THE PRACTICAL NEEDS OF INTEGRATING SCOPE, COST, AND TIME
Integrating scope, cost, and time

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Abstract

The primary goal of tracking scope, cost, and time throughout the construction process is to facilitate the early detection of problem activities that are running over budget or falling behind scheduled progress. Current practice tracks this information using separate processes, which leads to inconsistencies between the information and inaccuracies when determining the cost and schedule status. Project managers need an integrated suite of project management tools so that the project's scope, cost, and time are in sync and the work in place is accurately reflected in the project control system. In this paper, we will provide a case study that demonstrates the practical needs of project managers to support integration throughout the life of a project. We will also demonstrate how those needs are not being addressed by existing software tools, by standards developed for the project management domain, and by information models that have been developed in research. This paper will show that the following issues must be addressed to enable the integration throughout the construction process: the information must be integrated at the start of construction; the mapping scheme between the different hierarchical representations of scope, cost, and time must be defined; and the shared information must be defined.

Keywords: cost control, integration, schedule, project, construction, scope, design

1   Introduction

Integrating design, cost, and schedule information is not a new concept. Researchers and practitioners alike have been discussing the need for integration for decades. In 1985, the ASCE issued a report on Construction Cost Control that stated "the data collected for cost control (man-hours, cost, quantities of work performed) can be utilized for updating the schedule and can be utilized for earning calculations. This multiple use of data contributes to the overall accuracy of reports and significantly reduced the manual effort to enter data" (Carty 1985). However, despite technological advancements in the last 15 years, design, cost, and schedule information continues to be generated and maintained using separate processes, which continues to produce inconsistencies between the different types of information. Today, project participants update and maintain their part of the project control system based on their understanding of the project's status using the application that suits their needs. In an ideal world, contractors would enter information once, the project control system would be updated to reflect changes, and the project's cost and schedule status would be easily obtained. The solution to this problem would be to integrate the suite of project management tools so that the project's scope, cost, and time are in sync and the work in place is accurately reflected in the project control system.

So why are we still working in this less than ideal environment? Why is it so difficult to integrate this information? Our research addresses these questions. In this paper, we will discuss the following:

- the integration that is supported by information models developed in research, standard object definitions, and existing software tools,
- the issues that make integrating design, cost, and schedule information throughout the construction process difficult, and
- necessary research.

1.1   Practical motivation

Imagine being in the shoes of the general contractor who is responsible for constructing a highly technical building project for a pharmaceutical company. The project is under tight schedule constraints, requiring completion in nine months. In this example, we will be focusing on the foundation work but similar issues exist for all types of work. You have decided to self-perform most of the concrete foundation work, which consists of spread footings, grade beams, and a slab. Your direct work includes foundation excavation, concrete placement, and formwork, as you have subcontracted the reinforcing steel and concrete finishing. Consequently, as the general contractor, you are focused on controlling costs for your direct work, monitoring costs for subcontractors for billing purposes, and tracking schedule progress for all the work. You have allowed six weeks in the construction schedule to complete all the foundation work. As the foundation work approaches the fourth week of schedule progress, you might ask yourself:

- Do I have enough money in the budget to complete the foundation work?
- Have I allowed enough time in the schedule to complete the foundation?
- Is there enough time for my subcontractors to complete their work?

Contractors rely on their project control system to help answer these questions and facilitate the early detection of problem activities that are running over budget or falling behind scheduled progress. Project managers spend extensive amounts of time tracking costs and mapping them to the appropriate cost code, tracking quantities and measuring resource performance, and updating the construction schedule. Project managers use this information to forecast their total cost, which is based on the progress to date and costs incurred to date, and forecast their scheduled completion date. Yet how can contractors rely on these forecasts when there is no explicit relationship between the scheduled progress, resource performance, and the forecasted cost? Contractors track quantities to evaluate resource performance, yet this information is usually not explicitly related to the corresponding activity's progress. Contractors need to know the current schedule progress to forecast the total costs, yet there is no explicit relationship between costs and schedule status. Moreover, the information is generated and maintained by different people who organize the information in different ways to support their view of the project. In summary, contractors need a flexible yet consistent approach to model and track this information.

In the next section, we will describe previous research and standards developed to support the integration of scope, cost, and time throughout the life of a project.

