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COGNITIVE TASK ANALYSIS OF SUPERINTENDENT'S WORK: CASE STUDY AND CRITIQUE OF SUPPORTING INFORMATION TECHNOLOGIES

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SUMMARY: *Construction superintendents have a complex job that requires comprehensive information about the site and the work to be done. To enhance their performance, the supporting tools should be able to reduce the cognitive demand and help provide information in an effective and logical way. Existing tools seem to have failed to achieve this goal. They either do not help the superintendent do his job more efficiently, or increase the cognitive demand he/she has to meet due to the hassle associated with the unfriendliness and ineffectiveness of information technologies. Furthermore, these tools are not integrated in a meaningful conceptual framework. This paper applies cognitive task analysis (CTA) and artefact-based analysis to understand the work of construction superintendents as well as critique existing information technology (IT) tools to support superintendents' work. These are shown to be a useful methods for documenting the information requirements and cognitive needs of complex tasks like site planning. As such, they also provide a useful method to highlight inadequacies of existing computing tools as well as guide development of improved tools. Both specific critiques and recommendations are made to improve future design of tools supporting the job of superintendents.*

KEYWORDS: *Human-computer interaction (HCI), cognitive task analysis (CTA), superintendent, artefact-based analysis.*

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1. INTRODUCTION

Construction site tasks require considerable information collection and processing activities. As such, superintendents are likely beneficiaries of information technologies to support their work. However, with the notable exception of cell phones and perhaps e-mail, penetration of new information technology to the job site has been limited. Recent surveys show a broad spectrum of site related tasks have low adoption of information technologies (e.g. O'Connor et al. (2000), El-Mashaleh et al. (2006), Rivard (2000)). Several rationales have been posited for this from resistance to technology on the part of more senior workers to limited attention to job design activities. In a practice-based review of implementation issues in project websites, O'Brien (2000) posited that new software needs to be well integrated into standard job tasks for individuals or they will resist using it. More broadly, observers of technological innovation suggest that it can take years for industries to fully incorporate and benefit from the potential of new technologies (Brynjolfsson and Hitt (2000)). The relative lack of technology adoption suggests a need for observational and interpretive research. Such research could help speed adoption of new technologies on job sites by providing guidance on implementation as well as aid in the design of new technologies to make them better suited to worker needs.

For this research the authors chose to study construction superintendents because of the complexity of their job tasks as well as their impact on successful project execution. Superintendents have an extremely demanding job. They are responsible for completing the project on time, within budget and to the contract specifications. Their responsibilities and duties include monitoring site safety, noting design deficiencies, trade coordination and managing activity conflicts, estimating durations, and managing quality, among others. A variety of commercial and research information tools have also been proposed to aid superintendent work tasks, including scheduling and contract control software (e.g., Microsoft Project, www.microsoft.com/project, Primavera Project Management™ and Expedition™, www.primavera.com), 4D CAD modeling tools (e.g., Navisworks, www.autodesk.com/navisworks), and space and constraint based analysis research software (e.g. Akinci et al. (2002), Thabet and Beliveau (1994)). The complexity of superintendent work combined with existing software efforts to support their work makes observational research potentially rich both in terms of potential findings for job design as well as a source of evaluation of existing software.

A brief review of superintendent job tasks and work environment suggests the need for methodologies that take a broad view of the work involved. Two methods in particular were selected for this study: Cognitive Task Analysis (CTA) (Potter et al. 2002) and artefact-based analysis (Bizantz and Ockerman, 2002). CTA provides a top-down approach to organizing the cognitive framework that superintendents use to make decisions and process information. Artefact based analysis supplements the CTA view by examining the work and cognitive requirements imposed by use of specific artefacts such as drawings and specifications. Collectively, CTA and artefact based analysis allows examination of the interaction between humans, the environment and artefacts, and supporting information tools. This enables a comprehensive critique of existing tools and provides some guidelines to improve the functionality and effectiveness of the next generation of technologies.

This paper makes two specific contributions: First, through application, an evaluation of the suitability of CTA and artefact-based analysis for application in construction is conducted. Second, applying the techniques to make critiques provides recommendations for improvement in existing tools. This may drive research and development to make the tools more directly supportive of superintendents' cognitive processes. In support of these contributions, this paper lays out findings in detail: It first presents a review of CTA and artefact-based analysis methods and lays out the specific research methodology in sections 2 and 3. Section 4 presents the observations in detail (supplemented by the appendix) and section 5 details the authors' analysis. Final conclusions are presented in section 6.

2. COGNITIVE TASK ANALYSIS AND ARTEFACT-BASED ANALYSIS IN HUMAN COMPUTER INTERACTION

Human Computer Interaction (HCI) as a field of research emerged in the late 1970s. HCI is a fusion of behavioral sciences, most notably from cognitive psychology, and computer science with an emphasis on guiding design of software systems. Carroll (2003) reviews the development of HCI, noting the field's roots in cognitive psychology and its early development of human factors modeling. The literature on HCI includes a number of observational approaches for recording human behavior and needs and translating these findings to improve software design (e.g. Elm (2002), Hutton et al. (2003), Potter et al. (2002), Crandall et al. (2006)). An express goal of HCI research is to develop methods that improve the computing experience for users, both in terms of ease-of-use and utility. As such, HCI approaches range from specific approaches intended to improve specific input/output interaction with software (e.g., GOMS in Kieras (2004)) to broader methods of cognitive processing (e.g. Cognitive Flow in Crandall et al. (2006)) and user modeling (e.g. Concept mapping in Crandall et al. (2006)). Overall, one of the key insights of HCI is that computer tools should not impose additional cognitive workload on users (Roth et al. 2002); ideally, tools should speed or otherwise enhance cognitive processing.

Carroll (2003) further notes that the field has recently embraced “participatory design” in which users interact with software engineers to design prototypes as well as “contextual”, or “ethnographically informed design” where field studies describe usage contexts. Such contextual studies support the authors’ research goals to describe superintendent information needs and support broad critiques of existing software that do not satisfy these needs, contrary to directed evaluations of specific software tools. A wide range of ethnographic research methods exist both within and outside the HCI domain; to limit methodologies the authors imposed some evaluation criteria. First, as noted by Carroll (2003), many ethnographic approaches only loosely provide guidance to software design. Hence methodologies were screened for evidence they could provide directed critiques for software evaluation and design. Second, a focus on superintendents suggests a need for describing a broad range of cognitive demands. At the same time, the authors’ desired to focus on individual rather than group decision making. Two methodologies were found to meet these criteria: a method of Cognitive Task Analysis (CTA) known as cognitive work analysis (Potter et al, 2002), and artefact-based analysis (Bisantz and Ockerman, 2002). These methods are described below.

2.1 Cognitive Task Analysis

Cognition is central to human work (Darse, 2001). Designing systems that support and do not hinder cognition is a goal of HCI. Of course, mapping human cognitive approaches and describing use of tools to support work are challenging tasks. Contextual approaches can provide insight into how humans process information and make decisions. Among these, a common technique is Cognitive Task Analysis (CTA) which offers a structured approach to eliciting and describing a human’s cognitive framework within a domain of practice. CTA methods have been deployed in areas such as aircraft operation (Potter et al, 2002), train dispatching (Roth et al, 2001), nuclear plant control (Burns and Vicente, 2001), military command decision making (Potter et al, 2002), and fire rescue (Militello and Hutton, 1998). There is no single standard methodology for performing a CTA study, although all methods of analysis reviewed in this study have three main goals. The first goal is to identify the different factors that affect cognitive tasks in the job. The second goal is to uncover the methods that are developed by the subject matter experts to manage the different instances affected by the identified factors, which make cognitive tasks difficult to manage. The final goal is to develop methods to improve cognitive performance through the introduction of new or improved technologies, although this goal may or may not be explicit. All CTA methods share a structured approach to describing human cognition within a domain.

In relation to the construction domain, few studies have been made to analyze performance improvement through technologies with CTA methods. Distefano and O’Brien (2009) used Applied Cognitive Task Analysis to elicit information regarding the use of handheld devices for infrastructure assessment. Although this research was focused on U.S. Army’s combat engineer small units, the findings can be generalized to construction applications. The cognitive requirements for portable infrastructure assessment tools that can be deployed by users with limited experience are valuable to analyze construction workers performing inspections and engaging in supervision activities.

Of particular interest to the authors’ purposes, Potter et al. (2002) developed a CTA methodology that connects description of a cognitive environment with development of guidelines and specifications for improved decisions support tools. Their methodology has five components: (1) A functional abstraction hierarchy (FAH), (2) definition of decision requirements (DR), (3) supporting information requirements (IR), (4) display task description (DTD), and (5) a display design concept (DDC). The first three components describe the cognitive information demands of a user and the last two connect description to prescriptive recommendations for information system design. These components are organized into a sequence called the “design thread” such that the resulting decision support aid has an underlying information model that closely maps to the user’s mental model or worldview and hence is “transparent” (Potter et al. 2002).

The first step in Potter and colleagues' methodology is development of a functional abstraction hierarchy (FAH). The purpose of the FAH is to capture the essential concepts of the work domain and establish the relationships between them (Potter et al. 2002). In practice this can be an iterative experience as the researchers learn the problem space. Potter et al. use an "of course" test to evaluate the FAH – it should appear obvious to domain experts; the key point is that a good FAH will resonate practitioners but is unlikely to be something they could generate on their own. While a FAH lays out the cognitive landscape and goals, the second step deepens each node in the FAH by describing decision requirements (DRs). DRs document the cognitive demands of the problem space in the form of required decisions that must be made to accomplish goals in the FAH. As a third step in the process, information requirements (IRs) identify all kinds of information needed to help successfully resolve an associated DR (Potter et al. 2002). IRs can be associated with information sources (IS), making an explicit link to artefacts in use (see artefact based analysis immediately below). However, IRs should not be limited by existing information sources, but should be determined by a review of the information needed for decision making in terms of the identified DRs. Indeed, an IR that does not have an information source within the existing system under review can be a key design point for a novel information system. While a very specific framework, the FAH, DRs and IRs provide a broad view of the cognitive landscape facing practitioners. Ideally, not just the FAH but the DRs and IRs will be easily understandable to practitioners, allowing the researcher feedback and iterative improvement in the overall framework. The FAH, DR, and IR structure articulated by Potter et al. (2002) is similar to other CTA methods (e.g., ACWA in Elm (2002)). A key innovation of Potter et al.'s (2002) approach is provision of explicit methods to transform the cognitive landscape to detailed user interface and performance specifications for information system development. The FAH, DRs, and IRs are used to create a display task description, which addresses the visualization needs of the specific IRs. The display task description is then used to create a rapid prototype display, which is a quick representation of the display concepts. These can be commented on by prospective users and serve as a basis for design of new systems.

