Contextual Information Requirements of Cost Estimators from Past Construction Projects

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Abstract: Past project data sources provide key information for construction cost estimators. Previous research studies show that relying only on one's own experience during estimation results in estimators' bias. Having and referring to historical databases, containing objective information on what happened in past projects, are essential for reducing estimators' biases. The first step toward development of useful project history databases is to understand what information estimators require from past projects. The research described in this paper targets estimators' information needs identified through interviews, brainstorming sessions, task analyses, and card games conducted with estimators with different experience levels and specialized in heavy/civil and commercial construction projects, and exploration of historical and standard databases available in companies to determine what is being currently represented. Findings show that estimators need contextual information, depicting the conditions under which specific production rates were achieved, so that they can identify which production rate would be more realistic to use during the production rate estimation of an activity in a new bid. Comparison of the contextual information needs identified in this research with information items available in historical data sources (such as company cost reports, RSMeans, previous studies) highlighted some gaps and important opportunities for improvements in those sources. The identified contextual information items are significant for practitioners in developing ways to augment their existing project history databases to make them more beneficial for estimators.

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CE Database subject headings: Databases; Data collection; Costs; Decision support systems; Information systems; Construction management.

Introduction

Historical data about completed projects are important for learning from past projects and for accurate cost estimates (Picken and Mak 2001; Gurfinkel et al. 2006). When cost estimators estimate expected production rates of activities in an upcoming project, they frequently refer to historical data to understand production rates that were achieved for similar activities in past projects. Given that, estimators' contextual information requirements from past projects need to be identified to reduce estimators' biases, which might occur when estimators rely only on their experiences while estimating the production rate of activities in an upcoming project. Estimators' bias can result in underestimation or overestimation of activity production rates in upcoming projects, consequently, in cost overruns or missing job opportunities (Touran 1988; Paek 1993).

When using data from past projects, estimators typically face the situation of having to select from multiple production rates for a given activity. These production rates can highly vary; previous studies show a range of 50–200% difference in production rates achieved during construction in comparison to the estimated values (Kiziltas et al. 2006). In such cases, it is challenging to decide on which production rate to use as a basis of an estimate for a future project; unless estimators know under which conditions activity production rates were achieved in a previous project. Hence, from cost estimating point of view, it is important to have depictions of the conditions under which a production rate was achieved. Such depiction of conditions is referred as "contextual information" throughout the rest of this paper.

This paper describes the results of research done in identifying contextual information requirements of estimators that need to be stored in project histories. In identifying the needed contextual information items, the writers specifically focused on bulk excavation, formwork installation, and concrete pouring of cast-in-place walls and columns, since they are known to be more troublesome at job sites (Burati and Farrington 1987), get affected from a wider variety of factors at job sites, and occur in most projects (e.g., heavy/civil, commercial, and other types of projects). The identified information items were then compared with the findings of previous research studies, items currently being stored in existing industry-wide databases (such as RSMeans) and various examples of company specific project history databases. These comparisons highlighted some gaps and opportunities for improvements that need to be made in existing work and current industry practice to make the historical databases more useful for estimators.

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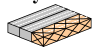
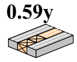
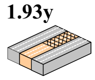
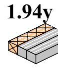
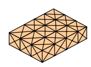
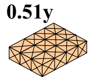
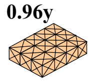
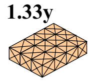
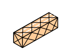
	Estimate prod. rate	Actual prod. rate	Contextual information stated by the project managers
CASE1	1y+	1.3y+  Zone A	Project Manager 1: "We performed the bulk excavation on three stages. This production rate was achieved on an outer stage (as shown with *Zone A)*. We used a *CAT 330* excavator* and *100 ton off-road trucks*, with *short hauling*" *: the authors later identified that maximum bucket capacity of the excavator was 2.55 cubic meters
		0.59y  Zone B1	Project Manager 1: "This production rate was achieved on an inner stage (as shown with *Zone B1)*. We started this stage using a *CAT 330 excavator* and *50 ton trucks* (since the traffic was on), *waited in traffic* for *long hauling distance*"
		1.93y  Zone B2	Project Manager 1: "This production rate was achieved on an inner stage (as shown with *Zone B2)*. We used a *CAT 330 excavator* and *50 ton trucks*, did not have a *traffic* problem, and the trucks had *short hauling distance*"
		1.94y  Zone C	Project Manager 1: "This production rate was achieved on the other end of the road (as shown with *Zone C)*. We used a *CAT 5110* excavator* and *100 ton trucks with no considerable hauling*" *: the authors later identified that it was a mining shovel with a maximum bucket capacity ranging between 7.26 to 7.5 cubic meters
CASE2	0.45y	0.29y 	Project Manager 2: "We performed the excavation work between the station numbers along the *entire width* of the road (hence we had no staging in parallel with the road width). This production rate was achieved with a *CAT 235 excavator* and *50 ton trucks* and up to *610 meters(m) hauling*" *: the authors later identified that maximum bucket capacity was 1.44 cubic meters for soil, 1.15 cubic meters for rock
		0.51y 	Project Manager 2: "This production rate was achieved along the route of the road *without a staging along the road width* with a *CAT 365* excavator* and *50 ton trucks* and up to *610 meters hauling"* *: the authors later identified that maximum bucket capacity was 4.6 cubic meters
	1.26y	0.96y 	Project Manager 2: "This production rate was achieved along the route of the road with a *CAT 5110 excavator* and *100 ton trucks* and up to *610 m hauling"*
		1.33y 	Project Manager 2: "This production rate was achieved along the route of the road with a *CAT 992G* excavator* and *100 ton trucks* and up to *610 m hauling"* *: the authors later identified that maximum bucket capacity ranged between 8.8 and 12.23 cubic meters

Legend  Highway portion  Zone to be considered

+: The actual production rates are not included here as they are considered as company-specific confidential data. Each production rate used in this paper is described relative to an initial baseline estimate, which is referred to as y m^3/man-hr.

