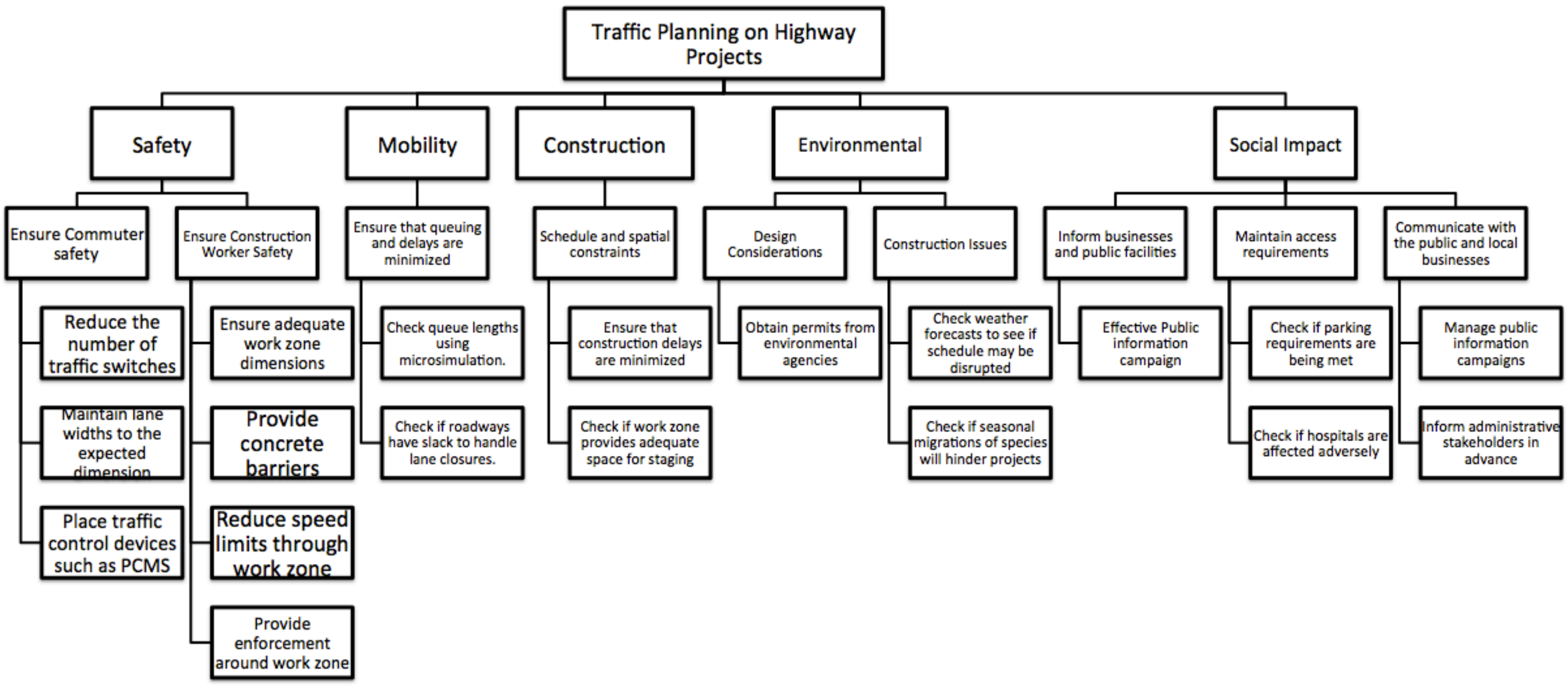

Fig 5. 11 Goal Hierarchy for the TMP process

Chapter 6: Conclusions

Developing a TMP and choosing between different strategies is a complex process involving a large number of variables. This process places high data processing demands on the practitioners. Moreover, given the importance of TMPs to project performance, optimal choice of TMP strategies is crucial. In this regard, assessment and evaluation of TMP strategies and associated knowledge transfer will help state DOTs develop more economical and effective TMPs.

Through the application of CTA methods, this thesis has proposed a new methodology for the elicitation of TMP practitioner knowledge and the dissemination of the elicited information. To our knowledge, this is the first instance of the application of CTA methods to the evaluation of TMP strategies on large infrastructure projects. The resulting knowledge representations, in the form of narratives, decision requirements tables and cognitive demands tables improve the current qualitative methods by providing specificity and formalism. The specific identification of decision requirements, information requirements and information sources will be useful to TMP practitioners with a wide range of expertise.

Another contribution of this thesis is identification of cognitive demands placed on TMP practitioners. The analysis of the cognitive demands has led to the identification of specific obstacles in the TMP process and has provided concrete insights for the development of decision support tools. Specifically, the need for the use of visualization in the TMP development process has been discovered based on an analysis of the interview products.