2.2 Artefact-Based Analysis

CTA operates in a top-down process. That is, it starts with identifying the goals to be achieved, then identifies the decision requirements and information needs that support those goals. In contrast, artefact-based analysis works in a bottom-up manner by observing the practitioner(s) and the artefacts that are used to perform work tasks to draw conclusions about cognitive demands (Carroll and Campbell, 1988). The basic premise of this approach is that artefacts embody implicit theories about the cognitive processes of users or conditions of their work practices/environment. This analysis can be especially useful in understanding complex and intentional environments where practitioners have a great deal of freedom to make choices about their work processes as it grounds the observations in specific actions and artefacts.

Bisantz and Ockerman (2002) used artefact-based analysis to both critique existing artefacts and support design of new artefacts. In their framework, artefacts are associated with a set of theories and realities. Theories are descriptions of practice or cognitive need as the artefact or tool assumes work should be accomplished, whereas realities are descriptions of actual practice. Reality-theory pairs are useful to contrast what is and what is posited by the artefact. In a theory followed by reality description, the analysis is particularly useful as a mechanism to identify where existing tools suit work practices or are incompatible. As a simple example, Bisantz and Ockerman (2002) studied a cook decision system where a theory embodied in the tool indicated that cooks' hands were clean when entering data, whereas the reality is that they are cooking and hands are not clean. This "clean hands" situation is an example of an environmental constraint, and reminders of conditional cooking procedures are an example of a cognitive constraint; both types of constraints affect the use of the system. In reverse order, reality following theory, the analysis is useful to describe current conditions and express specific requirements (theories) for new tools. This helps to ensure design of new artefacts that are well grounded in practice needs and conditions. Artefacts together with reality-theory pairs also support identification of specific strategies that practitioners use (or could use) to perform effectively in a given situation. A simple cognitive strategy from Bisantz and Ockerman's (2002) study is to monitor levels of prepared product and start to cook more when levels run low.

From the authors' perspective, artefact-based analysis makes a useful complement to CTA as it enforces development of concise observations about practice that are closely linked to physical conditions and specific cognitive constraints. As superintendents use a variety of artefacts (e.g., drawings, schedules, specifications, notes, etc.), artefact-based analysis enables generation of insights that may be missed when drawing down from the functional abstraction hierarchy in a CTA. Bisantz and Ockerman (2002) refine this observation, noting that artefact-based analysis can support design definitions that are means oriented and explicitly consider physical and/or cognitive constraints that may not be explicit in goal oriented design methodologies. Pairing artefact-based analysis with CTA provides complementary viewpoints that support thorough critique of existing and design of new tools.

3. METHODOLOGY

This research seeks to evaluate the applicability of ethnographic HCI approaches to the construction domain. In particular, the authors examine the work of a construction superintendent using a combined CTA and artefact-based analysis approach. Similar to the analysis of military decision making by Potter et al (2002), there are three main parts to analyzing a superintendent's tasks. First it is necessary to identify the factors that make a superintendent's job cognitively difficult to perform. Second, it is necessary to uncover the cognitive methods that the superintendent has developed to complete his or her tasks. Finally, it is possible to identify ways to improve cognitive performance and critique existing technologies from the information gained in the observation and interview processes. By applying both CTA and artifact-based analysis, the authors test the applicability of these approaches in construction both as descriptive tools as well as methods to generate critiques for action. As the sample size is typically small or unitary for cognitive analyses (discussed by Hoffman (1987) and Crandall et al. (2006)) the results should not be generalized without further review. However, having a single subject still allows a complete CTA methodology, as shown by Bisantz and Burns (2009) in their study of naval operators. For an initial study on the application of CTA methods in the construction domain, having a complete study enables exploration of the capabilities of CTA applied to this particular domain. Furthermore, it sets a stepping stone for future comparisons with other CTA studies on field managers.

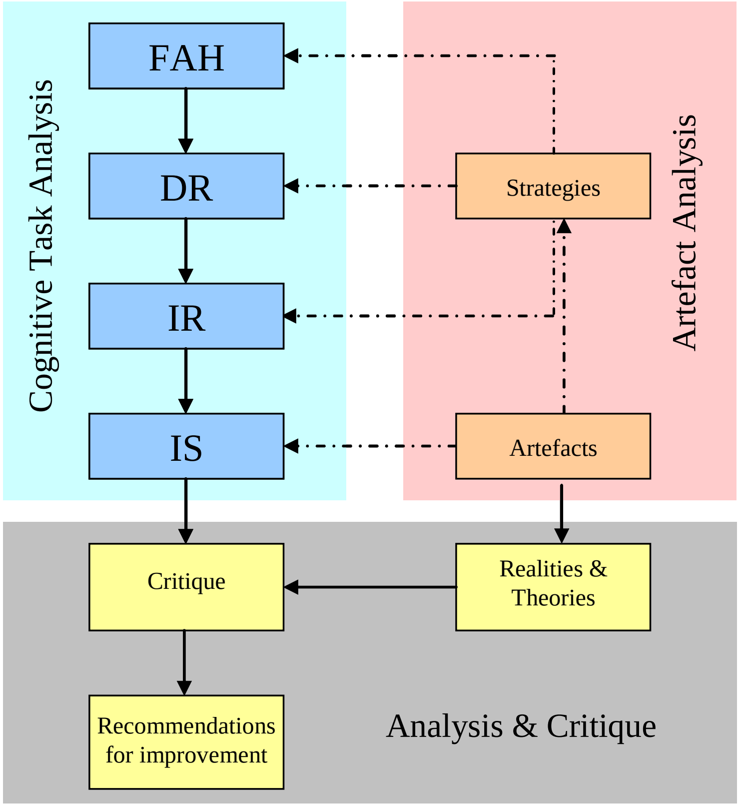


FIG. 1: Sequence of analysis combining CTA and Artefact approaches.

The sequence of analysis used in this research (Fig. 1) is drawn from the CTA work of Potter et al (2002), modified to include artefact-based analysis and development of critiques of existing technologies. First, a CTA method is used to generate a functional abstraction hierarchy (FAH) and supporting decision requirements (DR), information requirements (IR), and associated information sources (IS). This top-down approach is augmented by observation of artefacts and their use, including discussion of cognitive strategies the superintendent uses to organize his work. The documentation of superintendent cognitive tasks is thus structured and performed iteratively through observations and interviews with the goal of providing a clear yet complete picture of cognitive activities within the subject domain. It must be stressed that while each of the components of the CTA analysis provide insight into the subject matter expert's mental processes, all the components are required to express the cognitive activity corresponding to the expert. In this case, the FAH, the DRs, the IRs and the ISs are all necessary to understand what the superintendent tries to attain in his job, the large amount of information he needs to do so, and all the different sources where that information is available.

To begin the knowledge elicitation process, the superintendent was observed during field work hours. Over several weeks, a series of interviews were conducted to understand how decisions are made (particularly in the context of specific scenarios) as well as to verify the accuracy of the findings. The next step in the research methodology is generation of the critique of existing technologies. This is performed first through development of reality/theory pairs following artefact-based analysis. Each pair provides a focused criticism of existing technologies. The set of reality/theory pairs provides a starting point for a broader based critique of information technologies as well as specific recommendation for improvement. As noted above, Potter et al (2002) used the results of the CTA to generate specific display designs that formed the basis for a new decision support system. In theory, these new designs could be used to support a comparative critique of existing systems. For our purposes, we do not create new applications or screen designs, but do use the set of observations to provide an evaluation of existing technologies as aids for field managers.

4. OBSERVATIONS

This section reviews the development of the CTA and supporting field observations. The project studied was a medical office complex in Gainesville, Florida with an approximate cost of 20,000,000 USD and approximately 100,000 square feet of interior space. The expected duration for the project was 15 months; interviews were conducted in during construction. The General Contractor/Construction Manager for the project is one of the United States' leading general builders. The superintendent participating in the study had over 25 years experience. As one of the construction firm's most senior personnel he was often placed on difficult projects, although this project was not judged to be exceptional.

4.1 Functional Abstraction Hierarchy and Decision Requirements

Data collection was focused on management of jobsite activities such as scheduling and trade coordination. From that perspective, observations were made regarding the work done by the superintendent to fulfill his responsibilities. Those observations are expressed in the Functional Abstraction Hierarchy. The FAH is a view of the superintendent's cognitive map, representing the relation of individual entities to the overall goal of managing jobsite activities (Fig. 2). The FAH for the superintendent in this study shows 10 factors that affect the successful management of activities on a construction site. The factors are arranged hierarchically under sub-goals that support the overall objective, and must be addressed successfully to attain the sub-goals identified.

As noted above, the FAH should represent a reasonably complete map which appears straightforward to the practitioner (Potter et al. 2002). The FAH relationships are actual propositions of the superintendent's cognitive processes, so they must hold true for the superintendent's anecdotes and the observations of how he accomplishes work. Thus, the knowledge represented by the FAH depicted in Fig. 2 was verified by the superintendent once the diagram was completed and, as mentioned, throughout the interview process, to confirm the relationships expressed. Also, the elements of the FAH were compared to general construction references on productivity and management (e.g., Oglesby et al. (1989), Barrie and Paulson, (1992)). The FAH appears to be comprehensive, covering elements such as materials, methods, activity sequence, and safety, which are identified in the literature as constraints that affect activities in construction jobsites. This is an indication that the FAH reflects the mental model of the expert superintendent. However, the extent to which the superintendent understands these variables and how they affect particular instances of the job can only be observed in the DRs and the IRs. These are necessary pieces for representing the whole body of knowledge that the superintendent has to deal with when trying to manage field activities, in addition to the map provided by the FAH.