Fig. 1. Differences between estimated and actual production rates of bulk excavation activities executed in two case study projects and explanations of project managers as to why such differences exist

Needs for Identifying Contextual Information Requirements of Estimators: Retrospective Case Studies

The writers conducted detailed retrospective case studies on two highway construction projects, with the objective of understanding the current practice of collecting and storing project historical data that will later be used in cost estimates of upcoming projects. The first case study (Case 1) was on a 38-month highway reconstruction project with an estimated cost of $94 million. The second study (Case 2) was on another highway project, with a duration of 40 months and an estimated cost of $23 million with approximately 9.6 km (6 mi) of new roadway construction. On each of the motivating cases, the focus was on bulk excavation, as it was a significant cost item with approximately 13 and 25% of the total estimated project costs and had a large scope with 1 million and 10 million m^3 of excavation, respectively in each case.

Need for Identifying Contextual Information

Exploration of existing data sources showed that production rates for bulk excavation activities executed in two case projects fluctuated significantly (between 50 and 200%) as compared to their estimated production rates (Fig. 1). These fluctuations occurred mainly due to differences in conditions under which specific activities were executed. However, since current project history databases associated with these projects did not contain any information other than production, and crew hours, it became challenging to identify which production rate to choose as a basis for an estimate of an excavation activity in an upcoming project.

To understand the reasons behind the differences observed in production rates, the writers conducted interviews with the project managers responsible for these two retrospective case projects. Fig. 1 also provides statements of the project managers depicting why the observed productivity rates were different from the estimated values. The project managers described reasons behind differences observed as due to utilization of different combinations of equipment and varying hauling distances, as shown in Fig. 1. Their statements given in Fig. 1 were subjective, since, for instance, short hauling was defined as up to 6.4 km (4 mi) [i.e., 6,437 m (21,120 ft)] for Case 1, and up to 610 m (0.38 mi) [i.e., 610 m (2,000 ft)] for Case 2. This demonstrates how the definition of "short" can differ from one person to another; hence is subjective. Considering that in the current practice, estimators rely on their and others' (such as these project managers) experiences in determining the production rate of a future activity, it is clear to see that there will be problems associated with not having all relevant factual data or subjective assessment of a situation observed. Hence, there is a need for identifying contextual information items so as to provide factual information on conditions under which activities were executed and reducing the referral of subjective tacit knowledge of engineers who worked on previous projects.

One of the main challenges associated with identification of contextual information requirements is the fact that there are different information items needed by estimators depending on the type of a construction activity. For instance, as shown in Fig. 1, hauling distance was stated by both managers as a factor affecting the productivity of bulk excavation. However, hauling distance is not relevant for other types of construction activities, such as cast-in-place concrete work. Hence, identification of contextual information should be done in relation to specific set of construction activities to be constructed.

Research Objectives and Scope

Objectives of the research presented in this paper are defined as (1) developing a list of contextual information items for a specific set of activities that commonly occur on construction projects; and (2) conducting detailed assessment of previous research studies, RSMeans, and existing company databases, in satisfying contextual information requirements of estimators.

In identifying contextual information requirements of estimators, the writers focused on three construction activities: (1) bulk excavation activity; (2) formwork installation of cast-in-place walls and columns; and (3) concrete pouring of cast-in-place walls and columns. One of the reasons for selecting these activities to focus on is that they get affected from a variety of different factors occurring on job sites (e.g., unexpected weather conditions, soil conditions), and hence are more troublesome at sites (Burati and Farrington 1987). Therefore, it is expected that focusing on these activities will result in identification of a larger set of contextual information items required by estimators. Second, the nature of these activities is different; some of these activities include temporary work (formwork installation) and others include permanent work (concrete pouring, excavation). These activities are also associated with different types of components and resources; for example, excavation is more equipment intensive, versus concrete pouring is more labor intensive. Third, these activities do not just occur in a specific type of project but occur commonly on different project types, including heavy/civil, commercial, residential, and industrial. Hence, the findings of the research would be applicable and beneficial to a wider community.

Background Research

The research presented in this paper builds on the research studies done for on-site productivity related data collection and analyses, and development of data repositories.

Background Research on Data Collection and Analyses Related to On-Site Productivity

Many research studies focused on identifying data items needed to support productivity analyses (e.g., Russell 1993; Liberda et al. 2003). These studies either defined these required data items at an "activity level" (e.g., Ovararin and Popescu 2001; Kannan 1999) or at a "project level" (e.g., Koehn and Brown 1985; Herbsman and Ellis 1990). Activity-level productivity studies describe factors affecting the productivities of a specific set of activities, whereas project-level productivity studies describe general factors affecting the production rates in project, without focusing on factors specific to certain types of activities.

Productivity Related Studies That Focused on Identifying Activity Specific Factors. While reviewing the background research on activity-level productivity studies, we focused on the research studies related to bulk excavation, and formwork installation and concrete pouring of cast-in-place concrete walls/columns. Table 1 provides a synopsis of the factors identified in previous research studies in relation to the three construction activities stated above.

Many research studies, which focus on forming and concrete pouring of cast-in-place concrete columns and walls, identified factors related to the design of a project (e.g., Staub-French et al. 2003; Thomas and Zavrski 1999). Factors listed in these research studies included component dimensions, shape, orientation, openings/blockouts, and shape changes (e.g., steps on walls). In addition, some previous studies mentioned the impact of site conditions, formwork systems, and management (e.g., Touran 1988), as possible factors impacting the productivity of cast-in-place concrete operations.

Research studies, focusing on excavation activities, identified factors that can be grouped under two categories as operational level and operating conditions. Operational-level factors are related to specific operations (e.g., loading) of an excavation activity (e.g., Kannan 1999). Operating conditions include factors, such as site conditions affecting each operation.

The research presented in this paper builds on the factors identified by previous researchers, integrates and extends previous studies by identifying factors that have not been considered before. Table 1 shows that previous research studies have identified mainly design related factors for cast-in-place concrete forming and pouring activities, and did not state in detail process and site related factors. On the other hand, studies focusing on excavation activities identified process and site related factors and did not state in detail design related ones. Hence, the research described in this paper will complement the previous research studies by identifying groups of factors that were not identified in detail previously.

