# Contents

# Integrated Cost and Schedule Control Automation

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## ABSTRACT

Effective management of construction projects depends on good access to and control of data, especially data pertaining to cost and schedule control functions. Long recognizing the need to integrate these interrelated functions and to improve the quality, integrity, and timeliness of data, researchers have proposed conceptual models to achieve this purpose. However, the proper design of an automated solution has been lacking that would support the needs of integrated cost and schedule control and would acquire and store quality data in a timely manner. The purpose of this paper is to discuss the design of an automated data acquisition and storage model that overcomes the above-mentioned deficiencies. The data storage component is developed using a four-step process used to model engineering problems. The first step, problem definition, is accomplished by using the work packaging model to solve the integration problem and by using data collection forms developed by R.S. Means Company to identify what data items are collected in cost and schedule control. The second step, conceptual modeling, utilizes Nijssen's Information Analysis Methodology (NIAM). For the third step, computational modeling, the relational data model is selected. The Optimal Normal Forms (ONF) algorithm is used for mapping from the conceptual to the computational model. The fourth and final step, computer modeling, is accomplished by mapping the computational data model onto a computer database management system. The paper then discusses how bar coding will be used for automating the data acquisition component in support of integrated cost and schedule control. We believe that bar coding can improve the quality, integrity, and timeliness of data when coupled with a good database design.

## 1 Introduction

Information plays a key role in construction project management. In order for a construction project to be well managed, data from past projects, stored in a historical database, as well as data from the project at hand, must be readily available. It is an essential and valuable resource for project planning, control, reporting, and decision-making tasks. Project planning relies on information stored in the historical database built from records attained from past projects as well as from past experience in similar projects. Control depends on data acquired on the site during the execution of the project. Control is composed of a number of functions, including cost and schedule functions. These are essential components of any construction control system. Reporting and decision making are integral parts of a construction management system and are the results of processing the data acquired during the execution of a project. In each of these tasks, effective management of information is an integral part of a successful project management system, whose primary objective is completing the project on time and within budget limitations while meeting established quality requirements and other specifications.

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## 1.1 Problems and Needs of Cost and Schedule Control Functions

A majority of construction projects employ some method of cost and schedule control. Still, many projects suffer from ineffective control due to inefficient flow of information. Problems stemming from poor information flow are observed during the projects themselves at the time of their construction, as well as in the corporate historical database. A project may suffer from delays and over-expenditures due to the feedback problems. Historical databases may contain bad or unrealistic data that affects future planning abilities and results in lost bids or reduced profits on future projects. If new goals and plans are based on incorrect or unrealistic historical data, new projects will suffer from a continuous cycle of poor performance: a submitted bid may exceed what is really needed, resulting in a lost opportunity to win a contract. Also, an opportunity may be lost to achieve higher profits even if the project is finished on time and within budget, and the project may suffer from delays and cost overruns.

A solution to the problems described above imposes the challenges of integrating cost and schedule control functions and controlling the quality, integrity, and timeliness of data. As for the first challenge, it is well recognized among researchers that the two control functions need to be integrated. Such integration should exist at a sufficiently detailed level to make control more precise and effective. The need for an integrated solution is supported by such construction researchers as Ibbs, Hendrickson, and Teicholz [Ibbs 87, Teicholz 87, Hendrickson 89]. However, construction projects exhibit complex interrelationships between schedules and costs [Hendrickson 89]. A schedule delay has a direct impact on costs. Also, monetary constraints directly affect the duration of a project. Time-cost trade-offs are basic decisions exercised in project management.

Although the interdependency between schedule and cost is obvious, it is rare to find project control systems that integrate cost and schedule control functions [Hendrickson 89]. Rather, they remain two separate functions that are performed independently from each other and that use two different control structures: the Work Breakdown Structure (WBS) and the Cost Breakdown Structure (CBS). The WBS is a breakdown of the project into significant units of work, starting with the entire project at the highest level on the hierarchy and ending with the tasks needed to complete the project as the lowest level. On the other hand, the CBS is a breakdown of the project into smaller cost centers that contain all classes and categories of items pertaining to the different types of work.

The different levels of detail used by each function create a fundamental difference in the way cost and schedule data is presently maintained. The cost control function, represented by the CBS, is performed at a less detailed breakdown level than that of the schedule control function, represented by the WBS. Each collection of data has traditionally become independent from the other and is usually maintained separately. Project managers must then integrate the information coming from two sources, which reduces the efficiency of obtaining meaningful information and making prompt and fully informed decisions. For example, project managers might spend time and effort trying to isolate the costs of the concrete work on walls in area A on floor 4 from the total costs accumulated in the walls cost account.