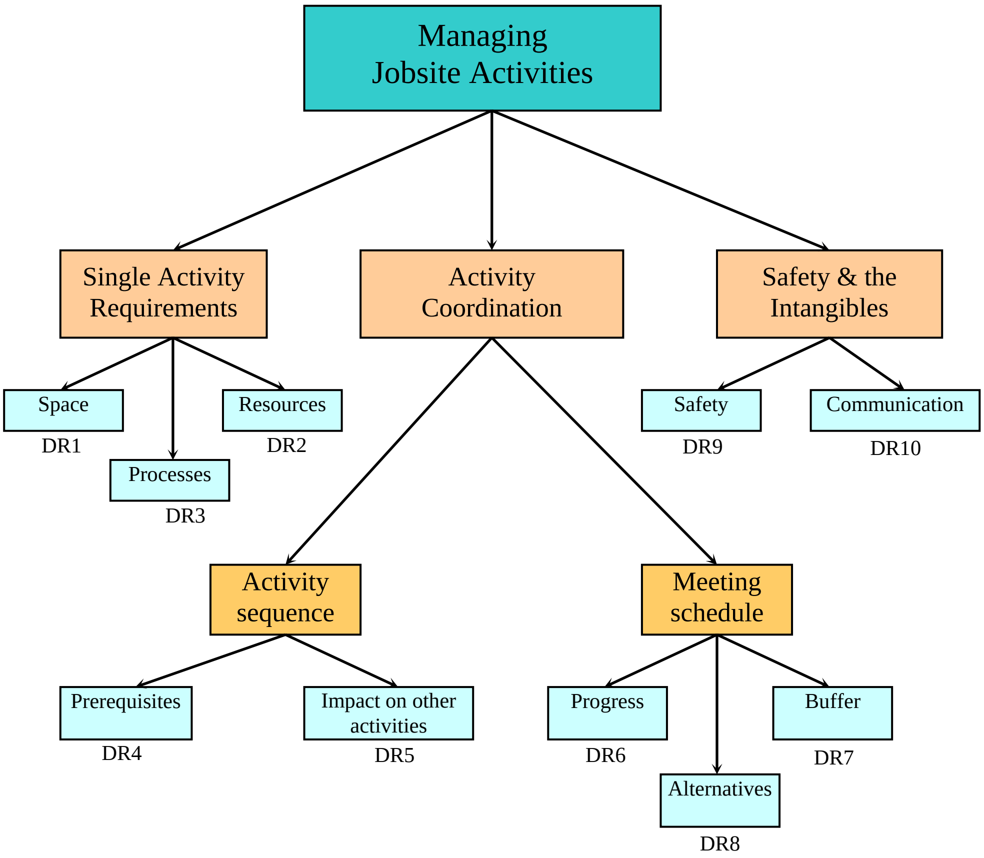


FIG 2: Functional abstraction hierarchy of jobsite management.

The next step in the process is to uncover or link the cognitive demands necessary to achieve the domain goals that are identified in the FAH. These are described in CTA as Decision Requirements (DR). As mentioned above, the sub-goals in the FAH must be attained successfully to perform the superintendent's job. Such successful performance implies making adequate decisions with the information that is available to the superintendent, thus decisions must be made on each of the factors associated with the nodes in the FAH. The factors are then considered the basis for Decision Requirements. It is important to note that the development of the DRs is not a linear process. Observations are made over the course of several interviews, which range from directed questions to open-ended discussion. As part of the knowledge elicitation process, Militello & Hutton (1998) suggest the use of a "simulation interview" that focuses on specific scenarios. This allows the practitioner to relate a specific story or problem from which the researcher can probe for cognitively related information such as job context, information sources used, decision processes, etc. The researchers' goal here is to abstract from the specific to a more general level. The overall map defined by the FAH aids this process by helping to identify gaps and providing structure. Table 1 defines the final DRs developed with and verified with the superintendent.

TABLE 1: Decision requirements for managing jobsite activities.

DR1	Determine the amount of space that is required for the task (workspace and storage).
DR2	Determine the resources and the equipment that are required for an activity.
DR3	Determine the processes that are required to complete an activity.
DR4	Determine what needs to be accomplished for the activity to start. (This decision evaluates the current situation and explores possible alternatives).
DR5	Determine the impact that this activity has on other activities.
DR6	Determine if an activity is going to meet its scheduled duration.
DR7	Determine how much of a buffer needs to be in place for a following activity to start.
DR8	Identify activities that can be expedited to get the project back on schedule.
DR9	Identify the safety concerns that are associated with this activity.
DR10	Identify who is performing the activity and what is their scope of work.

4.2 Strategies, Decision Requirements, and Timelines

Militello and Hutton's (1998) situational interview process supports identification of strategies that the superintendent uses to make decisions and direct his work. Strategies are uncovered, for example, by asking why a choice was made to sequence in a certain manner. During observations three expert strategies were discovered that the superintendent used to support his decisions in scheduling activities on the jobsite. Discovery of these strategies directly supports definition of the DRs.

The first strategy uncovered can be summarized by this statement: Lowest to highest, largest to smallest. Lowest to highest means that when constructing a project one must start with the lowest item on the plan (e.g. foundation plumbing and electrical should be roughed in before you pour the slab). Largest to smallest implies that bigger items take precedence over smaller items (e.g. with mechanical, electrical and plumbing the mechanical should go first because it is the largest, then plumbing, and then electrical). This strategy helps the superintendent determine the sequence the activities should have. The 'Lowest to highest; largest to smallest' strategy aided in the discovery of several decision requirements, especially DR4 – establishing activities prerequisites and evaluating alternative solutions.

The next strategy discovered dealt with one specific area, the bathrooms. However, the concept behind it can be applied to the entire project. While talking with the superintendent about the schedule and what activities received precedence he offered this advice: "You always want to start work in the bathrooms first." His reasoning was based on the amount of trade traffic that was involved in this area. A generalization of this strategy would be 'areas that involve many trades should receive top priority.' This strategy was influential in the recognition of several decision requirements. For example, DR5 – establishing what activities rely on the start or completion of a task and determining the impact an activity has on the project as whole, and DR7 – determining the amount of a buffer that an activity has.

The final strategy received was stated as "If you are planning activities for today then you are already behind schedule." This statement stresses the importance of being future-minded. This strategy can be seen in all of the DRs; to schedule jobsite activities successfully the superintendent always needs to look far ahead. This superintendent always used a three-week look-ahead schedule from which he worked backward to determine which tasks had priority and which conflicts could be avoided so that everything would be completed on time and within budget. Uncovering this strategy also supports identification of information sources and artefacts (e.g., the look-ahead schedule).

Another aspect that became apparent from interviews with the superintendent is the differing timelines used in decision making. Several decisions are made on a daily basis, others are performed weekly, and others are intermittent. Each timeline and its effect on the DRs and supporting Information Requirements (IR) are detailed below.

The superintendent, on a daily basis, performed many tasks that aid in addressing the decision requirements. The first thing the superintendent did each day was to meet with all of the subcontractor foremen to get an idea as to where and on what activity they would be working that day. This daily meeting also gave the foremen the opportunity to disclose information regarding delays or conflicts. Another daily task of the superintendent was to walk the jobsite. During his inspection he made mental notes of who was on the site, how much progress had been made, and identified any potential safety problems. The daily report from the subcontractor also helped him identify how many workers were on site, what they were working on, and identified any problems or conflicts that occurred or that were foreseeable. These daily activities were most useful in identifying the IRs needed to support the decision requirements.

Weekly, the superintendent performed tasks that dealt with the DRs in a more in-depth manner and integrative manner. The weekly tasks that the superintendent performed drew largely from information gathered during his daily activities. The weekly tasks included highlighting progress on drawings, creating a three-week look-ahead schedule, and conducting a more in-depth meeting with the subcontractors. For the superintendent to create a successful three-week look-ahead schedule, the amount of space an activity would consume needed to be addressed (DR1); activity prerequisites needed to be recognized (DR4); the superintendent needed to know what resources and material were needed for an activity (DR2); and what activities were dependent on existing activities (DR5). The superintendent had to address the impact a new activity would have on existing activities (DR5); estimate when activities would be completed (DR6); identify activities that could be expedited (DR8); have basic knowledge of the processes that were involved in a task (DR3); and to be able to establish buffers for certain activities (DR7).

Intermittent tasks include reviewing subcontractor’s contracts and reviewing submittals. Reviewing the contract documents helped the superintendent determine what resources were needed for an activity (DR2), identify who was performing the work and what was their scope (DR10). It also helped the superintendent identify the process that was required to complete an activity (DR3). Review of submittals provides useful knowledge about processes and materials (DR2, DR3) as well as potentially indicate activities that may be delayed (DR6).

4.3 Information Requirements, Information Sources, and Artefacts

Each Decision Requirement is supported by a number of Information Requirements. For this study, each DR is associated with a minimum of three and a maximum of eight IRs. Each IR, in turn, is supported by one or more Information Sources (IS). As discussed above, discovery of IRs, ISs, associated artefacts, and their relationship to DRs is an iterative process developed over the course of several field visits. Details on the IRs and ISs for each DR are given in the Appendix tables A.1-A10. Brief discussion is given below on a set of IRs, as well as a summary of the ISs and artefacts and their use as cognitive tools.

The IRs and ISs that support a given DR detail the specifics of the superintendent’s cognitive processes. In particular, the association of artefacts and their use to support a given DR/IR are particularly useful for documenting the work and thought processes of the superintendent. As an example, DR1 is concerned with the amount of space that is needed for a given task. This is a fairly complex DR as eight IRs are associated with it. The first four IRs are: (1) Identify the area needed for the task to be performed and how long the space will be occupied; (2) determine whether or not the task’s materials and equipment need storage space; (3) determine if the activity creates new space upon completion; and (4) determine if the activity consumes space upon completion (i.e., the space is no longer available for other work). Much of the information for these IRs are drawn from drawings and schedules, however additional sources include direct communication with subcontractors (e.g., how they will consume space, needed storage) and visual inspection of the site to identify potential conflicts and space availability. In addition, the base network schedule is augmented by a three-week look-ahead schedule developed by the superintendent, which is used to guide the length of time needed. Drawings are also marked-up by the superintendent to determine space and progress. The set of Information Sources includes artefacts such as drawings, schedules, specifications, daily logs and non-tangible sources such as personal inspections on site and daily meetings.