Project-Level Productivity Studies. Many studies considered factors affecting productivity or data collection needs for a construction project in general, without focusing on specific types of activities (e.g., Koehn and Brown 1985; Russell 1993). Table 1 provides a summary of the findings of these studies. The factors identified in these studies include management approaches, labor motivation, and contract agreements (e.g., Rau 1988) in addition to factors that are relevant to any activity on a job site, such as material availability, site supervision, and work hours (e.g., Touran 1988). These previous research studies were helpful in the research presented in this paper in suggesting ways to categorize the contextual information items that are identified.

Table 1. Summary List of Factors Identified in Previous Research for Concrete Formwork, Concrete Pouring, and Bulk Excavation Activities

	Activity-level factors	Project-level factors
CIP—formwork and concrete work (walls/columns)	*Dimensions of components* (Qabbani 1987; Touran 1988; Hanna and Sanvido 1990; Smith and Hanna 1993; Portas and AbouRizk 1997; Thomas and Zavrski 1999; Staub-French et al. 2003)	
	Shapes of components (Touran 1988; Smith and Hanna 1993; Thomas and Zavrski 1999; Staub-French et al. 2003; RSMeans 2005)	*Weather conditions* (Koehn and Brown 1985; Rau 1988; Touran 1988; Russell 1993; Liberda et al. 2003; Choy and Ruwanpura 2005; Ezeldin and Sharara 2006)
	Openings, boxouts, overhangs, bulkheads, and inserts (e.g., pilasters) on components (Qabbani 1987; Touran 1988; Hanna and Sanvido 1990; Smith and Hanna 1993; Thomas and Zavrski 1999; Staub-French et al. 2003; RSMeans 2005)	*Site congestion level* (Portas and AbouRizk 1997; Liberda et al. 2003; Choy and Ruwanpura 2005)
	Intersection/interactions with other components (Touran 1988; Smith and Hanna 1993; Thomas and Zavrski 1999; Staub-French et al. 2003)	
	Consistency of dimensions and directions of components (Touran 1988; Smith and Hanna 1993; Staub-French et al. 2003)	
	Corners and intersections on components (Qabbani 1987; Smith and Hanna 1993; Thomas and Zavrski 1999; Staub-French et al. 2003)	*Flow/availability of resources (equipment, tools, material) and planning* (Rau 1988; Russell 1993; Makulsawatudom and Emsley 2003; Liberda et al. 2003; Choy and Ruwanpura 2005)
	Repetition of spacing, orientations, and shapes of components (Burkhart et al. 1987; Touran 1988; Smith and Hanna 1993; Staub-French et al. 2003)	
	Stepped and sloped edges on components (Smith and Hanna 1993; Smith and Hanna 1993)	*Working hours (e.g., overtime)* (Liberda et al. 2003; Choy and Ruwanpura 2005)
	Surface finish (Smith and Hanna 1993)	*Crew skills and size* (Russell 1993; Portas and AbouRizk 1997; Portas and AbouRizk 1997; Liberda et al. 2003; Akbas 2003; Ezeldin and Sharara 2006)
	Component locations and elevations (Peurifoy 1979; Qabbani 1987; Bennett 1990; Smith and Hanna 1993)	
	Formwork system type and connections (Touran 1988; Smith and Hanna 1993; Portas and AbouRizk 1997; Ezeldin and Sharara 2006)	
	Formwork/concrete placement method (RSMeans 2005; Ezeldin and Sharara 2006)	*Human factors (morale, learning curve, skills)* (Rau 1988; Liberda et al. 2003)
	Number of reuse/repetition of formwork (Burkhart et al. 1987; Touran 1988; Hanna and Sanvido 1990; Smith and Hanna 1993; Portas and AbouRizk 1997; Ezeldin and Sharara 2006)	*Equipment breakdown and other types of interruptions (e.g., incomplete drawings)* (Makulsawatudom and Emsley 2003; Choy and Ruwanpura 2005)
	Supporting/shoring systems (Hanna and Sanvido 1990; RSMeans 2005)	
	Matching formwork standard size to component size (Touran 1988)	*Equipment/tools sizes* (Rau 1988; Akbas 2003, Liberda et al. 2003)
	Construction joint patterns (Smith and Hanna 1993)	*Rework and change order* (Makulsawatudom and Emsley 2003; Liberda et al. 2003; Choy and Ruwanpura 2005)
	Site conditions (e.g., material storage area, accessibility) (Smith and Hanna 1993; Portas and AbouRizk 1997; Ezeldin and Sharara 2006)	*Government regulations* (Rau 1988) *Contract* (Rau 1988)
Excavation	Operation level factors: *Loading, hauling, dumping, returning times, equipment type, equipment capacity, number of equipment* (Chao and Skibniewski 1994; Kannan 1999; Smith 1999; Shi 1999)	*Project location* (Touran 1988; Portas and AbouRizk 1997; Ezeldin and Sharara 2006)
	Operating conditions: *Depth of cut, Excavated material type, Length of haul roads, Space availability, Weather conditions, Traffic on haul roads* (Chao and Skibniewski 1994; Kannan 1999; Smith 1999; Shi 1999)	*Availability of resources (labor, material, equipment)* (Touran 1988) *Overtime* (Ezeldin and Sharara 2006)

Background Research on Decision Support Systems and Data Repositories Developed to Support Cost Estimating

We explored data repositories developed specifically for cost estimating purpose in previous research projects, to identify potential information requirements of estimators that were already considered in these systems and repositories. We specifically examined lessons learned (LL) repositories (e.g., Kartam 1996; Soibelman et al. 2003), and data warehousing applications (e.g., Chau et al. 2003; Fan et al. 2006), within which learning gained and captured as a result of the best and worst practices and know-how in processes are stored. These two approaches have emerged as a way to capture and reuse lessons and information items re--lated to projects completed in past projects. Preparation of such data repositories require identifying what types of information items should be in them as an initial step. The research presented in this paper provides a set of information items to be represented in such repositories developed for cost estimating purposes.