1.2 Technological motivation

There has been a significant amount of research on integrating design, cost, and schedule information. The focus of these research efforts varies from developing construction information models to developing prototype systems that support integration (Luiten et al. 1993; Luiten 1994; Aouad et al. 1994; Björk 1992; Froese 1992; Tolman, Bakkeren and Böhms 1994; Stumpf 1996; Tracey 1996). Froese (95) summarizes some of these research efforts and the conceptual models that have been developed to support computer integrated construction. In addition, substantial progress in developing standards has been made in the past several years. The Industry Alliance for Interoperability (IAI), an industry-based consortium, is developing standards for exchanging data between computer systems within the AEC industry in the form of Industry Foundation Classes (IFC's) (IAI 1998). These standards explicitly define the design components and the relationships between scope, cost, and time.

These research efforts and standards have laid the groundwork for developing integrated systems by describing the information that needs to exist and providing conceptual models that describe the relationships. These conceptual models represent a system-based approach that provides a structured framework for integrating scope, cost, and time. Such structure, however, does not allow project managers the flexibility needed for managing and sharing this information for the life of a project. Specifically, these models and standards do not formalize the relationships required to

maintain integration as the information changes, share information that is represented at different levels of detail, and support integrated time and cost control. In this paper, we demonstrate the need for these relationships, describe the relationship classes that must be provided, and identify the relationships that previous research and standards have not modeled.

Through case example, we illustrate the needs of project managers for integrated information and the modeling requirements to enable integration throughout the construction process. Specifically, we show that the following issues must be addressed to provide an integrated model:

- the information must be integrated at the start of construction,
- the relationships between the different hierarchical representations of scope, cost, and time must be defined, and
- the shared information must be defined.

In the following sections, we will discuss each of these issues and the related research opportunities.

2   Integration of scope, cost, and time prior to construction

Contractors must have an integrated scope, cost, and time model at the start of construction to maintain integration as construction progresses. If there are inconsistencies between the scope, cost, and schedule information prior to construction, then this information will never be in sync as construction progresses. We looked at the U.S. software market and picked the best suite of tools and tested their integration capabilities on an actual construction project (Staub et al. 1998).
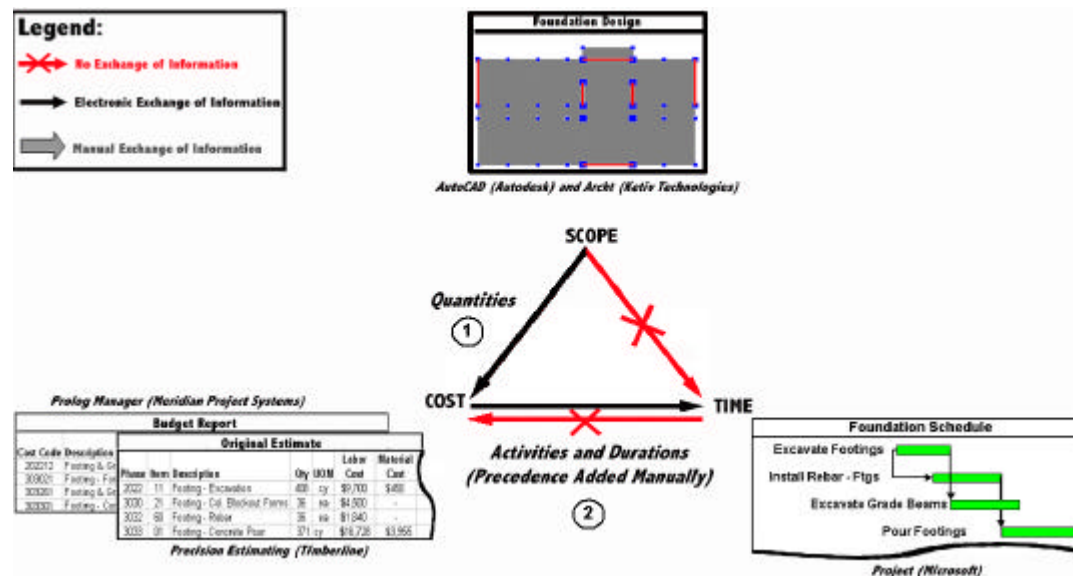

Fig. 1: Capabilities of current tools to integrate scope, estimate, and time

The next sections will show that existing tools do support integration of scope, cost, and time in an incremental manner. First, construction costs were estimated using the quantities from the CAD model (step 1 in Figure 1). Next, the schedule was generated from the cost estimate by converting estimating items into schedule activities (step 2 in Figure 1).