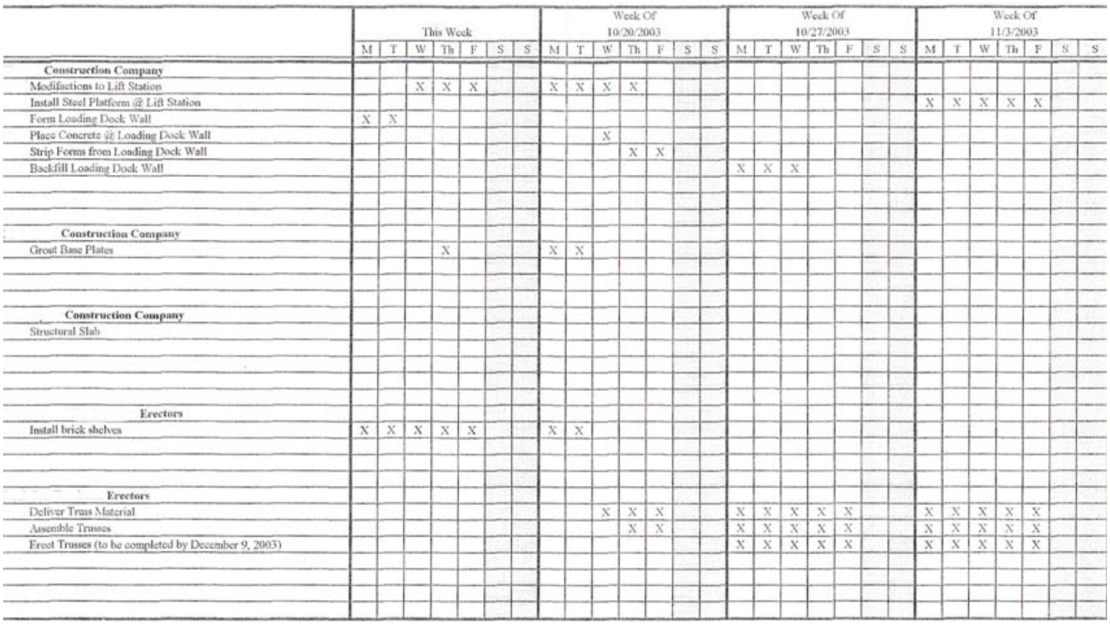
Table 2 lists the artefacts used by the superintendent, their use, and their cognitive benefit. Each of these artefacts are common on construction sites, suggesting a commonality of practice across projects. Perhaps most interesting are the artefacts developed by the superintendent, including the three-week look-ahead schedule and marked-up drawings. These are cognitive tools that support cognition and that are used to record information that the superintendent observes. That the superintendent creates and uses these artefacts is suggestive of several things: First, there are limitations in the other tools available to the superintendent, a finding that supports the observations about tools being able both help and hinder cognition. It is possible that existing tools such as network schedules hinder cognition. Second, the information environment posed by managing job site activities is complex and requires intermediate tools and artefacts to aid superintendent decision making. Third, given the multiple ISs and artefacts that support IRs, it is probably necessary to view these artefacts as a set or suite of tools that support cognition.

TABLE 2: Artefacts that superintendents use, their purpose, and the benefit that they provide.

Artefact	Use	Cognitive benefit
Master Construction Schedule/Divisional Schedule	Provides critical dates and an overall sequence of work.	Provides a baseline. Identifies milestones. Identifies critical activities
Three-week look-ahead Schedule.	Accounts for the progress to date and identifies activities that need to be accomplished in the near future as well as activities that need to start in the near future.	Helps to identify the steps that need to be taken to achieve project goals. Helps spread cognitive load to other people.
Drawings	Two dimensional representations. Site plan, Structural, Architectural (Floor plan, Elevations, Sections, Details, Door Schedules, Window, Schedules, Reflected ceiling plan), Mechanical, Electrical, Plumbing	Represents what the outcome of the project should be. Represents what, where, and quantity.
Highlighted Drawings and Dry Erase Board Drawings	Can be used to track progress of activities. Used to identify areas of concern. Used to coordinate work amongst the trades. Used to schedule work.	Provides a source to offload information and reduce cognitive load. Aids in the communication of cognitive processes.
Subcontracts	Identify who is performing the work and what they are responsible for.	Provides a record of what work the subcontractor is responsible for.
Specifications	Defines the type of material and standards of quality. (Specifications supersede drawings)	Reference source.
Superintendent’s daily report log	Daily accounting of the people on the job. Work that was performed, and any situation that arose	Area to offload memory. Reference source.
Subcontractor’s daily report log.	Identify the number of people on the job, the items that were worked on, and any problems that occurred or that are foreseen. It also records the ethnicity and gender of the workers.	Reference source. Identifies problems.
Submittal Log	Track what submittals are approved and which ones are still pending.	Reference source.

We briefly discuss the role of schedules and drawings to support the superintendent’s work in more detail. The master construction schedule on the project had 650 activities arranged in a precedence network. It was generated using common commercial software. The schedule included activities such as 60% drawing bid dates, procurement dates and submittal approval dates as well as traditional site activities. The divisional schedule contained the same activities as the master schedule, but activities in the same division or discipline were grouped together in the display or printout of the overall schedule. The divisional schedule was used primarily to view the overall scope of work for a given trade in a schedule format; it was less useful as a method to view interdependencies between trades. It is useful to note that both the master schedule and divisional schedules were used only in limited fashion by the superintendent; each was primarily used as a means of observing overall milestones for progress. Neither the master construction schedule nor the divisional schedule was updated. The superintendent supplied three reasons for this: First, the schedules were difficult to interpret by the majority of craft personnel. Second, schedules are difficult and time consuming to update. Third, updating the schedule with many small changes can be confusing to the owner. (Note: It is unclear how the contractor applied for progress payments from the owner.)

Lack of an updated master schedule places increasing importance on the three-week look-ahead schedule developed by the superintendent. The three-week look-ahead is, in essence, a four-week schedule that identifies the work that should take place over the next three weeks as well as this week, and the parties that were responsible for the work. Activities were delineated on a daily basis, allowing subcontractors to know which days they were allotted to work on a given activity. A sample schedule, without the subcontractor companies’ names, is shown in Fig. 3. Note that the three-week look-ahead was developed by the superintendent using pencil and paper; he gave it to the field engineer to put into a computer format for neatness. Scheduling software was used to record the look-ahead schedule, but no link was made between this schedule and the master schedule.



	This Week							Week Of 10/20/2003							Week Of 10/27/2003							Week Of 11/3/2003						
	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S	M	T	W	Th	F	S	S
Construction Company																												
Modifactions to Lift Station			X	X	X			X	X	X	X																	
Install Steel Platform @ Lift Station																						X	X	X	X	X		
Form Loading Dock Wall	X	X																										
Place Concrete @ Loading Dock Wall										X																		
Strip Forms from Loading Dock Wall											X	X																
Backfill Loading Dock Wall															X	X	X											
Construction Company																												
Grout Base Plates				X				X	X																			
Construction Company																												
Structural Slab																												
Erectors																												
Install brick shelves	X	X	X	X	X			X	X																			
Erectors																												
Deliver Truss Material										X	X	X			X	X	X	X	X			X	X	X	X	X		
Assemble Trusses											X	X			X	X	X	X	X			X	X	X	X	X		
Erect Trusses (to be completed by December 9, 2003)															X	X	X	X	X			X	X	X	X	X		

FIG. 3: Three-week look-ahead schedule.

The three-week look-ahead schedule can be considered the outcome of the superintendent’s overall decision making process for managing jobsite activities. Ideally, each iteration of the schedule involves most of the ten DR noted above. In this process, the superintendent first must identify how much progress the project would need to make in three weeks to maintain the overall schedule. Once desired progress was determined, the superintendent works backwards to identify the activities that were necessary to meet this goal. Construction status for the look-ahead schedule was obtained from marked-up drawings and white boards as well as the superintendent's memory. Specific decisions were developed using the DR – IR – IS combinations and supporting strategies (see above and Appendix). To a certain extent, analysis can be shortened by rolling each week forward in time provided no changes in anticipated conditions have occurred. At a minimum, this involves verifying site progress and subcontractor commitments, themselves time consuming tasks.

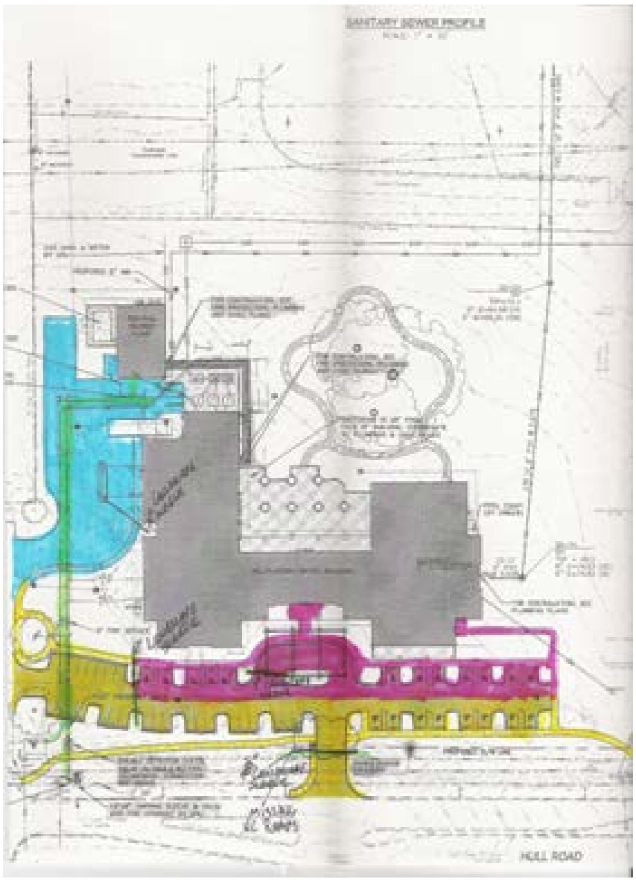


FIG. 4: Sample drawing marked-up by the superintendent.

While the rolling three-week look-ahead schedule was used as the culmination of the planning process (and as a simple communication tool with subcontractors), it was not used as a measurement of progress. To record progress the superintendent walked the jobsite, took note of what had been accomplished and what still needed work. After walking the project, he returned to his office and highlighted sets of drawings to record his observations. In some cases the superintendent would take drawings or copies of the drawing to a specific location on the site for reference or to record comments on the spot. Markups were always done on paper, never with CAD or other electronic means. Fig. 4 is a sample drawing annotated by the superintendent. Note the use of color to delineate areas and supporting notes. In fact, the superintendent kept three sets of drawings to markup: Highlighted drawings that tracked the progress of an activity; highlighted drawings that represented the sequence of work; and highlighted drawings that identified difficult areas of the plan. Marked-up drawings with problems that the superintendent could not resolve were given to a field engineer to generate a request for information (RFI) for the design team or appropriate party to resolve. Progress reporting was the set marked-up most frequently; once an entire drawing was colored in, that part of the project was finished.