Research Method

In identifying contextual information requirements of estimators from past projects, we used a triangulation based approach, which involves using multiple sources of evidences based on multiple methods (Yin 2003). We conducted the following data elicitation process in relation to the triangulation:

1. *Interviews and brainstorming sessions* with estimators, during which estimators were asked about possible reasons that might have caused some differences in the production rates of a set of activities that estimators supervised at the job sites. In addition, they were also asked to create a list of contextual information items that they need in relation to activities executed in projects that they did not work in.
2. *Direct observations and task analyses,* which included observing a group of estimators for 6 months during estimating and bidding and analyzing how they were using a variety of data sources. Detailed descriptions were recorded for how estimators used historical data sources and what information items they referred to.
3. *Exploration of the content of historical data sources existing in companies*, to identify the types of contextual information items that are currently being stored.

The elicitation process involves an in depth analysis of estimators' contextual information requirements based on extended discussion sessions with estimators, rather than being based on surveying data or short interviews. There were two criteria used in selecting the participants for the research study. First, participating estimators needed to represent a sample consisting of different experience level, such as junior, senior, and chief estimators. Such a criterion was necessary in demonstrating that the findings of this research represent the information needs of estimators with different experience levels rather than being specific to a specific experience level. Second, participating estimators needed to represent a sample consisting of being experienced with different project types, such as heavy/civil, commercial, and building projects. Such a criterion was necessary in demonstrating that the findings of the research are applicable to construction companies being specialized in different project types. Using these two criteria, it became possible to claim more generality of the research findings than it would have been the case if the participants were selected as only having a certain level of estimating experience or being focused on estimating only certain types of projects.

Participants of the study included 16 estimators, eleven from a company specialized in heavy/civil infrastructure projects (referred to as Company A throughout the rest of the paper) and five from a company specialized in commercial construction projects (referred to as Company B). For literal replication of results, which is replicating the results of a study with another study conducted with a similar group of participants, we divided the available number of estimators in Company A into two similar groups (in terms of their experience levels) and performed the defined set of tasks with each group. Group 1 and Group 2 were composed of five and six estimators of varying experience level (chief, senior, and lead estimators), respectively. We further extended the study, and performed the same set of tasks with estimators in Company B (named as Group 3) for face validation and external validation of the results. This study is detailed in the validation section.

In comparing the findings of this study with the industry practice, we used RSMeans as it is a widely used standard cost database for contractors in North America. Similarly, we used the findings of the research studies detailed in the background section while comparing our findings with the findings stated in previous research studies.

Activity Specific Contextual Information Requirements of Estimators from Past Projects

Contextual information items needed by estimators from past projects were composed in terms of queries that they asked, since estimators articulated these contextual information items as queries during the interviews and brainstorming sessions. Table 2 summarizes these queries. Contextual information items listed in Table 2 are grouped into four categories as

1. *Design related contextual information:* This category consists of data items that are specific to the design features (e.g., height of walls) of component(s) associated with activities. It includes data that can be extracted from design drawings or building information models. Since there are many queries/contextual information items related to design in Table 2, we further subcategorized them. These subcategories include queries related to
   a. *Size,* which includes dimension information and information that can be derived from dimensions,
   b. *Shape and appearance,* which include information related to the appearance of components, such as existence of steps and slopes, and
   c. *Blockouts*, which include openings or joints on components.
2. *Construction process related contextual information:* This category consists of information items that are specific to resources used in a construction process, and that can be collected at job sites or derived from schedules or process models. We further subcategorized this group of information items, as the ones depicting the *labor*, *material and equipment*, and *temporary items* used during the execution of an activity.
3. *Construction site related contextual information*: This category consists of information items that characterize the specific locations/zones within which activities are executed. Examples include site access conditions, soil conditions, and hauling information.
4. *Project characteristics:* This category consists of information items that characterize and depict general conditions of a project, such as its size, type, and owner.

Table 2 lists the specific queries asked by the interviewed estimators in relation to the specific activities focused in this research. There are a large number of contextual information items needed by estimators in relation to an activity. While most of these information items change based on activity type, some of them are common in all three activities focused in this study. For instance, size and dimensions of work, and labor and equipment used are queried by estimators regardless of an activity. These common queries exist since for all components, size, dimensions, and labor impact production rates. The queries that are not commonly asked for all three activities reflect the different nature of the activities. Examples of such unique queries include components with specific design features (e.g., blockouts), material

Table 2. Activity Specific Contextual Information Requirements of Estimators from Past Projects