The FHWA published general guidance for Design Build projects in 2013, with a discussion of two case studies. In general, there is a lack of discussion of TMP processes and strategies in the context of Design Build contracting strategy. The detailed discussion of a major Design Build project in the context of TMP processes is also a contribution to literature.

IMPLEMENTATION CHALLENGES

Performing a CTA is a challenging process, subject to constraints such as the availability of experts and lack of time and experience. A key consideration in the CTA process must be the scope of the analysis. A large scope would be extremely time-consuming. As can be seen, mobility planning involves aspects of processes and incidents. Therefore, we recommend restricting the use of CTA methods for major incidents. This will reduce the time taken for the analysis, without reducing the quality of the analysis.

RECOMMENDATIONS

This thesis has demonstrated the application of CTA methods for knowledge elicitation, through interviews of two experts. While the results of the analysis were validated with the experts, in order to evaluate the efficacy of CTA based knowledge elicitation versus traditional techniques, we recommend performing a CTA on a larger set of experts, with an explicit comparison made between CTA based elicitation and traditional techniques of questionnaires and self reports. This data will enable the formulation of better knowledge transfer programs across DOTs.

The cognitive demands identified in this thesis, along with the knowledge representations provide a useful starting point for the development of decision support tools for the use of TMP practitioners. Specifically, the tasks and goals identified in the goal hierarchy diagram may be used as concepts in Fuzzy Cognitive Maps based simulations of TMP processes, which would enable practitioners to run "what-if" queries.

Appendix

APPLIED COGNITIVE TASK ANALYSIS

Task Diagram Interview

Participant	
Date	

1. Can you describe the traffic planning processes at a high level on the ________ project?
2. Who were the major stakeholders on the TMP team?
3. How would you contact them?
4. What were your responsibilities during the process?
5. Can you break down the identified tasks into specific subtasks (more than 3 and less than 6)?
6. What guidelines were followed for this (%specific%) task?
7. Which of these subtasks would you say was challenging?
8. What was challenging about that subtask?
9. How would you gather data for the overall process?
10. How does the distribution of responsibilities with the contractor happen vis-à-vis the TMP?
11. Were there a lot of changes that occurred during the process?

Knowledge Audit

Participant	
Date	

1. Earlier, you mentioned that you relied on experience. What aspects of your past (either experience or training) were important for this task?
2. What would you say is important about this task? What is overall high level purpose of the task? Was the only priority ensuring mobility?
3. What are some of the key things that you notice immediately (or look for) when you begin the task?
4. Over time, with experience, experts learn to identify issues that a novice would have missed. Can you tell me of any such things that you spot now, which you didn't when you were a novice?
5. How would you evaluate your own decision of the TMP strategy, i.e., how would you be convinced of the decision?
6. How would you handle the microsimulation process?
7. How would you communicate your expectations of traffic control on the project to the contractor's design team?
8. Earlier, you talked about the issues that you were focusing during the TMP review phase. How would such issues emerge?
9. How would the information be communicated?
10. Were there issues in using the 2D design TCP sheets?

CRITICAL DECISION METHOD

Participant	
Date	

Sweep 1: Identifying the Incident

1. In the last interview, we discussed that the issues that arose during the review stage would be largely major or minor in terms on impact on the lane/ramp closure strategy. Can you give me an example of a major incident?
2. Can you give me an overview of the incident?
3. Who were the major stakeholders, who were involved in the decision making process?
4. Who were the stakeholders who would be affected by the outcome of the decision?

Sweep 2: Timeline Verification

Participant	
Incident	

1. Can we go over the sequence of the events that occurred, to check for accuracy?
2. Would this (%particular%) decision be a key decision?

Sweep 3: Deepening

Participant	
Incident	

1. What information would you be using for this decision?
2. You mentioned using experiential knowledge. Were there any incidents of a similar nature that occurred on past projects?
3. At this point in the process, what were your goals (safety, mobility, public impact)?
4. How would you generate alternatives?
5. How would you choose among different alternatives?
6. How would perform “what-if” queries?
7. What tools/people/resources did you turn to for guidance on the decision?

Sweep 4: "What If" queries

Participant	
Date	

1. At _______ decision point, you mentioned using experiential knowledge. Comparing your decisions when you were a novice to your decisions now, what are some things that you do differently, in the context of this decision.
2. If (%constraint/feature%) was missing, how would you change your choice of strategy?
3. In our previous interviews, you identified (%process%) as a pain point. What tools/technologies would have helped you?

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