2.1 Design-cost integration

The estimator linked estimating items and work packages with graphical objects in the CAD model and quantities were automatically calculated and inserted into the estimate. This link ensured that the project's design and costs were in line at the start of construction. However, the link only supports a one-to-one mapping between design and cost information because only one work package or estimating item can be attached to each design object. In addition, another limitation is that the relationship between the design and cost information is uni-directional. Consequently, the estimator cannot query the estimating items to determine what design object it was derived from.

2.2 Cost-schedule integration

The planner selects the estimating item or items that will become a construction activity, and the activity durations are automatically calculated based on the productivity rate. The planner then opens the file in the scheduling program and manually adds the precedence relationships. The cost-schedule link ensures that the resource assumptions made during the estimating phase are incorporated in the planning stage.

However, if the design or resources change as construction progresses, the activity durations must be updated manually. In addition, there is no explicit link between the schedule activities and the estimating items after the schedule has been created. Each activity doesn't know what estimating items it was derived from or what resource productivity rates were used when the duration was calculated. Finally, there is no inverse relationship between the schedule and cost. Consequently, if an activity's progress takes longer than expected, it is not reflected in the cost estimate.

In this integrated environment, and in many of the conceptual models developed in previous research, the relationships between scope, cost, and time are represented by a single arrow, as shown in Figure 1. However, when looking at this information from the user's perspective, we have found that the structure of this information and the relationships between this information is much more complex.

3   Relationships between the different hierarchical representations

As illustrated in Section 1.1, scope, cost, and schedule information is created at several levels of detail. Hierarchies are ideal to represent these different levels of detail and the different types of aggregations and decompositions.

3.1 Design models

The design information generated today is often represented at a high level of detail. The designs depict the final state of the components but do not generally model the materials that compose the final product or the materials that are required to build the product. Software programs have been developed to address the lack of detailed design information represented in design models today. For example, Eagle Point's StrucPro automates reinforced concrete detailing, which would automatically layout the reinforcing steel in the foundation system described above (Eagle Point 1998). In addition, research efforts have also attempted to generate construction product information automatically, such as temporary structures (Aalami 1998).

3.2 Cost estimates and cost control

Contractors generate very detailed cost estimates that are often broken down in many different ways. On the Sequus Project, the estimate was divided into the following sections for all direct work: Area, Group Phase (such as concrete), Phase (such as footing concrete), and Item (such as 2,000 psi concrete). The left part of Figure 2 shows the footing portion of the foundation estimate. Therefore, estimators need to be able to structure estimates using different hierarchical representations.

Fig. 2: Estimate, cost control, and schedule of values for foundation

Costs are typically tracked with less detail than the estimates. Figure 2 shows the breakdown of costs for the footing portion of the foundation work, which shows that there are eight items that track the footing costs. To track the footing costs, the project manager created cost items by aggregating several estimating items for the footing work, by aggregating like items from a different part of the foundation work, and by transferring a single item directly from the estimate. Therefore, project managers must be able to aggregate different estimating items to facilitate tracking this information and to obtain the production information desired.

The schedule of values is represented with even less detail than the cost control system. The schedule of values is the cost breakdown of the pay items for which general contractors and subcontractors submit billings each month. On the Sequus Project, all pay applications for concrete work were submitted under one schedule of value, as shown in Figure 2. Therefore, project managers create additional aggregations of cost information for billing purposes.

3.3   Schedule models

Schedules are often generated at multiple levels of detail to support different views of the construction progress. Figure 3 shows the summary and detailed views of the footing portion of the foundation work. In addition, construction schedules are often broken into zones and areas to show work flow. For example, the concrete placement consisted of the aggregation of the footing and grade beam concrete, whereas the reinforcing steel consisted of a decomposition of the work into construction zones. Therefore, project planners and superintendents must be able to aggregate and decompose construction activities quickly and easily to support different planning strategies.