Activity specific contextual information requirements of estimators from past projects			Construction activity E	W-F	C-F	P
Design	Size	1. What were the average depth of cuts/heights of components?	+	+	+	+
		2. What was the total area of formwork/the surface area of excavation?	+	+	+	+
		3. What were the average length and width of excavation work/components?	+	+	+	+
		4. What was the total volume of work (e.g., each poured section)?	+	−	−	+
		5. Was the work continuous on one location or discrete at multiple locations?	+	+	+	+
		6. What was the form factor (i.e., formwork area/volume of concrete in a pour)?	−	+	+	+
	Shape and appearance	7. Were there steps on building components (e.g., walls) or were they flat?	−	+	+	+
		8. Were the components battered or did they have constant width?	−	+	+	+
		9. Did the components have constant height or was the height changing?	−	+	+	+
		10. How was the shape of the components (e.g., straight, curved, clipped)?	−	+	+	+
		11. What kind of surface finish was required? Was a special formliner required?	−	+	+	+
		12. Were there any pilasters, bulkheads, overhangs, and anchor blocks?	−	+	−	+
		13. Were the components waterproofed?	−	+	+	+
	Blockout	14. Were there any openings?	−	+	−	+
		15. Were there any incidental items/embeds? (e.g., water-stops, weep pipes)?	−	+	+	+
		16. Were there any construction/expansion joints? How many?	−	+	+	+
Construction process	Equipment	17. What were the types and sizes of equipment used to perform operations?	+	+	+	+
		18. What were the types and number of equipment used (e.g., number of hauling units)?	+	+	+	+
		19. How was the equipment condition (i.e., number of years served)?	+	+	+	+
		20. What was the percentage of equipment failure?	+	+	+	+
	Labor	21. What was the crew composition?	+	+	+	+
		22. Was the crew composition available that was in the initial bid?	+	+	+	+
		23. What was the skill level of crew (i.e., ave. years of experience of all workers)?	+	+	+	+
		24. Which shift (i.e., day shift, night shift) was the crew working?	+	+	+	+
		25. Did the crew work straight time or overtime on the average?	+	+	+	+
	Material	26. What was the strength and slump of the concrete used?	−	−	−	+
		27. What was the concrete pour rate (i.e., ft/hr) for components?	−	−	−	+
		28. What was the yield percent of concrete (i.e., waste)?	−	−	−	+
		29. What were the types (e.g., wooden), the sizes and the brands of formworks?	−	+	+	−
		30. How was the condition of formworks (i.e., brand new, new, old, very old)?	−	+	+	−
		31. What was the forming context (e.g., one sided forming, two sided forming)?	−	+	+	−
		32. Was the formwork height compatible with component height?	−	+	+	−
		33. What was the gang form size (i.e., sf of ganged-panels)? Was it new assembly?	−	+	+	−
	Temporary	34. What was the number of pours per subsystem (e.g., foundation)?	−	−	−	+
		35. What type of bracing was used to stabilize forms?	−	+	+	−
		36. Was winter protection required during concrete curing?	−	−	−	+
		37. Did the excavation work require temporary support?	+	−	−	−
		38. How was the excavated dirt managed at job site (i.e., hauled, stockpiled)?	+	−	−	−
		39. Was dewatering required on the job site?	+	−	−	−
Construction site		40. What was the type of site (i.e., green-field or brown-field)?	+	+	+	+
		41. How was the access to the site (e.g., bounded from one side, all sides)?	+	+	+	+
		42. How was the ground condition (e.g., hard and even, wet and slushy)?	+	+	+	+
		43. What was the soil type?	+	−	−	+
		44. What was the rock ratio in soil?	+	−	−	+
		45. What was the percentage of moisture content in soil?	+	−	−	+
		46. Where were the components located at the site (i.e., at, above or below grade)?	−	+	+	+
		47. What was the average hauling distance, direction, grade, width of haul roads?	+	−	−	−
		48. Were there any existing utilities/wires on the area (e.g., in excavation zone)?	+	−	−	−
		49. How was the weather (e.g., ave. temp., rain/snow; what was man hours lost)?	+	+	+	+
		50. What was the time of year (e.g., summer, winter) during activity execution?	+	+	+	+
		51. Was traffic a factor around the job site (i.e., hours lost due to traffic)?	+	+	+	+
		52. How was the concrete delivery quality (i.e., right quality, quantity, prompt)?	−	−	−	+
Project characteristics		53. Who were the owner and the manager? Where was the project located?	+	+	+	+

Note: E (excavation activity); W-F (wall formwork installation activity); C-F (column formwork installation activity); P (wall and column concrete pouring activity); (+) shows that a contextual information is applicable to an activity; and (−) shows that a contextual information is not applicable to an activity.

types (e.g., hand-set formwork versus panels), and being susceptive to certain site conditions (e.g., soil conditions).

Another observation related to Table 2 is the number of queries within each category of contextual information. This number changes with the types of activities. Estimators would like to know more information items about design conditions or used material types for forming and concrete pouring of components as opposed to a bulk excavation activity, since wall and column components incorporate specific design features or materials. At the same time, the number of construction-site related and equipment related queries are larger for excavation activities than forming and concrete pouring activities, since excavation activities get impacted more by the performance of the equipment used.

The next analysis that was performed by the writers was to identify the frequency of referrals of contextual information items by estimators. Table 3 provides the frequencies of referrals of each identified activity specific contextual information item by estimators based on their experience levels. Bold and italic written contextual information items have been identified as the most frequently referred information items by all the three groups of estimators. Bold and italic written items also could be stated by Group 1 or Group 2, and 3 (i.e., from both companies), as Group 1 and Group 2 are almost identical and belong to the same company. Bold written ones represent the information items that were frequently referred only within Group 3, and the underlined ones represent the items that were frequently referred information items only in both Group 1 and Group 2.

The most frequently referred contextual information items by all the groups of estimators were highlighted in Table 3 with bold and italic text. The most frequently referred items from design related contextual information group include information items from all subcategories, such as size, shape, and blockouts for formwork and concrete pouring activities. From the other categories of contextual information items, for formwork activities, formwork characteristics, such as type, brand, number of reuses, forming contexts were frequently referred by estimators; whereas soil type was specific to excavation activities and also frequently referred. Similarly, for all the three activities, equipment information, crew composition, time of year for activity executions, and project characteristics were referred frequently.

Information items, which were most frequently referred by the estimators in Group 3 and not frequently referred by Group 1 and Group 2 estimators, represent information items that are important for activities executed in commercial construction projects, but not as frequently referred in heavy/civil construction projects. These information items (i.e., items written as bold in Table 3) include existence of openings, incidental items/embeds within building components and strength of concrete for formwork and concrete pouring activities, and dirt management at job site for excavation activities. The reason why these information items are referred by majority of the estimators in Group 3 is that walls in commercial building projects have such features more commonly as compared to retaining walls in heavy/civil projects that typically do not have such features. Excavated material is usually stockpiled in commercial projects if site has extra space, and not hauled to long distances, as compared to heavy/civil projects. That is why dirt management is highly referred in Group 3.

The information items that were frequently referred by only within Group 1 and Group 2, and not in Group 3 are also shown in Table 3 with underlined text. This group of information items represents the information items that are highlighted by the estimators who have experience in heavy/civil construction projects. Examples include whether the work is similar and continuous at the job site or discrete at multiple locations, heaving battered components or not, hauling distance, weather conditions, and site access conditions.

To understand the importance of experience levels of estimators on the identified information items, we analyzed the queries asked by estimators of different experience levels. Each group of estimators (e.g., Group 3) was formed to include at least one chief, senior, and lead estimator. Titles of estimators were given by their companies based on the number of years served. Table 3 shows that the number of information items identified by estimators was close for the three experience levels. However, senior estimators' contribution was the highest, as they identified more information items as compared to lead and chief estimators. It is because senior estimators are more experienced as compared to lead estimators, and more involved with basic estimating stuff as compared to chief estimators, who are more involved with controlling and finalizing the bids. Information items that were only identified by chief and senior estimators but not identified by lead estimators, include crew composition, availability of the same crew composition decided in the bid for all activities, and the number of pours and concrete delivery quality for concrete pouring activities. Only one information item was only identified by chief estimators, but not by senior or lead estimators, as "percentage of equipment failure"; one information item was only identified by lead estimators as "straight time versus overtime"; and three information items were only identified by senior estimators as "width and lengths of components," "equipment condition," and "type of site."