As for the second challenge, researchers had long been concerned with the data entering and flowing through the cost and schedule control systems. It is well recognized that data needs to be controlled, either at the acquisition stage by paying careful attention to the data acquisition task, or after data has been acquired by screening it for errors before processing. The need for enhancing the quality, integrity, and timeliness of data is supported by such construction researchers as Barrie, Ibbs, Paulson, and Teicholz [Barrie 84, Ibbs 87, Hendrickson 89].

### 1.2 The Need for Automated Information Management System

Automation in support of integrated cost and schedule control is essential to achieving a solution to both the integration and data quality, integrity and timeliness problems. To achieve the desired integration, cost and time data must be acquired and maintained using an established common denominator control account defined at a sufficiently detailed level. However, it is not enough to simply establish and maintain a common denominator. What is also needed is an automated information management system that can truly integrate cost and schedule control functions on one hand, while acquiring, storing, and presenting quality data and information in a timely manner on the other hand. To satisfy those needs, the work packaging model was identified and selected as the integrated model [Abudayyeh 90, Rasdorf 90b]. New automated data acquisition and data storage methods are developed to overcome its limitations. Figure 1 shows the overall architecture of the desired automated information management system. As shown in the figure, the system is composed of three major components: data acquisition, data storage, and data processing. This paper will focus on the data storage and the data acquisition components. The two components are described in Sections 2 and 3, respectively.

## 2 A Methodological Approach to Modeling Construction Data

Cost and schedule control systems require the acquisition, storage, and use of large amounts of data that are essential to both controlling the present project and planning future ones. Therefore, managing information becomes vital to the success of the management process. One mechanism to effectively store and use construction data is a database management system. The difficulty, however, is that the proper use and management of data requires that it be well modeled. Unfortunately, engineering data models, such as construction management models, are almost universally developed in an ad hoc manner. This paper shows that there is a preferable, formal methodology by which to develop such models. To develop an automated and integrated database solution for the cost and schedule control problem, a four-step process for modeling engineering problems has been used. The process is shown in Figure 2. The subsections below describe the four steps.

### 2.1 Step 1: Problem Definition

The problem definition step involves identifying the data items needed and describing the behavior of the engineering system with respect to the methods and mechanisms used in acquiring, storing, and processing data. This step has been accomplished by using the work packaging model as a solution to the integration problem and also by using data collection forms developed by R.S. Means Company to identify the data items that are collected by the cost and schedule control functions during the construction process [Means 86]. These issues are further discussed in the paragraphs below.

In analyzing and assessing a number of integrated cost and schedule control models, we concluded that the work packaging model was the most likely model to provide a true integrated solution [Rasdorf 90b]. This model describes the conceptual organization of data as well as the data processing mechanisms involved in integrated cost and schedule control, but it had to be modeled to provide the necessary automated support.

In analyzing the construction data acquisition task, we observed that construction data is presently acquired using a variety of forms. A number of data collection forms are available in the literature and in construction firms [Means 86, Halpin 85]. These forms are designed to collect fundamentally the same data items, though in different formats and structures. The Means Company forms have been selected for our analysis. It has developed a large set of construction forms that covers all of management's data needs. A subset of these forms that was directly related to the cost and schedule control functions was identified and analyzed to determine the content of the data items. The analysis yielded a large number of data items that are currently being collected on a construction job site. Many redundancies were observed in these forms. However, this was to be expected because the two functions are not integrated: some forms are designed to support cost control, while others are designed to separately support schedule control.

Utilizing the data-item contents of these forms and the knowledge provided by the work packaging model, the problem definition becomes complete. The outcome of this step is a formal set of specifications for the desired information management system represented by what is called a set of examples or elementary facts that describes how integrated cost and schedule control is performed in the context of the work packaging model.

## 2.2 Step 2: Conceptual Modeling

The conceptual modeling step accepts an engineering problem definition as input and produces a conceptual data model that represents the design of the data storage module. This step has been accomplished by using a fairly recent formal data modeling methodology: Nijssen's Information Analysis Methodology (NIAM) [Rasdorf 90a, Nijssen 89]. This methodology helps in designing the information management system used to support the work packaging model. Specifically, it systematically develops a conceptual data model that captures the meanings of and relationships between the data items as provided by the problem definition step. The methodology produces a conceptual data representation model called the Conceptual Schema Diagram (CSD). The outcome of this step is viewed as an engineering drawing for the design of the desired information system.