In summary, drawings modified by the superintendent are the primary place for him to record information about the site and are a central cognitive tool for offloading memory to a permanent location as well as supporting analysis. A demonstration of the relevance of drawings is that each of the ten DR identified above are supported to some extent by drawings. Updating the drawings is part of the superintendent's daily work, together with making small adjustments to plan and coordinating the daily activities of the subcontractors on-site. These daily activities support a weekly planning process where the superintendent updates the three-week look-ahead schedule as part of a complex planning process that involves a number of DRs and which is also directed by various strategies such as ‘largest to smallest’. Various other information sources and artefacts support the daily and weekly management process.

5. ANALYSIS AND CRITIQUE

This section applies findings from the superintendent’s artefacts, decision strategies and information-seeking behaviors to explore technologies and their support, or lack thereof, for his cognitive processes. Reality-theory pairs from artefact-based analysis define specific needs for new technologies and hence limitations in existing technologies. Similarly, DRs, IRs and ISs from CTA outline the needs for specific functions in these technologies, some of which are already available but impose a higher cognitive load on the user when presenting information in an unconventional way. This analysis is generalized to broader critiques of existing scheduling software that leverage the set of information developed in the previous section.

5.1 Realities and Theories

Bisantz and Ockerman’s (2002) method of reality-theory matching was adopted to identify the essential characteristics of improved artefacts to support the cognitive tasks of superintendents. This reality-theory concept makes the design concepts of new tools transparent in terms of their functionalities, and how they should work around the physical and mental limitations of humans rather than imposing operational constraints on them. The realities presented below refer to observed practice of the superintendent’s use of construction drawings and constructions schedules. The theories should be considered as design guidelines of qualities and virtues that the new generation of artefacts should embody rather than final detailed design specifications.

Drawings are increasingly being generated using CAD tools, and there is considerable potential to leverage these tools during construction. However, considerable inertia remains in the use of paper drawings on-site. To improve paper drawings, it is necessary to understand how they are currently being used and to identify their useful and frustrating aspects. Realities will show how drawings are being used, and theories will identify the useful or frustrating aspects that need to be considered when redeveloping this artefact.

Whereas drawings are important cognitive tools for the superintendent, schedules are somewhat less important for daily use. The master and divisional schedule are primarily used for reference and the three-week look-ahead schedule is the culmination of a planning process that involves extensive use of drawings. Superintendents are not using schedules to their full potential. By identifying the realities of why schedules are not being used to their potential, we can formulate theories that would help to make schedules more useful and usable.

Reality 1. Superintendent references drawings at various locations throughout the job site.

Superintendent often needs to verify that activities were completed according to the plans. Instead of writing down or memorizing the details on the drawings that need to be checked, the superintendent copies a section of the drawing or takes the drawing to the location in question.

Theory 1. (Technology enhanced) drawings need to be mobile.

Reality 2. Superintendent often takes notes directly on the drawings.

Superintendent notes design discrepancies directly on the plan. He also highlights areas where work has been completed or current progress. Areas of concern are also noted on the drawings. Being able to highlight and place notes directly on the drawings is a primary method for the superintendent to offload items in short-term memory for later use.

Theory 2. Drawings must be easily annotated and highlighted for a variety of purposes.

Reality 3. Drawings provide the superintendent with information about materials, quantities, and locations relative to work areas.

The ability to easily highlight drawings also means that it is easy to mark specific work areas. As drawings a printed to scale, it is relatively easy for the superintendent to perform a quantity takeoff and assess the materials needs for a given work area.

Theory 3. Drawings need to identify the different materials and their quantity broken into work areas or activities/tasks.

Reality 4. Drawings are easily and inexpensively copied and distributed and read by everyone.

Drawings are often copied and used to aid in the communication of an idea or concern. On the observed project the site plan was copied and highlighted to represent the sequence in which the work was to be performed, and then distributed to the proper subcontractors. There was another occasion on the observed project when a drawing was copied and the areas that needed to be completed first were highlighted.

Theory 4. Drawings need to be easily replicated in a format that is accessible to everyone.

Reality 5. Addenda are taped to their respected drawings to add the additional information that is required to complete the project and to keep all of the information in one location.

Throughout the project architects issue addendum which contain corrections to the drawings as well as information that was left out. Superintendents post all of the addendums on a set of drawings. By posting all the addenda to a drawing set the superintendent does not have to refer to several documents for all of the relevant information. All of the addendum issues have notations that identify when they were issued.

Theory 5. Drawings need to be updateable, and the updates need to be traceable.

Reality 6. Drawings are rendered on large sheets of paper to show greater detail and area.

Construction drawings are on large sheets of paper, allowing both representation of detail and the relationship to other areas of the plan. The superintendent is typically able to focus on one or two drawings for most information, particularly within a given discipline.

Theory 6. Drawings need to be readable for details and relate these details to the other areas of the plan.

Reality 7. Drawings are two-dimensional representations of three-dimensional objects; more than one two-dimensional drawing is needed to identify the complete three dimensional objects.

The floor plan, elevations, and section cuts are needed to accurately picture and build a project. For a superintendent to understand what construction needs to take place to complete a room, he or she may have to look at the floor plan, wall section, reflected ceiling plans, structural plans, electrical plans, and mechanical plans. That said, existing two dimensional drawings are divided into well defined sets of information by discipline and suffice for the majority of typical work as well as communication with subcontractors. Two dimensional drawings also allow simple representation of work areas and rapid updating via mark-ups and highlighting (for example, see Fig. 4). The superintendent's work to visualize three dimensions is often limited to special cases and complex interfaces.

Theory 7. Three dimensional plans better represent the project; however these do not replace the need for two dimensional drawings in terms of updates and communication.

Reality 8. Schedules are not updated to reflect the actual progress on the site.

The preferred method of tracking the progress is done with highlighted drawings. Updated schedules currently only provide the superintendent with the percent completed, and do not represent what work has been completed.

Theory 8a. Updated schedules need to provide the location of where the work has been completed as well as the work that remains.

Theory 8b. The three-week look-ahead schedule needs to be updateable and coordinated with the master schedule.

Reality 9. Superintendent does not follow the sequence that the schedule portrays.

Construction schedules do not necessarily provide a realistic sequence of activities. In some cases scheduled activities are broken into multiple work areas, and in some cases work areas as performed by trades do not match directly with master schedule activities.

Theory 9. Construction schedules need to be easily adapted to reflect the condition of the jobsite.

Reality 10. The master schedule is not useful for communication with workers and trades.

The three-week look-ahead schedule was the most useful to the workers because it was simple and easy to understand and dealt only with activities that were related to that specific time frame, including daily activities that coordinate with worker planning and management.

Theory 10. Schedule information needs to be flexibly represented for different timeframes and communication needs.

These realities help to show why schedules are not being used to their intended potential. The theories identified would help to make the schedule a more useful artefact. The major problem that was identified in the realities is that schedules only provide part of the information that is needed. The realities offer ideas that would make schedules more useful and usable.

Recent technologies have made efforts to address these theory-reality mismatches in order to improve the tools. The reality-theory pair number 8 for drawings, for example, is one motivation for the development of 4D models. Similarly, software developers have also supported look-ahead scheduling tasks via work packaging with tools such as as ConstructSim by Bentley (www.bentley.com/ConstructSim). The reality-theory pair has also been addressed in the “last planner” or “last planner system” used to implement the schedule at the work package level to complement the traditional system of master schedules that plan activities to cover a long period of time (Ballard and Howell, 1994).

5.2 Cognitive demands and recommendations

The IRs and ISs obtained in the CTA identified specific ways in which the superintendent uses available tools to gather information. Existing computer software used in the construction industry contains functions that support some of the superintendent’s information needs. However, there are two important limitations for information technologies in relation to the cognitive capacity of the user: These are differences in the amount of functions the user is provided with, and differences in the amount and location of information that the user has to process. The direct effect of these limitations is an addition to the cognitive load that is regularly managed by the user, which may lead to decreased performance and reluctance of the intended users to include technology in their work. The IRs and ISs provide insight to these limitations and effects, and allow identification of functions and processes that harm the superintendent’s work.

The superintendent observed in this study would not utilize the scheduling software available, since it only tracked a single, detailed master schedule. To use a tool with such few functions would have required for the superintendent to work without having important information at hand, thus heavily increasing his cognitive load. The scarcity of functions available to serve the superintendent’s IRs forced him to create the three-week look-ahead. This personalized artefact provides the superintendent with meaningful information, as it is developed based on the schedule and other ISs that will affect the planning and sequencing of work activities in the upcoming weeks. The concept of look-ahead scheduling is nothing new in construction. The literature has long established the need for such schedules in which activities can be exploded in great detail and assignments made to crews and individual workers (LCI 2005). Superintendents have also been using these for a long time. Activity explosion is a very critical task that needs to be performed consistently if the project is to be completed on time. Functions supporting this task should be an important component of any scheduling program to be developed.

Existing scheduling technologies allow for the creation of personalized look-aheads similar to what the superintendent used. They are, however, subject to interactivity limitations that constraint the amount of information to be added manually and its location. Table 3 presents the IRs that use ISs related to schedule documents, as well as the functions that commercial scheduling software offers for such need. This is followed by a description of the difference in cognitive demands associated with the way scheduling computer programs present information. The programs used for this analysis are Microsoft Project and Primavera P6.

TABLE 3. Difference in Cognitive Demands when using Scheduling Software.

IR3.3 - What steps are involved in that completion of the specified activity?

- *A schedule may have the activity 'install drywall.' Installing drywall involves hanging the drywall, taping the joints, and several passes of joint compound and sanding before the activity is complete.*

Software Functions	Project and Primavera allow creation of subtasks for each activity. They also permit adding notes, inserting images and adding bullets or steps as part of an activity's additional information.
Cognitive Demands	Helps in organizing annotations and information. Limited information available at one time on the screen calls for additional visual sources that need to be retained and processed. Limited interaction with features does not allow presenting the data with additional information (e.g. striking, underlining, coloring and check marks) that permits easier identification and reduces processing,.

IR5.1 - What activities are reliant on the start or completion of this activity?

- *The schedule will identify what activities are critical and their linked activities.*
- *Assessment of the current progress on the project.*

Software Functions	Project and Primavera can show activity progress and its relationships to other activities in a Gantt chart. Estimated times can be shown in the network diagram.
Cognitive Demands	Obstructs visual comparison of the master schedule and the look-ahead, they cannot be viewed simultaneously. Dependencies not modeled in the network (e.g., space) are not shown.

