# AC 2008-2942: USING SPREADSHEETS AS A TOOL IN TEACHING CONSTRUCTION MANAGEMENT CONCEPTS AND APPLICATIONS

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# Using Spreadsheets as a Tool for Teaching Construction Management Concepts and Applications


## Abstract

Spreadsheets are becoming very powerful tools in solving engineering problems. The Excel spreadsheet, for example, is becoming an integral part of any computer program library. The applications of spreadsheet programs can do basic financial calculations such as cost estimates, schedule control, and cost control to solving complicated problems. In addition, they can create charts and graphs from data.

This paper is presenting the use of spreadsheets in teaching construction management-related concepts ranging from simple to very advanced applications. Several templates were developed to explain the concepts and their use in the classroom. Samples of Excel templates developed to help understand several concepts and to be used by students in classrooms are presented. The templates are addressing several concepts ranging from a simple constructing cost estimate problem to a very advanced application like scheduling linear and repetitive projects.


## Introduction

Spreadsheets made their first appearance for personal computers in 1979 in the form of VisiCalc, an application designed to help with accounting tasks[1]. Since that time, the diversity of applications of the spreadsheet program is evidenced by its continual reappearance in scholarly journals. Spreadsheets are, therefore, among the earliest software innovations that had a profound effect on the widespread use of personal computers. Among the strong features of spreadsheets are their intuitive cell-based structure and the simple interface that is easy to use, even for first time users[2]. Underneath the structure and the interface is a host of powerful and versatile features that can be utilized in teaching, from data entry and manipulation to a large number of functions, charts, and word processing capabilities. Newer spreadsheet versions have also added many productivity features for Internet connectivity, workgroup sharing, powerful programmability options, and a number of add-in programs[3]. With their wide use, spreadsheets have been used as tools for developing computer models that can be used as a tool for teaching construction management concepts, for which ease of use, versatility, and productivity are the main issues. Hegazy and Ersahin[2] used Excel to develop an information system for subcontractors and small/medium-sized contractors. Their developed spreadsheet stores resource data for labor, equipment, crews, material, subcontractors, and alternative methods of construction for various tasks. In addition, a separate worksheet is designed for each project to be used for estimating and control purposes.

Ickert and Huston[4] developed a spreadsheet that can be used to analyze multiple solutions for engineering problems efficiently and accurately, and to produce graphs that convey the solution to the end users. Thiriez[5] developed several spreadsheets as educational tools for students. One example is to use the drawing capabilities of Excel to represent decision trees and where window switching and macros allow the educator to animate his presentation. Another example presented by Thiriez[5] is the use of Excel in dynamic programming, deterministic or stochastic, where Excel functions facilitate the development of specialized models[5]. From primary to tertiary levels, the spreadsheet is gradually increasing in its importance as a tool for teaching and learning.

In this paper, Microsoft Excel[6] is used for developing spreadsheets that can be used for teaching construction management concepts and applications including construction data management, time-cost tradeoff analysis, optimum markup estimation, simulating and scheduling construction activities with uncertain durations, scheduling linear and repetitive projects, schedule and cost control, and optimization of construction operations. First, the use of spreadsheets as a tool for teaching construction management concepts in general is discussed. Three illustrative examples are then presented to demonstrate how spreadsheets can be used as a powerful tool in teaching.

## Spreadsheets as a Tool for Teaching Construction Management Concepts

The basic paradigm of an array of rows-and-columns in spreadsheets with automatic update and display of results has been extended with libraries of mathematical and statistical functions, versatile graphing and charting facilities, powerful add-ins such as Microsoft Excel's Solver, attractive and highly functional graphical user interfaces, and the ability to write custom code in languages such as Microsoft's Visual Basic for Applications.

Spreadsheets with these powerful capabilities can be used as an effective tool for teaching construction data management, time-cost tradeoff analysis, optimum markup estimation, simulation, and optimization of construction operations. Since the core of any information system is the storage of the data and information for management operations, database capabilities in spreadsheet programs can be used as an effective tool to develop complex data management system for construction information. Few basic, but infrequently used, spreadsheet features need to be known and can be used to develop practical and powerful models for construction applications: (1) data lists; (2) data menu options; (3) basic spreadsheet functions such as ''vlookup''; and (4) pivot table reports.

Excel can also be used in linear programming, where the solver is used, and where the spreadsheet's graphing capabilities are used both to represent the feasible set and the objective function, and to interactively animate the objective function or constraint movements. Excel can also be used in simulation, where stochastic simulation may be facilitated through the use of an add-in, and a decision support system may thus be built from scratch.