## 2.3 Step 3: Computational Modeling

The computational modeling step takes a conceptual data model as input and transforms it to a computational model suitable for developing automated environments. This step has been accomplished by transforming the NIAM CSD into the relational data model. It is believed that the relational data model provides the necessary, standardized, and widely accepted automated mechanisms for data storage and retrieval, and its concepts (tables and records) are the natural mechanism for representing and processing cost and schedule data. The NIAM methodology provides an algorithm called the Optimal Normal Form (ONF) that transforms a NIAM model into an optimum relational data model. The ONF algorithm has been used to transform the NIAM CSD into a relational database schema.

## 2.4 Step 4: Computer Modeling

Computer modeling is the final step in the modeling process. It takes the computational model as input and maps it onto a computer data model that represents the automated computer system solution to the problem. This step has been accomplished by mapping the relational data model onto a database management system (DBMS) schema using the data definition language (DDL) provided by the DBMS package. For this step, the ORACLE DBMS and its Structured Query Language (SQL) DDL are selected for developing the computer database solution.

# 3 Improving Data Acquisition Mechanisms

Researchers realized that data acquisition mechanisms need to be improved in an attempt to control the quality, integrity, and timeliness of data in support of cost and schedule control, as well as other managerial functions. To achieve this goal, research efforts have focused on exploring and utilizing new automated data acquisition technologies such as bar coding (BC), magnetic stripes (MS), radio frequency (RF), optical character recognition (OCR), digital imaging (DI), and voice recognition (VR). Of all of these technologies, only BC has received significant attention by construction researchers. BC has been proven to be an effective automated data acquisition tool in materials and equipment management systems for identifying and tracking a variety of information on a construction job site. The research efforts related to the implementation of these automated data acquisition technologies are described in reference [Abudayyeh 90]

In addition to university research efforts, some construction firms have also explored ways to improve materials management, inventory control, and document control by using automated data acquisition technologies, in particular BC. Bechtel Power has already taken steps to implement BC technology in an effort to track information for circuit raceways. More recently, Bechtel has used BC to support the process of valve installation in power plants [Bechtel 87]. Brown & Root, Inc. is also investigating the potential use of BC in document control, specifically the control of engineering drawings [ENR 89].

The general consensus that emerged from such efforts is that automating data acquisition to support the different management functions is evolving as a key issue in the design of future project management systems. The subsection below discusses the status of our work in this area.

## 3.1 Bar Coding-Based Data Acquisition

This phase of our research is still in its early stages at the time of writing this paper. Our intention in this phase is to develop an automated data acquisition system to support the existing design of the automated data storage component. Bar coding technology has been selected as the automated tool that will be used for this phase. To build the automated data acquisition system, the final list of data items will be analyzed to determine which of them will be bar coded. Bar code labels will then be developed for the data items identified here. Next, the bar code labels will be organized on sheets or in a log book for use by the system operator(s). Then, two methods will be used to acquire data: remote and on-line electronic forms. The first method will be designed and implemented on a portable remote-reader device called the transaction manager (TM), which can understand bar-coded data entry using a scanner as well as the TM's keyboard. The second method will be designed and implemented by using a forms utility provided by ORACLE DBMS, which can also use a combination of bar-coding scanner and keyboard data entries.

# 4 Summary and Conclusions

The integration of cost and schedule control functions and problems relating to the quality, integrity, and timeliness of data entering and flowing through cost and schedule control systems have long been of concern to construction researchers and professionals. This paper suggested that the work packaging model is currently the well integrated existing model that can solve these problems. However, to improve the performance of the work packaging model, it was also suggested that automated mechanisms are needed. The research effort described in this paper focused on the issues and needs with respect to designing an automated information management system to support the work packaging model and briefly discussed the automation of the data acquisition task.

We believe that automation of data acquisition and storage to support integrated cost and schedule control will help solve the problems described in Section 1.1. In seeking an automated solution, we have identified a sound, foundational integrated cost and schedule control model (the work packaging) that needs automation support to operate effectively and successfully. In our effort to achieve automation, we have succeeded in identifying and using a formal systematic methodology (NIAM) that develops conceptual data models, which are transformable into optimal relational database schema designs. Such a methodological design approach is lacking in most of the engineering database development efforts, though it is essential to the success of the design an information management system. We have used this methodology to model the work packaging model, and to subsequently automate it by developing a computing database model for it. This methodological design approach constitutes one unique contribution of the research effort presented in the paper.