IR5.3 - What task should receive priority?

- *The schedule indicates which activities have long durations, and which activities are critical.*

Software Functions	Both Primavera and Project can show durations and highlight critical activities in a Gantt chart.
Cognitive Demands	Aids identification of critical activities. Helps to identify long activities and sub-activities fast Durations, progress and performance can be shown by the software, thus aiding to identify priorities. Hinders identification of important tasks, since these are visually reduced to the set of critical tasks, without considering task with long durations or tasks that may quickly become critical as they run late.

IR5.4 - Will this activity interfere with other activities?

- *An assessment of the current progress on the jobsite is necessary. This is done by inspecting what work is in place. This information can be stored and represented on highlighted drawings..*
- *Inspection of jobsite to see if there is enough space..*
- *The 3-week look-ahead schedule identifies what activities are in progress, activities that are nearing completion and activities that are pending.*

Software Functions	Project and Primavera can show activity progress in a Gantt chart. Primavera can also highlight activities that should be worked on, given a particular timeframe.
Cognitive Demands	Helps to show activity and project progress, as progress updates are immediately reflected in the schedule. Aids site supervision, since the number of resources per task can be shown right next to each Gantt bar. Constraints the addition of information from other ISs to a note-taking plain text box. Hinders the identification of priorities and important details by limiting the amount and style of text and annotations.

IR5.6 - If this activity was delayed what would it do to the rest of the project?

- *The schedule and the three week schedule are used to determine what activities are linked to a given activity.*

Software Functions	Project and Primavera can show a network diagram including all activities and their relationships
Cognitive Demands	Allows identification of predecessors and critical activities. Obstructs identification of non-critical activities that are ahead and behind schedule. Dependencies not modeled in the network (e.g., space) are not shown.

IR6.3 - How long has that activity been in progress and how much time is left?

- *The schedule indicates the overall duration of the activity.*

Software Functions	Activity durations and progress are available in both Primavera and Project.
Cognitive Demands	Obstructs user's estimations on schedule, as the user must perform calculations of durations and estimated start and finish dates for activities that are not going according to the master schedule. Hinders identification of non-critical activities that must be finished, which cannot be highlighted manually.

IR8.2 - What activity is on the critical path that could be expedited?

- *The master schedule should identify what the critical activities are.*
- *The 3-week look-ahead schedule should identify the activities that need to be completed.*

Software Functions	Both Primavera and Project highlights activities in the critical path. In addition, Primavera can highlight activities that should have started or finished during the day.
Cognitive Demands	Identifies activities that must be worked on during the day Hinders identification of non-critical activities that must be finished, which cannot be highlighted manually. Users must identify other relevant activities on their own. Limits identification of activities that are ready to be started, given resources and space availability.

IR8.4 - Will the decreased duration of this activity place other activities on the critical path?

- *The 3-week look-ahead schedule should address the change in the schedule and the impact that it will have.*

Software Functions	Primavera can change the critical path as the schedule progress is updated. Project does not have this capability.
Cognitive Demands	Highlighted critical path helps to bring attention to critical important activities. Hinders identification of non-critical activities that must be finished, which cannot be highlighted manually. Harms reorganization of activities' sequence, since the software cannot take information from any other IS Restricts the superintendents' opportunity to think through and re-plan the sequence of activities as the project goes on.

IR8.6 - What are the different options?

- *The drawings and the schedule can be used to determine if any other options exist.*

Software Functions	The network diagram shows sequence dependencies among activities.
Cognitive Demands	Restricts information to what is shown in the network diagram. Limits identification of relationships between various ISs.

Table 3 contains specific critiques to existing scheduling software based on the cognitive activity of the superintendent. Instead of reducing the cognitive load by processing or holding information for the user, the scheduling software actually requires the user to manage additional information, causing a disruption to their work practice. For example, the reduced interaction allowed by the computer, in comparison with pen-and-paper artefacts, affects IRs 3.3, 5.4, 6.3, and 8.2. The superintendent is used to highlight and mark his three-week look-ahead, using different colors to provide himself with cues that aid in quickly identifying and remembering relevant details. In this way, the superintendent offloads his memory and can make sense of the schedule faster, which is essential for making timely, appropriate decisions. The technologies analyzed here do not allow such levels of interaction as the user is limited to type text as notes and attach images in a text box. This difference is not insignificant, as the superintendent is confronted with a different way of adding information that will be less meaningful than his color-coded marks.

The limitation to mark relevant information hinders the superintendent's work when he needs to revise documents and quickly identify explicit information relationships. This is related to the conceptual design of the schedule, which does not integrate functions in a way that responds to the mental model of the superintendent. He needs to relate information within the schedule, and also to relate information from other ISs in order to achieve the main goal of managing the jobsite. The limitations of existing functionality results in technology tools that increase the cognitive demands on the user.

5.3 Discussion and recommendations

Based on the specific cognitive demands identified in Table 3, recommendations can be made for existing scheduling software. To aid the superintendent in relating information within the schedule documents, it is proposed to further increase input for groups of tasks regarding the different factors identified as DRs, such as the use of space, available equipment, and number of resources. This is motivated by the cognitive demand of functions that harm the user's capacity to overview the project and consider different alternatives that allow for continuation of work on different site areas (Table 3, IRs 3.3, 8.4 and 8.6). Current functionality provides a summary task bar for sets of tasks, but it can be difficult to discern tasks in a heavily populated schedule. So, the first recommendation is to increase the visual and textual support of tasks groups, for example, by adding a frame around task groups, providing enough space between groups, and allotting text fields in that space for comments regarding the whole group. This would be a valuable aid for the superintendent attempting to manage the equipment, resources, space and safety concerns for a given area of the jobsite.

The second recommendation is based on the cognitive demand of functions that obstruct identification of potential conflicts for activities that are non-critical (Table 3, IRs 5.6, 6.3, 8.2, 8.4). There are functions that can help identify critical tasks with a given color, but they can distract the user from identifying tasks that may quickly become critical as they run late. Thus, it is recommended to add color-coded schemes that indicate the total float for task bars, for example, critical tasks identified in red, tasks with small floats in orange and tasks with large floats in yellow. As with the previous recommendation, this functionality would aid the user in identifying potential issues for individual tasks and make feasible alternatives evident in the context of a given area of the jobsite.

To aid the superintendent in relating information across different sources of information, it is proposed to include functions that allow for global identification of information in the project. This third recommendation is related to the superintendents' need to identify important details in the schedule, which is hindered by some functions that limit the capacity to annotate schedule documents (Table 3, IRs 3.3 and 5.4). In particular, coloring and drawing the document can be restrictive compared to work possible in paper documents. In particular, two situations are representative of this problem. One situation is that users are allowed to format the task list, but formatting of the Gantt chart's rows and columns is more limited. The other situation is similar, as the software allows to draw predefined shapes in the Gantt area, but not over the task list, a limitation that the superintendent does not face when using pen and paper. Thus, it is proposed to allow more flexibility for formatting and drawing schedule documents while keeping the schedule's logic. For example, being able to format weekend Gantt columns with one color and crews' vacations in another color would be valuable for the superintendent. Another example is that the superintendent may want to circle or draw arrows over the task names, durations and dates, not just over their duration bars. Addition of text to drawings should also be improved to allow inclusion of notes and comments more freely. Overall, these recommendations should improve the capacity for expressing information relationships in a way that is straightforward for the superintendent.

Other existing technologies are more apt to aid in processing the fragmented, unrelated information that the superintendent encounters in the domain. 4D CAD models integrate a buildings' virtual 3D model with the time dimension of the schedule, and are used by construction practitioners to detect potential time and space conflicts, manage material movement and plan for optimal activity sequence (Riley, 2003). These models explicitly show the relationship between the schedule and drawings, which are two ISs that the superintendent had to deal with separately. Such reduction of ISs would directly account for a reduction in the cognitive load of the user by taking on some of the information relationship tasks.

However, 4D models have not been able to provide users with an appropriate level of details required for each task (Akinci et al, 2002). For example, the simulation for an equipment installation task requires more detail than the simulation of the overall progress of the project. Piping and electric system installation might need details to the nuts and bolts level, while steel erection needs large-scale space coordination details. While this situation is critical for development of comprehensive 4D models, low levels of detail could still provide cognitive support for superintendents by relating the schedule documents with drawings. In particular, the cognitive demands (Table 3) concerning limited visualization of tasks for areas of the project (IR 3.3), determining sequence and interference of tasks (IR 5.4), observing potential delays (IR 5.6) and alternative sequence options (IR 8.6) could all be further reduced with the information provided by a 4D model that is not highly detailed. In addition, an overview of the sequence of work would provide information required to determine the amount of space an activity consumes (DR1), thus expanding on the pieces of information that a scheduling system can provide.

In general, the recommendations above for improving scheduling software can be applied in a 4D environment. Inclusion of functionality that responds to the logical framework that superintendents have of the domain would increase the software's effectiveness in delivering required information. In this sense, it is recommended for 4D CAD software to include functions that allow analysis of the jobsite as a set of areas of work, facilitates by labeling areas, grouping tasks, and admitting input (markups and comments) for these task groups. This is a strategy that the superintendent in this study uses for managing sets of activities, as it can be seen repeatedly throughout the IRs. Also, allowing annotations on the model via text, drawings, and color, provide the practitioner with tools to relate, store and communicate information without adding a cognitive load. Interaction with the model is also a critical issue to consider in future development of 4D CAD tools.

The superintendent's modifications and additions to the schedule documents are in fact visualization techniques that are meant to make relationships between information more explicit. As described by Liston et al. (2000), visualization techniques such as highlighting certain parts of documents or overlaying different pieces of information into a single view enable construction project team members to quickly observe existing relationships between project information. The IRs and ISs show that the superintendent is attempting to gain advantage of quick information processing through visual techniques when he highlights and draws on documents. In turn, the superintendent's capacity to visually relate –and rapidly process– information is notably inhibited by the scheduling software that restricts the capability to produce these visuals. In theory, 4D models can explicitly relate the drawings and the schedule documents, which relieves the user from the cognitive task of relating information across these two sources. With effective visualizations, constraints and rationale inherent to project information are quickly understood, and the superintendent can better compare or evaluate the project information, thus improving the overall decision-making process.