Current tools address this issue by providing summary bars (Microsoft Project) or hammock activities (Primavera). Consequently, the aggregated activity simply inherits the start date of the earliest activity and finish date of the latest activity. Each decomposed activity, however, doesn't know that it is a part of a higher level activity and each aggregated activity doesn't know that it is composed of the lower level activities. Many research projects have addressed this limitation by providing hierarchical planning approaches, such as MDA, Oarplan, CasePlan, and CMM (Jagbeck 1994, Darwiche et al 1988, Dzeng et al 1997, Aalami et al 1998). The Construction Method Modeler (CMM) provides the most promising approach, however, because it represents components, actions, resources, and sequencing constraints ("CARS") at every level of detail. This is a necessary step to support model-based reasoning and enable integration between scope, cost, and time at multiple levels of detail.
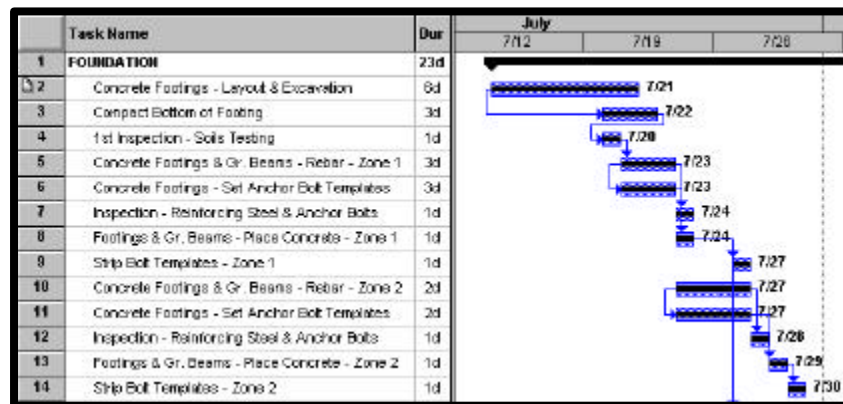
	Task Name	Dur	July 7/12	7/19	7/26
1	FOUNDATION	23d			
2	Concrete Footings - Layout & Excavation	6d	7/21		
3	Compact Bottom of Footing	3d	7/22		
4	1st Inspection - Soils Testing	1d	7/20		
5	Concrete Footings & Gr. Beams - Rebar - Zone 1	3d	7/23		
6	Concrete Footings - Set Anchor Bolt Templates	3d	7/23		
7	Inspection - Reinforcing Steel & Anchor Bolts	1d	7/24		
8	Footings & Gr. Beams - Place Concrete - Zone 1	1d	7/24		
9	Strip Bolt Templates - Zone 1	1d		7/27	
10	Concrete Footings & Gr. Beams - Rebar - Zone 2	2d		7/27	
11	Concrete Footings - Set Anchor Bolt Templates	2d		7/27	
12	Inspection - Reinforcing Steel & Anchor Bolts	1d		7/28	
13	Footings & Gr. Beams - Place Concrete - Zone 2	1d		7/29	
14	Strip Bolt Templates - Zone 2	1d		7/30	

Fig. 3: Footing portion of the foundation schedule

In summary, design, cost, and schedule information are represented at different levels of detail and have different hierarchical organizations. Consequently, to integrate this information, a mapping scheme must be developed to support the relationships between the different hierarchical representations.

3.4 Mapping scheme between the different hierarchical representations

Figure 1 showed the scope, cost, and time triangle with arrows illustrating the relationships between the information. This representation fails to show the complex structure of this information and the multitude of relationships that must exist to share the necessary information. As the previous sections illustrated, the scope, estimate, cost control, and schedule data are all represented with different hierarchical organizations. Project managers must be able to work with the different hierarchies with changes in each hierarchy correctly propagating to the other. Moreover, project managers must be able to work with the information at different levels of detail and create aggregations and decompositions to support their view of the information. Figure 4 shows the hierarchical representation of the foundation scope, cost control (estimate not shown), and schedule information.