A second unique contribution of the research effort described in this paper is the attempt to automate the data acquisition task in support of integrated cost and schedule control by using bar coding. Bar coding has already been successfully implemented in material management system, and we believe that it will be equally successful in integrated cost and schedule control as well. However, this remains to be evaluated.

Finally, we hope that by combining the automation of data acquisition and data storage (BC and DBMS) with the integrated cost and schedule control concept represented by the work packaging model, we can provide a good automated solution to the problems described in the introduction section, and we can lay a platform for integrating other managerial functions, such as material management, with cost and schedule control.

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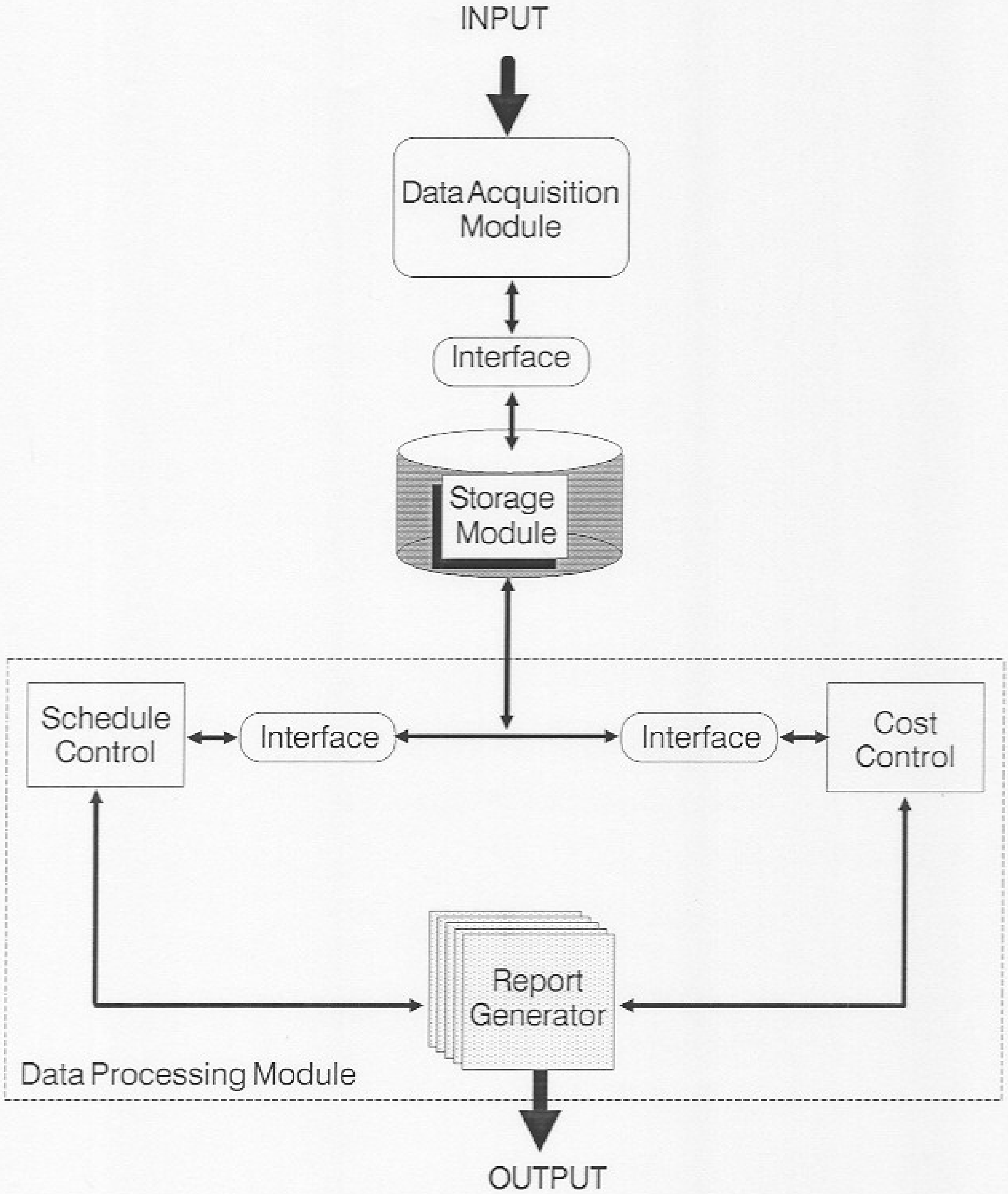