As noted above, there is room for improvement in 4D tools that link schedule to 3D models. However, recent software developments are more responsive to the mental models of field managers, including functionality to define and manage work areas on the jobsite. For example, Bentley's ConstructSim uses 4D technology with work package definitions, and Vico Control™ uses flowline scheduling, both of which improves delivery of IRs for the user in a graphical, straightforward manner. In doing so, there is an increased support for decisions such as potential alternatives for work sequence (DR4), allotting space for individual tasks in certain areas (DR1), identifying activities that are running late (DR6) or activities that could be expedited (DR8). However, while these tools can provide information well suited for some DRs, others remain conceptually unattended, like safety (DR9) and processes (DR3). Similarly, while ISs like drawings are better integrated, information from supervision and meetings is quite unstructured and drive the users' need for flexible annotation tools that are not yet present in these systems. In other words, consideration for the whole set of DRs, IRs and ISs can provide further guidance for future development of effective information tools for field managers.

6. CONCLUSIONS

Existing IT tools supporting the job of a construction superintendent are not as effective as they should be. In many ways they are complicated, difficult to use and do impose an additional mental workload on the superintendent. Furthermore, tools developed tend to support separate job goals. There is limited integration among them. This results in additional cognitive effort for the practitioner. To overcome this problem, there is a need to document the implicit conceptual structure incorporating all the goals to be achieved by the superintendent and the tasks associated with these goals. In this research, a CTA was used to identify and structure the central aspects of the superintendent's job. The framework obtained from this analysis helps define the logical inter-relationships between individual cognitive tasks. The conceptual approach of CTA was reinforced by the artefact-based analyses of the current practices, which identify the gaps between the requirement of the tasks to be performed and the capabilities of the tools to support them. As such, one contribution of this paper is to demonstrate the applicability and usefulness of CTA and related analyses in a construction setting. While time consuming, CTA lends itself to a comprehensive review of work practices. Collectively, the set of decision requirements and supporting information requirements and sources provides a view of needs that is not generally found with other approaches. This can provide new perspectives for the design of tools and processes. Hence, a second contribution of the research is the application of the analysis to generate critique and recommendations for scheduling software. In general, it is recommended that scheduling tools (both traditional CPM based as well as visualization tools) should allow more flexible grouping and commenting across tasks. The advent of new work package based software shows new functionality that is compatible with the analysis and recommendations made above (although there is room for further improvement of the software). It is hoped that further research to extend the documentation of superintendents' cognitive models and follow-on analysis will support further enhancements to software and work processes.

It must be noted that CTA analysis is time consuming. The recommendations and critiques made in this paper are, the authors' believe, well considered and consistent with other literature in construction. However, they ultimately stem from a study with a single (albeit very experienced) superintendent. Further research is needed to confirm and extend the research in this paper. CTA analysis of other superintendents in the context of both similar and dissimilar projects as well as across industry sectors would be helpful in generalizing the findings. Based on the specific critiques and recommendations, more focused research could be developed to test specific propositions. For example, specific exploration of the cognitive demands of marking up drawings/schedules could be developed and tested on a number of subjects. This would be a way to test and extend key CTA findings in an efficient manner that might directly support translation to new software functionality.

7. REFERENCES

Akinci B., Fischer M., Levitt R., Carlson R. (2002). Formalization and automation of time-space conflict analysis. *Journal of Computing in Civil Engineering*. 16(2): 124-134

Ballard G. and Howell G. (1994). Implementing lean construction: stabilizing work flow. *Proceedings, 2nd Annual Conference of the International Group for Lean Construction*, Santiago, Chile.

Barrie D.S. and Paulson B.C. (1992). Professional construction management, *McGraw-Hill*, New York, NY.

Bisantz, A.M. and Burns, C.M. (2009). Applications of Cognitive Work Analysis. *CRC Press*, Boca Raton, FL.

Bisantz A. M. and Ockerman J. J. (2002). Informing the evaluation and design of technology in intentional work environments through a focus on artefacts and implicit theories. *International Journal Human-Computer Studies*, 56: 247-265.

Brynjolfsson, E. and Hitt, L. M., (2000). Beyond computation: Information technology, organizational transformation and business performance. *The Journal of Economic Perspectives* **14(4)**, 23-48.

Burns C.M. and Vicente K.J. (2001). Model-based approaches for analyzing cognitive work: a comparison of abstraction hierarchy, multilevel flow modeling, and decision ladder modeling. *International Journal of Cognitive Ergonomics*, 5(3): 357-366.

Carroll J. and Campbell R. (1988). Artefacts as psychological theories: the case of human-computer interaction. Research Rep. RC 13454. *IBM Watson Research Center*, Yorktown Heights, N.Y.

Carroll J. (2003). Introduction: Towards a multidisciplinary science of human-computer interaction, in *HCI models, theories, and frameworks: towards a multidisciplinary science* (Carroll J., editor), Morgan-Kaufmann, San Francisco**,** 1-10.

Crandall B., Klein G., Hoffman R.R. (2006). Working Minds – A practitioner's guide to Cognitive Task Analysis. *The MIT Press*, Cambridge, MA.

Darse F. (2001). Providing practitioners with techniques for cognitive work analysis. *Theoretical Issues in Ergonomics Science* 2(3): 268-277.

Distefano M.J., O'Brien W.J. (2009). Comparative Analysis of Infrastructure Assessment Methodologies at the Small Unit Level. *Journal of Construction Engineering and Management,* 135(2): 96-107

Elm W., Potter S., Gualteri J., Easter J., Roth E. (2003) Applied cognitive work analysis: a pragmatic methodology for designing revolutionary cognitive affordances, in *Handbook of Cognitive Task Design* (Hollnagel E., editor). Lawrence Erlbaum Publishers, Mahwah, NJ. Ch. 16

Elm W. (2002). Applied cognitive work analysis: ACWA. Unpublished briefing given at *http://mentalmodels.mitre.org/cog_eng/ce_references_V.htm*

El-Mashaleh M.S., O'Brien W., Kang Y. (2006). The impact of IT use at the firm level: an empirical study of contractor performance. *Center for Construction Industry Studies*, Report No. 34, University of Texas at Austin.

Hoffman, R.R. (1987) The Problem of Extracting the Knowledge of Experts from the Perspective of Experimental Psychology. *AI Magazine* 6(2):26-30

Hutton R.J.B., Miller T.E., Thorsden M.L. (2003) Decision-centered design: leveraging cognitive task analysis in design, in *Handbook of Cognitive Task Design* (Hollnagel E., editor). Lawrence Erlbaum Publishers, Mahwah, NJ. Ch. 17

Kieras D. (2004). Task analysis and the design of functionality, in *The computer science and engineering handbook* (Tucker A., editor), 2nd ed. CRC Inc, Boca Raton, FL.

Lean Construction Institute (LCI) (2010). Extracted from *http://www.leanconstruction.com/glossary.htm*

Liston K., Fischer M. and Kunz J. (2000). Designing and evaluating visualization techniques for construction planning. *The 8th International Conference on Computing in Civil and Building Engineering*, Stanford University Silicon Valley, CA., August.

Militello L. G. and R. J. B. Hutton (1998). Applied cognitive task analysis (ACTA): a practitioner's toolkit for understanding cognitive demands. *Ergonomics* 41(11): 1618-1641.

O'Brien W.J., (2000) Implementing issues in project web sites: a practitioner's viewpoint. *Journal of Management in Engineering*, ASCE, 16 (3): 34–39

O'Connor J., Kumashiro M., Welch K., Hadeed S., Braden K., and Deogaonkar M. (2000). Project-and phase-level technology use metrics for capital facility projects. *Center for Construction Industry Studies*, Report No. 16, University of Texas at Austin.

Oglesby C. H., Parker H. W., and Howell G. A. (1989). Productivity improvement in construction, *McGraw-Hill*, New York.

Potter S. S., Elm W. C., Roth E. M., Gualtiere J. W., and Easter J. R. (2002). Bridging the gap between cognitive analysis and effective decision aiding, in *State of the Art Report (SOAR): Cognitive Systems Engineering in Military Aviation Environments: Avoiding Cogminutia Fragmentosa!* (M. D. McNeese and M. A. Vidulich, editors). Wright-Patterson AFB, Human Systems Information Analysis Center, 137-168.

Rivard H. (2000). A survey on the impact of the Information Technology on the Canadian Architecture, Engineering and Construction Industry. *Journal of Information Technology in Construction*, 5:37-56

Riley D. (2003). The Role of 4D Modeling in Trade Sequencing and Production Planning. *4D CAD and Visualization in Construction: Development and Applications*. (Issa R., Flood I., and O'Brien W., editors). The Netherlands, A. A. Balkema**,** 125-144.

Roth E. M., Malsch, N., and Multer, J. (2001). Understanding how train dispatchers manage and control trains: results of a cognitive task analysis, *U.S. Department of Transportation*.

Roth E., Patterson E., Mumaw R. (2002) Cognitive engineering: issues in user-centered system design, in *Encyclopedia of Software Engineering* (Marciniak J.J., editor), 2nd ed. NY: John Wiley and Sons.

Thabet W., and Beliveau Y. (1994). Modeling work space to schedule repetitive floors in multistory buildings. *Journal of Construction Engineering and Management*, 120(1): 96–116.

8. APPENDIX – TABLE OF DECISION REQUIREMENTS (DR), INFORMATION REQUIREMENTS (IR) AND INFORMATION SOURCES (IS)

TABLE A1. Determining the amount of space an activity consumes.

DR1

Determine the amount of space that is required for the task (workspace and storage). (This decision is derived from the need to establish the impact that an activity will have on the entire project.)