## Spreadsheets Developed for Teaching Construction Management Concepts

In this study, several spreadsheets were developed to teach construction management concepts such as construction data management, time-cost tradeoff analysis, optimum markup estimation, simulating and scheduling construction activities with uncertain durations, scheduling linear and repetitive projects, schedule and cost control, and optimization of construction operations. Three examples are presented in this paper to demonstrate the use of spreadsheets in teaching construction management concepts. The first example illustrates the use of Excel for the management of construction information. In Excel, a data list is a simple structure of columns and rows that contain data (e.g., range A1:C6 in Fig. 1). Entering data into a large spreadsheet list may become extremely tedious and prone to error. The ''Data-forms'' menu option in Excel provides a simple way for editing or deleting existing records in a list or adding new records. Fig. 1 shows one such form, which was activated for the ‘‘Labor’’ sheet of the developed construction data management system. Sorting the data helps bring similar records together for visual inspection or other purposes such as preparing reports and charts. Using the ‘‘Data, Sort’’ menu option, the list’s data can be arranged in an order that is chosen by sorting the records. Filtering the data is also a useful way to view a subset of the records that compose a list. To filter a list is to extract records from it, based on criteria set by the user. Referencing and searching the list is another important part of the data management process. In realistic systems, where several lists of data are available, a link needs to be established among them (similar to the relational database concept).

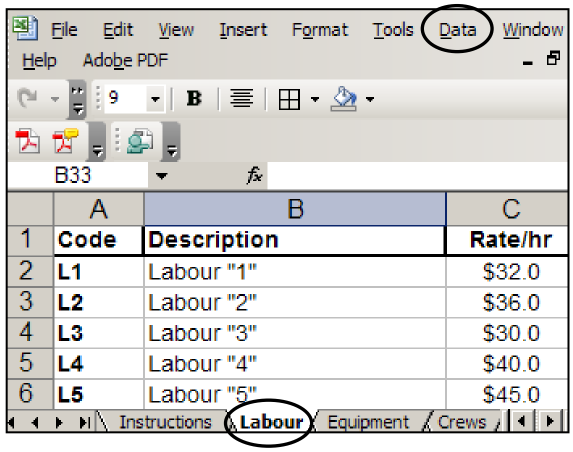


Fig. 1. Excel Data List

One simple and important spreadsheet function ‘‘vlookup’’ can be used to link separate lists of information by making a reference to where the original data are. For example, consider the situation when a new list is used for estimating purposes (Fig. 2) and this list refers to the ‘‘Code’’ of the labor being used. Accordingly, it is possible to determine the cost by using the “vlookup” function to search the original labor list and determine its associated ‘‘Rate/hr’’ value, as shown in Fig. 2. If the resource code specified in cell A4 of the estimate is changed (e.g., L5 is used), the costs will be adjusted automatically in cells C4 and D4 of the estimate.

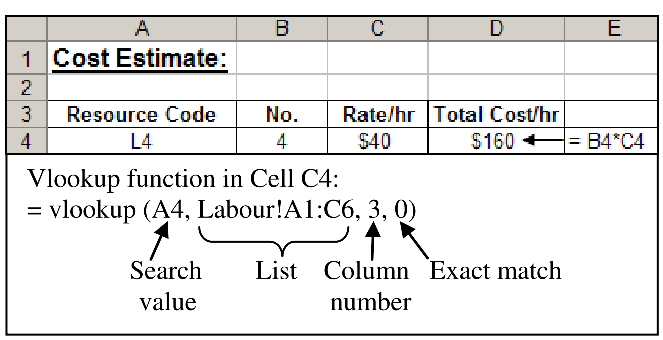


Fig. 2. Referencing Data List

In addition to the ‘‘vlookup’’ function, the ‘‘Match’’, ‘‘Index’’, and ‘‘Offset’’ functions provide further control over the data in a list. The help system of Excel can be used to obtain information about the syntax and use of these important functions. Reporting is another essential requirement for obtaining summary data on resources and operations. In Excel, the pivot table wizard provides an automated report generator. Pivot tables can be used to arrange projects’ information in the needed format, summarize long lists in a compact format, find relationships within lists that are hidden by all details, display data in the form of subtotals, averages, percentages, summations, etc.