This figure illustrates the complexity of mapping the relationships between these information items. During implementation, we will determine whether a direct mapping between views is the solution versus mapping to and from a core model to derive different views. The relationships shown in Figure 4 need to be classified to ensure the appropriate information is shared and to ensure consistency when calculating cost and schedule status.
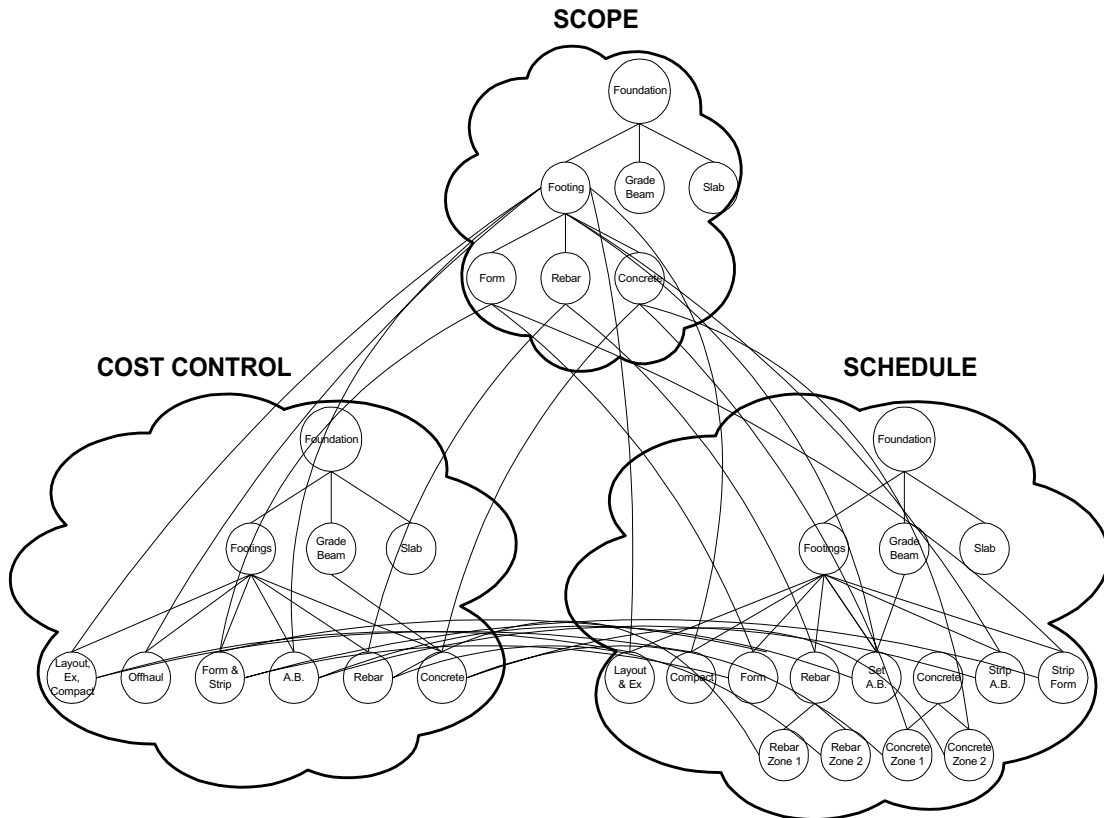

Fig. 4: Relationships between hierarchical representations

4 Classes of relationships and shared information

Previous research and current tools share quantity information and resource production information when calculating costs and schedule status. However, quantity information is not always available, resource performance is not always measurable, and schedule progress is not always derivable from the quantities installed. Consequently, the relationships between the information need to be classified according to the type of information that is shared. Table 1 shows the classes of relationships and the shared information that we have defined thus far. Previous research and standards do not model many of these relationships. Specifically, they do not reify the following relationships: quantity-based relationship between the estimate and cost control; the labor time-based relationship between estimate and cost and between estimate and schedule; and the progress-based relationship between the schedule and cost control information. The following case examples demonstrate the need for these relationships, as project managers must continually determine activity progress and forecast the corresponding costs.

Table 1: Classes of relationships and information shared

Classes of Relationships	Information Shared	From	To
Quantity-Based	Quantity	Design ⟶	Estimate
		Estimate ⟶	Cost
		Design ⟶	Schedule
Labor Time-Based	Resource hours	Estimate ⟶	Cost
		Estimate ⟶	Schedule
User-Based	Activity Progress	User ⟶	Schedule
Progress-Based	Activity Progress	Schedule ⟶	Cost

In some instances, an activity's progress can be measured by the quantity installed, such as concrete placement and excavation. In addition, an activity's progress can also be measured by the amount of time a labor resource has worked on that activity, such as pressure testing the pipe installed. In contrast, some activities' progress can only be determined through visual inspection. For example, determining the progress of rebar installation can't simply be measured by the pounds of steel that is placed in a concrete slab. The progress of that activity also depends on the spacing of the rebar and whether it has been tied appropriately, which can't be quantified. The user should enter such progress measurement after visual inspection of the work in place. Finally, the cost forecast for a particular scope of work depends on the corresponding activity's progress. Therefore, quantities installed, resources consumed, and activity progress must be shared to support integrated time and cost control and the corresponding relationship classes are necessary to enable this integration.

These relationship classes give project managers a consistent approach to calculating schedule progress and forecasting the corresponding costs. Furthermore, it provides a flexible environment by allowing project managers to work with the information at different levels of detail and to create aggregations and decompositions

that support different views of the information.

Our research focuses on determining and formalizing other necessary relationships to support integration of scope, cost, and time throughout the construction process. We will demonstrate the usefulness of these relationship classes by implementing and testing software prototypes on actual construction projects.

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