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Review

Critical evaluation of cognitive analysis techniques for construction field management

Fernando A. Mondragon Solis *, William J. O'Brien

The University of Texas at Austin, Department of Civil, Architectural and Environmental Engineering, 1 University Station C1752, Austin, TX 78712-0273, United States

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ABSTRACT

Cognitive analysis techniques to document field personnel's knowledge have been a recent topic of interest in construction. However, the decision to utilize such techniques remains a difficult one, given their perceived complexity, their variety of scopes and means and their expected limitations for utilization in jobsites. This paper presents a critical review of cognitive analysis techniques to analyze their value for construction management research. The evaluation is geared towards identifying the function of different types of techniques as well as constraints for their implementation in construction environments. In the evaluation, the components of techniques are dissected to uncover their individual capabilities and applications, while also providing insight into the actual difficulties to collect and represent knowledge. This analysis is complemented by the authors' experience in previous cognitive analysis studies, which helps produce a set of recommendations about the practical challenges and implications of deploying specific techniques in construction jobsites.

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1. Introduction

Construction field managers occupy a key position in construction projects, as they are in charge of coordinating available resources for production. Their job is very complex given the dynamic and uncertain character of the many variables involved; besides, the relationships between these variables can be difficult to discern and understand. Adequate support for field manager's work requires a thorough analysis of the variables involved and their relationships. These characteristics have called for a shift in the methods utilized for analyzing job patterns and practice. Traditional observational techniques, which focus on analysis of manual tasks, have proved inadequate to capture abstract activity; cognitive analysis techniques have been developed to understand the knowledge, thought processes and goal structures that underlie observable task performance [1]. These techniques enable the description of work—from a practitioner's perspective—to analyze and design information technologies, work systems, work processes, decision support tools, and learning aids, among other purposes [2].

* Corresponding author. Tel.: +1 512 471 4638; fax: +1 512 471 3191.
E-mail addresses: mondragon@utexas.edu (F.A. Mondragon Solis), wjob@mail.utexas.edu (W.J. O'Brien).

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Recent studies in the construction domain have utilized cognitive analysis for capturing the work of different practitioners. These studies demonstrate, through application, the suitability of cognitive analysis techniques to model construction work and provide decision aids. For instance, the results obtained from these techniques can be used to analyze and review the design of information technologies for their capacity to serve the information needs of practitioners [3]. However—despite these successful applications—many practical challenges are associated to cognitive analysis techniques: the number of techniques available in the literature is quite large, their scopes and methods vary significantly from one another, and the deployment of these techniques also tends to be complex and demanding. From the construction studies it is unclear how adequate techniques were selected and how viable it was to utilize them in construction jobsites.

The purpose of this research is to do a critical review of cognitive analysis techniques to support their utilization in the construction domain. To such purpose, this paper presents a review of techniques that have been used in construction and also a review of criteria found in the cognitive analysis literature to evaluate the techniques' capabilities and functionality. In this way it is possible to assess the suitability of the techniques, or their components, to address issues related to construction field work. In addition, the authors' experience in deploying cognitive analysis techniques to study construction superintendents ([3–6]) supports the discussion of the practical implications of using these techniques in construction sites. Altogether, this paper supports the systematic assessment of techniques' capabilities and applications for gaining access to valuable knowledge for improving construction industry practices.

Through this critical review, the paper makes a contribution by informing readers about the state of utilization of cognitive analysis in construction and also by improving the understanding of where these techniques are applicable and how they can be applied in the context of jobsite environments. This may support future studies in which cognitive analysis is utilized, and ultimately facilitate the implementation of different work systems—such as best practices, information technologies, and training programs—that the industry has long struggled with. To develop this contribution, the paper is structured in the following manner: Section 2 presents a review of cognitive analysis, as well as the application of cognitive analysis techniques in the domain. Section 3 lays out the methodology followed for this research, and Section 4 reviews specific aspects of cognitive analysis to evaluate the capacity and functionality of techniques. In Section 5, lessons learned from previous studies are added to the process of planning and developing techniques in the context of construction jobsites; this analysis yields specific recommendations for the techniques reviewed. The last section presents conclusions for the paper.