The second example illustrates the use of probabilistic models to analyze the behavior of the contractor’s competitors bidding for a job in order to optimize the markup used in bidding for a job. The probability approach has historically been the most popular technique for the construction of bidding models. Most bidding models based on probability theory have been derived from the work of Friedman[7]. Friedman claimed that, in a tender, it was possible to model each bidder's behavior as a function of the estimated cost by means of a probability distribution. The general approach assumes that there are a number of bidders competing regularly against each other in the same market place and, given a sufficient number of opportunities to tender against known competitors, any one player can collect sufficient information to model the relationship between its own markup on future projects against the probability of submitting the lowest tender. This approach also assumes that the basic prime cost is similar for all competitors, and by comparing the competitors' tender figures for past projects with its own estimate of prime cost, a contractor can therefore develop a probability distribution for each of its competitors showing the likelihood of winning future tenders with different markups.

Using Friedman’s model, the probability of winning against a range of contractors ($P_{win}all$) is the product of the chances of beating them each individually, and the maximum expected profit (EP) can be calculated as follows:

$$\text{Expected profit (EP)} = \text{Profit} \times Pwin_{all}$$

$$\text{Where: } Pwin_{all} = Pwin_1 \times Pwin_2 \times \ldots\ldots\ldots\ldots \times Pwin_n$$

n: is the number of competitors

Gates[8] suggested that by comparing its own bid to the winning bid a contractor could calculate the markup which would have been needed in order to win the contract. Again this implies that cost is the most important criterion:

$$P(Win_{all}) = \frac{1}{[(1 - P(Win_1)) / P(Win_1)] + \ldots\ldots + [(1 - P(Win_n)) / P(Win_n)] + 1}$$

To illustrate this concept to students, the two approaches were modeled using Excel and a spreadsheet was developed to calculate the optimum markups using both Friedman and Gates approaches. When a contractor bids for a new job, it is assumed that he/she knows other competitors bidding for the same job. To estimate the optimum markup for the contractor, the user will only enter the number of previous bids for each competitor bidding for the job, the competitors’ bid values for these bids, and the contractor’s estimated cost (Fig. 3). As shown in Fig. 3, Excel will calculate the mean and standard deviation for the previous bids of each competitor.

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | Our Estimated Cost for the New Job: | | | $5,000,000 | | |
| 3 | | # of competitors: | 4 | | | | |
| 4 | | # of Bids | 3.0000 | 4.0000 | 6.0000 | 4.0000 | 1.0000 |
| 5 | | Mean | 1.0145 | 0.9440 | 1.0032 | 0.9827 | 1.1190 |
| 6 | | St. Deviation | 0.1381 | 0.1039 | 0.1433 | 0.1926 | |
| 7 | **Bid No.** | **Cost Estimate** | **A** | **B** | **C** | **D** | **E** |
| 8 | 1.0 | $2,600,000 | $2,900,000 | $2,100,000 | $2,100,000 | $2,350,000 | |
| 9 | 2.0 | $3,400,000 | | $3,600,000 | $3,600,000 | $2,900,000 | |
| 10 | 3.0 | $2,100,000 | $1,800,000 | | $2,500,000 | $1,900,000 | $2,350,000 |
| 11 | 4.0 | $1,700,000 | | $1,600,000 | $1,900,000 | | |
| 12 | 5.0 | $1,300,000 | | | $1,200,000 | $1,650,000 | |
| 13 | 6.0 | $6,350,000 | $6,800,000 | $6,150,000 | $5,850,000 | | |

Bidding

Fig. 3. Input Sheet for Optimum Markup Estimation

As shown in Fig. 4, Excel will also calculate the probability to win each competitor separately and the probability to win all competitors, using Friedman and Gates models. For both models, the maximum expected profit (max. EP) is found using the "Max" function. The maximum expected profit using Friedman's model, for example, is found to be $2389.47. Excel will then find the markup corresponding to the maximum expected profit for both Friedman and Gates models using the ''vlookup'' function. For the example in hand, the optimum markups using Friedman and Gates models are 3% and 7%, respectively.