Figure 1: Integrated Cost and Schedule Model

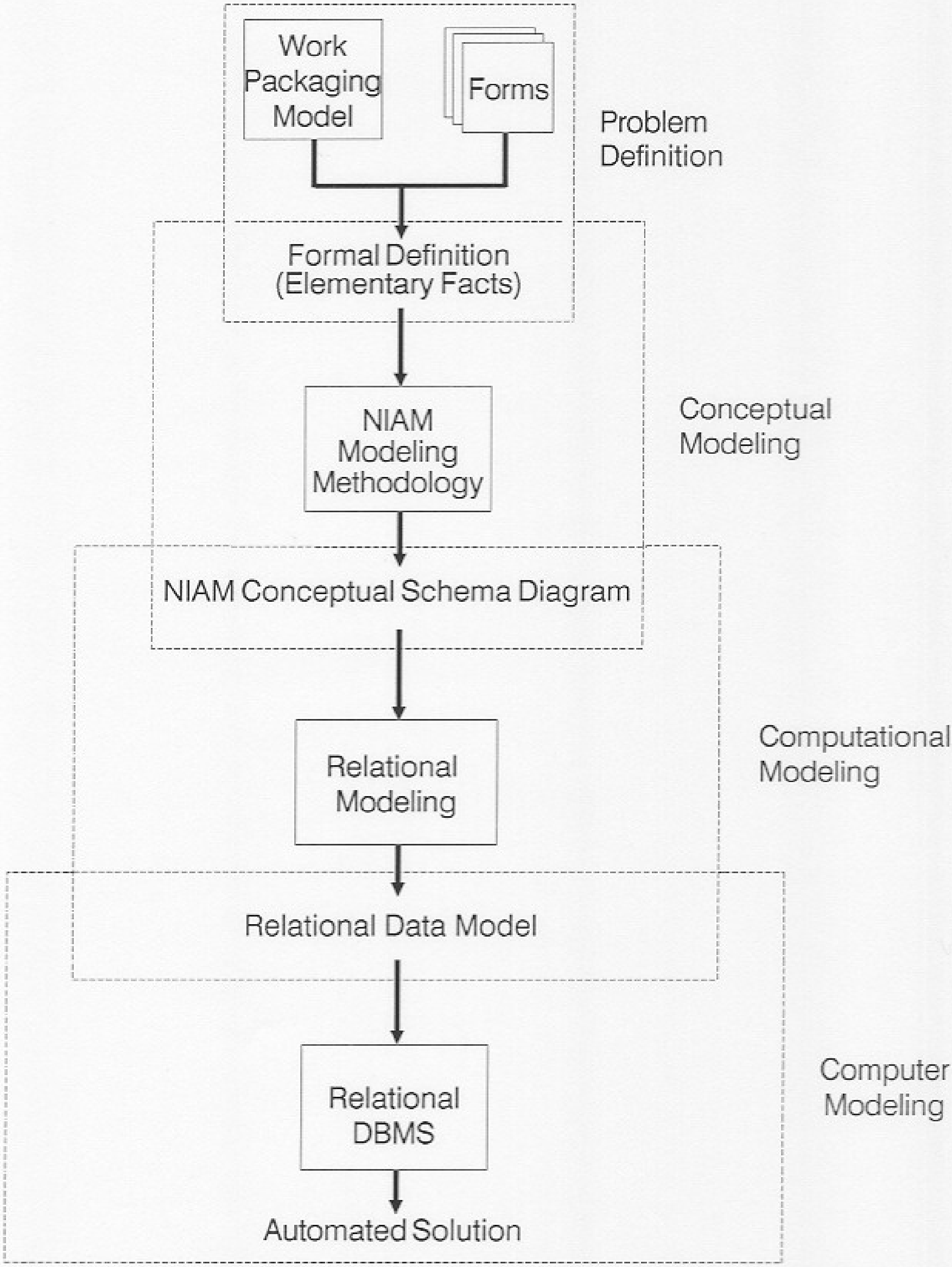


Figure 2: A Construction Problem Modeling Example