2. Cognitive analysis in construction

This section provides a background on previous efforts to utilize cognitive analysis in construction. As previously mentioned, there has been some interest in the domain in studying the cognitive dimension of construction field work. For instance, Memarian and Mitropoulos [7] analyzed masonry work, and identify masonry tasks' mental demands associated to project attributes and work practices. Another example includes Wang and Dunston's [8] analysis of the cognitive aspects that affect the applicability of mixed reality systems to support construction activities. These studies recognize the importance of the cognitive dimension of work performance. Furthermore, they recognize that supporting cognition can enhance control over the many variables involved in construction work. To such purpose it has also been of interest to observe and analyze the cognitive tasks that make up the work activities that occur on site, since they provide insight into how practitioners understand the variables of the domain, and how these variables come together as part of everyday goals and responsibilities. The rest of this section focuses on techniques that can analyze such tasks and their application in the construction management domain.

2.1. Cognitive analysis techniques

A number of techniques and protocols have been developed to document and represent what is known as cognitive tasks. Such type of tasks describe decision making in naturalistic settings—that is, decisions that occur at work settings, as opposed to a laboratory. One group of these techniques is comprised under the term Cognitive Task Analysis (CTA). CTA techniques have the primary purpose of describing a job, from a practitioner's perspective, as a set of decision tasks in terms of the necessary information processes [9]. In particular, the objective of specific CTA procedures is to help researchers understand how cognition makes it possible for people to get things done, and then turning that understanding into aids for helping people get things done better [10]. These approaches are numerous, due to the different elements and activities that can be modeled; some techniques of cognitive analysis are useful to analyze a single task or parts of it, and others are useful to analyze a complete job or even a work system. Given the different approaches and names that techniques have acquired over time, in this paper the term cognitive analysis is used to describe these techniques in general.

Cognitive analysis techniques are often developed in domains with high consequence. For example, Lind [11] was motivated to analyze nuclear power plant operators because of the complexity and impact of the job; similarly, there are studies focused on train dispatchers [12], air commanders [13] and emergency service providers such as firefighters [14] and healthcare practitioners [15]. However, the applications of these methods can be found increasingly in other domains [10]. This is possible because cognitive analysis techniques are geared towards analyzing and supporting decisions in general, not just for a specific type of activity or domain.

2.2. Applications of cognitive analysis in construction

Several studies can be found in the literature where cognitive analysis techniques are applied to support the work of construction practitioners. To gain an understanding of these applications of cognitive analysis, the rest of this section reviews each research study, making an emphasis on the objectives of research, the cognitive analysis technique utilized, the characteristics of each technique, the products obtained, and how the output of cognitive analysis supports the objective of each research study. Table 1 summarizes the studies that have been reviewed, the techniques that were used in each study and the applications of resulting products from cognitive analysis. Then, the representations of knowledge that are produced through each technique are described in more detail.

Several studies can be found in the literature where cognitive analysis techniques are applied to support the work of construction practitioners. To gain an understanding of these applications of cognitive analysis, the rest of this section reviews each of the studies found, making an emphasis on the cognitive analysis technique utilized, the characteristics of each technique, the products obtained, and how the output of cognitive analysis supports research applications in construction. Table 1 presents a summary of such aspects. Then, the representations of knowledge that are produced through each technique are described in more detail below to illustrate the capabilities of each technique.

- In *Fuzzy Cognitive Maps*, the data obtained from practitioners about the major concepts of work and their interrelationships can be represented both by a causal diagram (Fig. 1) and an edge matrix, to show the connectivity of concepts. In the case of construction projects, major concepts include project duration, late design changes, and low productivity.