As a summary, this analysis shows that information items listed in Table 2 are not identified by each estimator but by a collective effort of all the participating estimators. Though some of the information items were highly referred by majority of the estimators, this analysis showed that there are information items that are needed by estimators from a certain experience level, and hence all identified information items need to be stored in project histories for future use.

Assessment of Existing Company Specific Project History Data Sources in Supporting Contextual Information

Two major categories of data sources, which contain information and data about past projects, exist in construction companies. These are *primary* and *secondary* data sources. Primary data sources are the ones that an estimator has direct access to and frequently use during estimating. Examples of primary data sources are cost reports, corporate production databases, and estimators' folders including information about the actual and estimated production information on past projects by a company. Secondary data sources are the ones that estimators do not have direct access and infrequently use during estimating. Examples include drawings, time cards, and schedules of previous projects. Among primary data sources, we studied 65 cost reports, two corporate production databases, and 16 estimators' folders from two construction companies. Among secondary data sources, we studied 330 time cards, generated for a month by eleven foremen in a previous project.

Our studies on primary data sources showed that, all the explored primary data sources provided data to answer the query asking for *total quantity of work,* listed under the size subcategory, and among the secondary data sources, time cards provided this information item in different percentages. However, data for

Table 3. Referral Frequencies of Contextual Information Items by Estimators

Activity specific contextual information needs of estimators from past projects			Groups G1	G2	G3	Experience C	S	L
Design	Size	1. ***Average depth of cuts/ heights of components***	***5/5***	***6/6***	***5/5***	+	+	+
		2. ***Total area of formwork/the surface area of excavation***	***4/5***	***4/6***	***3/5***	+	+	+
		3. Average length and width of components	1/5	4/6	2/5	−	+	−
		4. ***Total volume of work***	***3/5***	***4/6***	***5/5***	+	+	+
		5. *Continuity and similarity of work on multiple locations*	*4/5*	*4/6*	2/5	+	+	+
		6. Form factor (i.e., formwork area/concrete volume)	1/5	2/6	2/5	+	+	+
	Shape and appearance	7. ***Existence of steps on building components***	*2/5*	***6/6***	***4/5***	+	+	+
		8. *Battered or constant width components*	*5/5*	*6/6*	1/5	+	+	+
		9. Constant height of components	1/5	1/6	2/5	+	−	+
		10. ***Shape of the components***	***5/5***	***6/6***	***3/5***	+	+	+
		11. ***Surface finish of components***	*2/5*	***5/6***	***5/6***	+	+	+
		12. ***Existence of pilasters, etc.***	*2/5*	***5/6***	***4/5***	+	+	+
		13. Waterproofing	0/5	1/6	1/5	−	+	+
	Blockout	14. **Existence of openings**	2/5	2/6	**3/5**	−	+	+
		15. **Incidental items or embeds**	1/5	2/6	**4/5**	−	+	+
		16. ***Location and number of construction joints***	*1/5*	***4/6***	***5/5***	+	+	+
Construction process	Equipment	17. ***Types and sizes of equipment used***	***5/5***	***6/6***	***5/5***	+	+	+
		18. *Number of pieces of equipment used*	*4/5*	*4/6*	1/5	+	+	+
		19. Equipment condition	1/5	1/6	1/5	−	+	−
		20. Percentage of equipment failure	1/5	0/6	0/5	+	−	−
	Labor	21. ***Crew composition***	*2/5*	***5/6***	***3/5***	+	+	−
		22. Availability of crew used in bid during construction	1/5	0/6	1/5	+	+	−
		23. Skill level of crew	2/5	2/6	0/5	+	+	+
		24. Crew's working shift	1/5	3/6	2/5	−	+	+
		25. Straight time or overtime	1/5	0/6	0/5	−	−	+
	Material	16. **Strength and slump of concrete**	0/5	0/6	**5/5**	+	+	+
		27. Concrete pour rate	1/5	4/6	2/5	+	+	+
		28. Yield percent of concrete	2/5	4/6	1/5	+	+	+
		29. ***Types, sizes and brands of formworks***	***5/5***	***6/6***	***5/5***	+	+	+
		30. Condition of formworks	0/5	2/6	0/5	−	−	+
		31. ***Forming context***	*2/5*	***4/6***	***5/5***	+	+	+
		32. Formwork height compatibility	0/5	1/6	1/5	−	+	+
		33. ***Gang form size, new assembly or reuse***	*2/5*	***3/6***	***4/5***	+	+	+
	Temporary	34. Number of pours	0/5	2/6	1/5	+	+	−
		35. Type of bracing	0/5	2/6	2/5	+	+	+
		36. Winter protection usage	0/5	1/6	1/5	−	+	+
		37. Temporary support usage	2/5	2/6	0/5	+	−	+
		38. **Dirt management**	2/5	2/6	**4/5**	+	+	+
		39. Dewatering	1/5	2/6	2/5	+	+	+
Construction site		40. Type of site	0/5	0/6	2/5	−	+	−
		41. *Site access to the site*	*4/5*	*5/6*	2/5	+	+	+
		42. Ground condition	3/5	3/6	1/5	+	+	+
		43. ***Soil type***	***5/5***	***6/6***	***5/5***	+	+	+
		44. Rock ratio in soil	5/5	2/6	2/5	+	+	+
		45. Moisture content in soil	4/5	2/6	1/5	+	+	+
		46. **Component locations**	2/5	3/6	**3/5**	+	+	+
		47. *Hauling distance, etc.*	*5/5*	*6/6*	1/5	+	+	+
		48. Existing utilities/wires on the work area	2/5	4/6	1/5	+	+	+
		49. *Weather condition*	*3/5*	*5/6*	2/5	+	+	+
		50. ***Time of year***	***4/5***	***4/6***	***3/5***	+	+	+
		51. Traffic around job site	0/5	2/6	1/5	−	+	+
		52. Concrete delivery quality	3/5	1/6	1/5	+	+	−
Project characteristics		53. ***Project location, owner, manager***	*2/5*	***4/6***	***3/5***	+	+	+