Information Requirements	Information Source
IR1.1 What is the area need for the task to be performed? Is the space dynamic?	Drawings provide the location of the activity as well as the quantity of material. The schedule provides an estimate of the duration that will be required to complete an activity. Subcontractors communicate their need for space. Inspection of the intended space to identify any conflicts with other activities.
IR1.2 Will storage space be needed for this activity? (Stored material can interfere with other activities; having material stores not in close proximity to the activity can increase the duration of the activity.)	Drawings will provide the quantity of material needed for the activity. Subcontractors will state their need for storage. Specification may define how materials shall be stored.
IR1.3 Will this activity create new space? (e.g. the addition of floors)	Drawings indicate what the activity will create.
IR1.4 Will this activity consume existing space? (e.g. once carpeting is in place that area is typically not used for storage)	Drawings will identify what is being placed and what is left. Specification may place limits on what can be done once materials are in place. The schedule will provide durations and linked activities.
IR1.5 What is the duration that the space will be consumed?	The schedule will provide the duration for an activity. Subcontractors will communicate their needs
IR1.6 Knowledge of the processes required to complete the activity.	This knowledge is gained for experience, and from communication with the subcontractor.
IR1.7 Identify the space that is available for work and for storage. An assessment of the overall project is necessary. Activities that are in progress as well as activities that are pending need to be considered.	This information is gathered from visual inspection of the jobsite, the information that is gathered from the inspections can be recorded on highlighted drawing, dry erase boards, and / or written or mental notes. Activities that are pending can be determined by looking activities that are nearing completion. The project schedule can be used to identify dependent activities. The 3-week look-ahead schedule is useful in identify activities that are nearing completion as well as activities that are about to start.
IR1.8 Identify the space that is required for equipment. (E.g. crane roads, additional space for scaffolding, etc.)	Drawings provide the location of the activity, this will help determine the method of delivery, and additional equipment required for the installation. Drawings can also be used to identify the access paths for material and equipment. The schedule and the three week schedule will identify activities that are in progress or activities that will be starting. Highlighted drawing may indicate areas that have work in progress, and areas that work

	has been completed. Inspecting the actual area and visualizing the equipment in the area may be necessary.

TABLE A2. Identifying the resources and equipment required for an activity.

DR2

Determine the resources and the equipment that are required for an activity.

Information Requirements	Information Source
IR2.1 What if any equipment is needed for this activity?	Drawings will identify where the activity is located and what materials are being used. This can be used to determine how the materials will be transported in addition to equipment (e.g. scaffolding) will be needed. Communication with subcontractors about their intentions.
IR2.2 Will the equipment consume additional space or interfere with any other activities? (scaffolding takes up additional space and may interfere with activities below)	Drawings and specification will identify the material that will be used in addition to where the material will be placed. Inspecting the area where the work is to be performed to identify what will be needed for the activity. Highlighted drawings that indicate where work is completed and being performed may be used to judge the impact that an activity may have.
IR2.3 Will the equipment work within the limitations of the site? (Will a lift reach that high or will a crane be need, is the soil stable enough to support a crane.)	Knowledge of limits of equipment. Inspecting the site to see if there is room for equipment use.
IR2.4 What resources or equipment are we responsible for (dumpsters, water, electricity, etc.)	Contracts will identify who is responsible for what.
IR2.5 Knowledge of the activity and the processes required to complete it.	Drawings and specification will identify the material that will be used. Communication with subcontractors will identify their intent.
IR2.8 Knowledge of what equipment is on the job site and who is responsible for it and its use.	This knowledge is gained from talking with the subs and inspecting the jobsite.

TABLE A3. Understanding the knowledge of the processes that are involved with an activity.

DR3

Determine the processes that are required to complete an activity.

Information Requirements	Information Source
IR3.1 What materials are used for this activity?	Drawing and specifications identify the material that is required for the activity.
IR3.2 What is the method of installation?	Specifications may specify a specific method of installation. Experience with this specific activity. Communication with subcontractor about his or her plan.

IR3.3 What steps are involved in that completion of the specified activity?	A schedule may have the activity ‘install drywall.’ Installing drywall involves hanging the drywall, taping the joints, and several passes of joint compound and sanding before the activity is complete.
IR3.4 What equipment if any is required for this activity?	Drawings will indicate the area of the activity; this will help determine if equipment is need for the delivery or installation of materials.

TABLE A4. Identifying activity prerequisites and exploring potential alternatives.

DR4

Determine what needs to be accomplished for the activity to start or if there is a way around this. (This decision evaluates the current situation and explores possible alternatives.)

Information Requirements	Information Source
IR4.1 Is this task dependent on the completion of other activities? (e.g. you cannot start sheet rocking until the mechanical and electrical are in place)	The schedule should show what tasks are reliant on this activity. Lowest to highest; Largest to smallest strategy. Drawings provide details of what is required for an activity to start.
IR4.2 How much of a buffer needs to be in place before the start?	What is the rate of installation? How much space is required for the activity? What is the dependent activity, what is it rate of installation, and how much space does it require?
IR4.3 Is there any way to start the activity without the prerequisite? (E.g. can walls be left out until equipment is in place?)	Lowest to highest; Largest to smallest. Drawings are used to identify what needs to be where; they can also be used to identify what can be modified to allow progress to continue. Schedule may be used to analyze alternate sequences.
IR4.4 Knowledge of the activity and the processes required to complete it.	Drawings provide that material and the location of the activity. Communication with subcontractors and experience are used to determine the methods and processes.
IR4.5 What is the status of the submittals? (Work should not begin until submittals have been approved).	The submittal log identifies the status of all submittals. Communication with the field engineers may provide greater insight to the status of a submittal.
IR4.6 Are there any pending change orders or request for information?	Communication with the field engineer.

TABLE A5. Identifying activities that are impacted by an activity.

DR5

Determine the impact that this activity has on other activities.

Information Requirements	Information Source
IR5.1 What activities are reliant on the start	The schedule will identify what activities are critical and their linked activities. Drawings indicate what is required.

or completion of this activity?	Assessment of the current progress on the project.
IR5.2 Is the dependent activity reliant on the completion of the entire task or just part?	Drawings are used to identify what goes where and the order in which they should be accomplished. Communication with subcontractors determines their needs.
IR5.3 What task should receive priority?	Drawings are used to determine which areas have several activities needed. The schedule indicates which activities have long durations, and which activities are critical.
IR5.4 Will this activity interfere with other activities?	An assessment of the current progress on the jobsite is necessary. This is done by inspecting what work is in place. This information can be stored and represented on highlighted drawings and or dry erase drawings. Inspection of jobsite to see if there is enough for the space to be completed. The 3-week look-ahead schedule identifies what activities are in progress, activities that are nearing completion and activities that are pending.
IR5.5 What can be done to minimize interference? (better coordination)	Drawings can be used to identify areas in which work is in progress. Schedule indicates what needs to be complete (critical and non critical). Inspecting the area that the activity is to take place may be necessary to identify any areas of conflict.
IR5.6 If this activity was delayed what would it do to the rest of the project?	The schedule and the three week schedule are used to determine what activities are linked to the activity. The drawings are also used to identify related activities.
IR5.7 What is the area that this activity consumes? (work area, storage area, and access paths)	Drawings indicate the area that activity consumes, and the possible access paths for the activity. Highlighted drawing can indicate areas that are in progress, this can be used to rule out the alternative access paths. Inspecting the site to conceptualize the best path may be necessary.

TABLE A6. Identifying whether an activity will finish on time.

DR6
Determine if an activity is going to meet its scheduled duration.

Information Requirements	Information Source
IR6.1 What is the total amount of work that needs to be performed?	Drawings provide the quantity of work.
IR6.2 What is the amount of work that is already in place?	Inspection of the work that is in place. This can be recorded on highlighted drawings.
IR6.3 How long has that activity been in progress and how much time is left?	The superintendent's daily log should indicate on what day the activity started. The schedule indicates the overall duration of the activity. Communication with the subcontractor to determine the remaining duration.
IR6.4 How many men have been on the job?	Daily reports from the subcontractor indicate who was on the job for them. This sometimes needs to be verified. Communication with the subcontractor can indicate their availability of labor.
IR6.5	This knowledge is gained from communication with the subcontractor. Some contractors

What is the staffing intention of the subcontractor?	may start an activity with little manpower and increase it once the activity is set up. Some subcontractors may send more manpower once they have completed other obligations.

TABLE A7. Establishing buffers for activities.

DR7

Determine how much of a buffer needs to be in place for a linked activity to start.

Information Requirements	Information Source
IR7.1 What is the rate of installation for both activities?	Communication with subcontractor regarding duration. Observed work. Experience.
IR7.2 How much space is required for both activities?	Communication with subcontractor on his or her space requirement. Drawings indicate the area for the activity.
IR7.3 How much time is available?	Schedule.

TABLE A8. Identifying activities that can be expedited.

DR8

Identify activities that can be expedited to get the project back on schedule.

Information Requirements	Information Source
IR8.1 Knowledge of the activity and the processes required to complete it? (is it an activity that can be sped up by increasing the work force)	
IR8.2 What activity is on the critical path that could be expedited?	The master schedule should identify what the critical activities are. The 3-week look-ahead schedule should identify the activities that need to be completed.
IR8.3 Are additional resources available? (Does the subcontractor have more men?)	Communication with the subcontractors might reveal additional resources.
IR8.4 Will the decreased duration of this activity place other activities on the critical path?	The 3-week look-ahead schedule should address the change in the schedule and the impact that it will have.
IR8.5 What needs to be done to get to where the project needs to be?	Work backwards from where you need to be and identify the processes that need to be complete to reach that destination.
IR8.6 What are the different options?	The drawings and the schedule can be used to determine if any other options exist.

TABLE A9. Addressing safety issues of an activity.

DR9
Identify the safety concerns that are associated with this activity

Information Requirements	Information Source
IR9.1 Are hazardous materials used in this activity?	Specifications and drawings indicate what material is used. Subcontractors should provide hazardous material safety data sheets (MSDS)
IR9.2 What are the risks associated with this activity?	Drawings indicate the location of where the work is to be performed. Subcontractors provide their safety plan.
IR9.3 Knowledge of the activity and the processes required to complete it.	Previous experience. Communication with the subcontractor concerning their material and methods.
IR9.4 What can be done to minimize the risk and who is responsible? (E.g. guardrails placed on a leading edge.)	Subcontract may specify that safety concerns need to be addressed.
IR9.5 What subcontractors are working where?	This knowledge is gained from inspecting the jobsite and making note of where the different subcontractors are.
IR9.6 Has the subcontractor provided their safety plan, and have their works gone through our company's safety program.	Review checklist.

TABLE A10. Identifying who is responsible for an activity and what that subcontractor is responsible for.

DR10
Who is performing the activity and what is their scope of work.

Information Requirements	Information Source
IR10.1 Who is the subcontractor?	Subcontractor contract will identify the subcontractor and have contact information.
IR10.2 What is their reputation? (a weak sub may require more guidance)	Word of mouth can provide insight to a subcontractor's ability. Observing the subcontractor ability.
IR10.3 What is their scope of work?	Subcontractor contract.
IR10.3 What is not in there scope and who is responsible for it?	Contracts identify what is to be accomplished by whom.
IR10.4 How many workers do they have on site?	Subcontractor's daily reports indicate the number of workers they had on site.