Note: G1/G2: Group 1 and Group 2 estimators from Company A; G3: Group 3 estimators from company B; C: Chief; S: Senior; L: lead estimators; ***bold and italic***: high-frequently referred items by all the groups of estimators or Group 1/2 and Group 3; **bold**: high-frequently referred items only in Group 3; *italic*: high-frequently referred items only in Group 1 and Group 2.

the rest of the queries within the size subcategory, such as dimensions of components, were not stored in either category of data sources. In estimators' folders, we observed some comments related to the component dimensions next to production rates for the projects listed in a folder by an estimator. These comments, such as 'deep shallow cut' or 'wide-long cuts' were rare (around 5% considering all the examined folders and projects listed in them), subjective, and not helpful for estimators, who are not familiar with the particular project during which the production rates were achieved. Queries within the subcategories of shape and appearance, and blockouts were not stored in primary or secondary data sources for estimators even though queries related to such information were more frequently asked by estimators (Table 3). Within estimators' folders, next to production rates, there were also some comments (e.g., wall top elevation changing, wall on slight curve) related to shape and appearance subcategory; however, these comments were also subjective and were misleading.

Within the construction process category of contextual information, information about labor and equipment subcategories were available on daily timecards and in corporate production databases (as typical crew composition); whereas the rest of the data required under that category (refer to Table 2), such as crew overtime and specific material information (such as formwork types, gang sizes), were not stored in company specific data sources. Generally, the information stored in primary and secondary data sources include equipment and labor information as equipment type, and typical crew compositions.

With respect to the remaining two categories of contextual information, construction site related information items (e.g., soil type in an excavation activity, weather condition) were not stored in primary data sources. Other than weather conditions, secondary data sources do not contain information about the information items listed within the construction site group. Project characteristics were usually appeared in the cover page of each cost report.

An assessment of the company specific data sources showed that cost reports and corporate databases do not contain information about 86% of all the queries listed in Table 2 and estimators' folders do not contain information about 72% of the queries. Considering all the primary data sources, 86% of contextual information items needed by estimators from past projects do not exist in primary historical data sources. The primary data sources do not store contextual information items other than project type, owner, location, hauling distance, total quantity of work (area, volume), and type of equipment. In terms of secondary data sources, about 70% of queries cannot be answered with the information stored in time cards. All of these results highlight that currently company specific data sources do not contain majority of the information items needed for supporting estimators' decisions.

Assessment of Previous Research Studies and Existing Standard Databases in Supporting Contextual Information

This section provides an overview of the assessment of previous research studies and existing standard databases in accommodating estimators' contextual information requirements. Productivity effecting factors, defined by RSMeans and the previous research studies, overlap with most of the queries identified in this research. However, there are still things that estimators would like to know in detail from a past project but not mentioned in either previous studies or in RSMeans. Given Table 2, approximately 26 queries were not mentioned in either previous studies or in RSMeans. These missing items are distributed across different categories

1. For the information items identified in the design related contextual information category, total excavation area, form factor, and incidental items were not explicitly mentioned in previous research studies; whereas continuity of similar work in one location or being distributed over multiple locations, form factor, steps on building elements, and changing height of building elements along their lengths were not mentioned explicitly in RSMeans.
2. For the information items identified in construction process category, equipment condition, availability of estimated crew composition during construction, pouring rate of concrete, formwork conditions, forming context, and dirt management at job site were not highlighted in both of the data sources explicitly. In addition, height compatibility of formwork was not listed in RSMeans, whereas strength of concrete, yield percent of concrete, winter protection, temporary support, and dewatering were missing from the previous studies.
3. For construction site related category; site type and concrete delivery quality were not mentioned in either of the two sources. Existence of traffic on haul roads, and ground conditions were additional information items that were missing from RSMeans.

In summary, standard databases and a collection of previous research studies were good sources for indicating the factors affecting productivity of activities; however, there are still gaps in supporting estimators' contextual information requirements. The information contained in these sources should be augmented to include the items that are currently missing.

The research presented in this paper provides a detailed analysis of information requirements of estimators by depicting what should be represented in project histories in a structured way for estimating purposes. There are several ways of recording and storing the identified information items. Examples of data recording approaches are mobile handheld devices, or reality capture technologies (e.g., laser scanners, radio frequency identification tags, on board instrumentations), whereas examples of data storing approaches are forming project specific databases, or datawarehouses depending on company practices. One possible approach for recording and storing estimators' information needs is overviewed in Kiziltas and Akinci (2008) and builds on the findings detailed in this paper. This approach is composed of two modules. The first module enables automated identification of estimators' contextual information requirements for different activities using a construction-method specific approach. Using the developed approach, estimators can generate customized data collection templates for each construction method used at a job site. Once information items needed by estimators are collected, they can be stored in a structured way to help estimators understanding the context under which each production rate of activities was achieved. In this module, project design and construction information stored in a project model is augmented with collected production and contextual information for each activity. These approaches will have different costs depending on the technologies available and company practices performed. Hence, the identified information items can be used to compare different data capturing and storing approaches in terms of their capabilities.

The findings also constitute a good foundation for assisting estimators while estimating activity production rates, by defining their information needs from past projects. Production rates can be calculated and provided to estimators for any activity of inter-

Table 4. General Information about the Participants of the Study from Two Construction Companies

4a Company A: heavy/civil				4b Company B: commercial	
Group 1		Group 2		Group 3	
Title of estimator	Experience level (years)	Title of estimator	Experience level (years)	Title of estimator	Experience level (years)
Chief	35	Chief	27	Chief	28
Senior	24, 28	Senior	24, 25, 26	Senior	15, 30
Lead	15, 25	Lead	10, 10	Lead	12, 26

est together with collected contextual information items. With this, estimators will be able to base their estimates on factual historical data, which is expected to eliminate estimators' bias and improve accuracy of cost estimates.

Validation and Analyses of Results

Our validation of contextual information requirements included three methods as (1) *literal replication*, which is replicating the results of a study conducted with a user group with another group having similar characteristics (i.e., same experience levels and project types in this case) with the initial group; (2) *face validation*, which is evaluating a set of findings to determine if a group of participants believe that these findings define what were initially anticipated to be obtained (Kidder and Judd 1986); and (3) *external validation*, which is conducting the same set of studies that was done with a group of estimators that is not similar to the previous groups in terms of project types that they are experienced in.

For literal replication, we divided the estimators in Company A into two equal groups based on their experience levels, and used one of the groups (i.e., Group 2) to check whether the results obtained with the first group (i.e., Group 1) are replicated with them. Table 4 gives an overview of the participants in both of these groups. The initial list of contextual information requirements identified through Group 1 was comprehensive such that they were replicated within the second group of estimators as shown in detail in Table 3. Among the 53 identified information items listed in Table 3, 44 of them (shown with zero frequencies) were identified collectively by Group 1, and among these 44 items, all were identified by Group 2 as well, other than three information items. These three items are (1) availability of the crew decided in the bidding during construction; (2) crew overtime; and (3) equipment failures, as detailed in Table 3. In addition, there were information items that were identified by Group 2 but not by Group 1 among the 53 information items listed in Table 3. There are seven such information items, as listed in Table 3 (with Group 1 with zero frequency and Group 2 as nonzero). Examples from these seven information items include existence of pilasters, height compatibility of components and formwork, and temporary structures. The ratio of the newly identified items by Group 2, with respect to all identified information items from Group 1 (i.e., 7/53), and the ratio of the missed information items by Group 2 to all identified information items are quite low (i.e., 3/53). Hence, we can confidently state that the results were successfully replicated.

For external validation, the objective was to see how representative the identified contextual information requirements were for estimators who were working on different project types. In this research project, the face validation was done with estimators working on commercial projects since the initial elicitation and literal replication were done with the estimators working on heavy/civil infrastructure projects. Table 4 provides an overview of the participants from Company B that is specialized in commercial construction projects. The objective was to see how representative the identified contextual information requirements would be for estimators working in different companies. As shown in Table 3, among the 53 information items, five of them could not be identified by Group 3 estimators. These information items appear in Table 3 with zero frequency for Group 3 and nonzero by at least Groups 1 or 2. These were (1) percentage of equipment failures, (2) skill level of crews, (3) crew overtime, (4) condition of formworks, and (5) temporary support for excavation activities. Similarly, two information items (i.e., type of site and concrete strength) were identified only by Group 3 but neither by Groups 1 nor 2. Since the external validation percent is high ($\sim$91%), we can conclude that identified items are representative as the activities focused in this research are executed in different project types.

For face validation, we designed a card game and played it with all the estimators participated in our research (i.e., with Group 1, Group 2, and Group 3). The idea behind the card game was to understand whether the contextual information requirements identified during elicitation and literal replication processes were representative of what the estimators actually meant to say. So, in the card game, we combined the contextual information requirements identified through the elicitation and literal replication processes, and represented each information item as a card. The card game has a collection of cards, and each card in a given game provided a value for a specific contextual information that an estimator might need for an activity executed in a past project. Each estimator was asked to estimate the production rate of a specific activity using historical data provided in the cards. Estimators could not see what were written on the cards unless they specifically asked for the information item written on a card. Whenever an estimator queried for a specific information item, the relevant card was given to the estimator, and hence the estimator got the data values for a specific contextual information item. This game continued until an estimator said s/he needed no more information items to make a decision. A detailed discussion of the developed card game is provided in Kiziltas et al. (2007). Cards included actual production and contextual information observed during a bulk excavation activity, formwork installation and concrete pouring of wall and column elements. These activities were executed in a seven-storey condominium project and a highway construction project.

For face validation results we looked at the (1) average results of all card games in terms of the number of information items that were available and used; (2) average number of information items that were available and not used; and (3) maximum number of unavailable and requested information items, for helping estimation of production rates for each construction activity. The maximum number of additional information items requested in card games was four and occurred for a card game for excavation activity. The information items that were requested but not initially in the cards for an excavation activity were (1) correctness of the survey points required for calculation of volume of work; (2) speed limit for the haul roads; (3) existence of mines underneath the excavation activity; and (4) special treatment for hazardous material within an excavation zone. Similarly, maximum two information items were additionally requested in a card game for formwork activities as (1) special preparation for walls having formed on only one side and (2) schedule constraints.

As a very small set of information items were missing from the cards, the validation result provides evidence that the information items available in the card games were comprehensive enough to represent possible contextual information requirements of estimators for the activities focused in this research. It was found out that those information items were not directly related to the scope of the research (such as correctness of the survey points, existence of mines underneath excavation zone). However, speed limit, schedule constraints, and special preparation for one-sided walls should be included into the list of contextual information presented in this paper.

As shown in Table 4, the identified contextual information requirements are not specific to a given estimator experience level but incorporate collective effort of estimators having experience levels ranging from 10–35 years. Similarly, card game results were related to two different project types and were not specific to a certain group of estimators having the same experience level. These results show that the contextual information requirements identified in this paper reflect the needs of estimators of a wider experience range, and working on different project types and in different companies.

Conclusion

Contextual information items depict the conditions under which an activity was executed in a past project and needed by estimators while estimating activity production rates in new bids. The contextual information items, identified for three construction activities [i.e., bulk excavation, cast-in-place (CIP) concrete pouring, and forming of walls and columns], can be grouped into four categories as (1) design related (e.g., number of openings on walls); (2) construction process related (e.g., type of formwork used); (3) construction site related (e.g., site access conditions); and (4) project characteristics (e.g., type, size, and owner of projects).

The research highlighted existing gaps within standard databases and company specific databases in supporting estimators' contextual data requirements. Gaps included several missing contextual information items within design, construction site, and construction process categories, such as form factor, forming context, and traffic on hauling roads.

The list of contextual information requirements of estimators from past projects provided in this research can be used in future research studies, focusing on developing a formalism to formally identify estimators' contextual information requirements for different construction activities. Similarly, research studies, which focus on developing an approach for integrated storage of project histories for estimators, can build upon the findings of this paper. These contextual information requirements can also be used by construction companies in augmenting what needs to be represented in company specific databases.

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