| | A | B | C | D | E | F | G | I | J |
|---|---|---|---|---|---|---|---|---|---|
| 15 | **Markup** | **Pwin A** | **Pwin B** | **Pwin C** | **Pwin D** | **Freidman $\text{Pwin}_{all}$** | **Gates $\text{Pwin}_{all}$** | **Freidman EP** | **Gates EP** |
| 16 | 0.01 | 0.5129 | 0.2628 | 0.4810 | 0.4436 | 0.0288 | 0.1411 | 1437.72 | 7053.28 |
| 17 | 0.02 | 0.4840 | 0.2323 | 0.4532 | 0.4232 | 0.0216 | 0.1260 | 2156.90 | 12595.30 |
| 18 | 0.03 | 0.4552 | 0.2040 | 0.4257 | 0.4030 | 0.0159 | 0.1120 | 2389.47 | 16798.41 |
| 19 | 0.04 | 0.4266 | 0.1778 | 0.3985 | 0.3830 | 0.0116 | 0.0991 | 2316.04 | 19826.43 |
| 20 | 0.05 | 0.3984 | 0.1539 | 0.3719 | 0.3633 | 0.0083 | 0.0873 | 2070.92 | 21834.18 |
| 21 | 0.06 | 0.3708 | 0.1322 | 0.3458 | 0.3440 | 0.0058 | 0.0766 | 1748.79 | 22967.24 |
| 22 | 0.07 | 0.3437 | 0.1127 | 0.3204 | 0.3251 | 0.0040 | 0.0667 | 1412.06 | 23361.82 |
| 23 | 0.08 | 0.3175 | 0.0953 | 0.2959 | 0.3067 | 0.0027 | 0.0579 | 1098.21 | 23144.75 |
| 24 | 0.09 | 0.2921 | 0.0800 | 0.2722 | 0.2887 | 0.0018 | 0.0499 | 826.51 | 22433.42 |
| 25 | 0.10 | 0.2678 | 0.0666 | 0.2495 | 0.2712 | 0.0012 | 0.0427 | 603.79 | 21335.71 |
| 26 | | | | | | | | | |
| 27 | | | | | | **Max. EP:** | | 2389.47 | 23361.82 |
| 28 | | | | | | **Optimum Markup:** | | 0.0300 | 0.0700 |

Bidding

Vlookup function in Cell I28:
= vlookup (I27, I15:K25, 3, 0)

Fig. 4. Optimum Markup Estimation Sheet

The third example illustrates the use of spreadsheets for teaching the concept of scheduling construction activities with uncertain durations, or what is known in the literature as scheduling using the program evaluation and review technique (PERT). Using this technique, each activity has three durations; the optimistic time (a), the pessimistic time (b), and the most likely time (m). PERT uses a weighted average of the three times to find the overall project duration. This average time is called the expected time ($t_e$), which is equal to (a + 4 m + b)/6. To determine the probability of a project to be completed earlier or later than expected, the variance (v) of each activity along the critical path is calculated as follows: $v = (b - a)^2/36$. Sine the duration of each activity is uncertain; the time of occurrence of each activity is also subject to uncertainty. The measure of uncertainty of the final event in a PERT diagram is the standard deviation of the expected time, denoted as $\sigma_{TE}$. The $\sigma_{TE}$ is the square root of the sum of the activities ahead of the event and, therefore, the $\sigma_{TE}$ for the last event is the square root of the sum of the variance of all activities along the critical path. Also the expected time of the last event in the project is denoted as $T_E$. To determine the probability of completing a project earlier or later than expected, the deviation (z) needs to be calculated; where $z = (T_S – T_E)/\sigma_{TE}$ and $T_S$ is the scheduled time to finish the project.

A spreadsheet was developed to illustrate this concept. For the five-activity project shown in Fig. 5, the user is asked to input the optimistic time (a) and the pessimistic time (b) for each activity in the project and their corresponding variances ($v = \sigma^2$) are then calculated automatically. Several iterations are used by selecting random numbers between the optimistic and pessimistic times using the Excel "rand()" formula. For the purpose of this example, four iterations are used. A random duration for activity 1-2, for example, is 8.344 days (iteration 1), as shown in Fig. 5.

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | PERT: MonteCarlo Simulation: | | | | | Iteration 1 | Iteration 2 | Iteration 3 | Iteration 4 |
| 2 | | $\sigma^2$ = | **Activity** | **Min duration (a)** | **Max duration (b)** | Duration | Duration | Duration | Duration |
| 3 | | 0.444 | **1-3** | 18 | 22 | 18.952716 | 20.74601049 | 19.659048 | 18.9843177 |
| 4 | | 0.028 | **1-2** | 8 | 9 | 8.343844 | 8.78379801 | 8.0262854 | 8.5076750 |
| 5 | | 0.111 | **2-3** | 10 | 12 | 10.819349 | 10.76583437 | 11.977332 | 11.4731547 |
| 6 | | 0.694 | **3-4** | 10 | 15 | 12.47362 | 12.93151218 | 10.55319 | 13.8628110 |
| 7 | | 0.111 | **4-5** | 10 | 12 | 11.524187 | 11.57922506 | 10.415994 | 11.195421 |

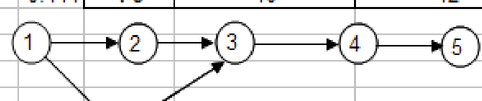


Fig. 5. Input of Activities' Duration Using PERT

Each path in the network is identified by the user and, following the logic of the network, the critical path is automatically calculated by identifying the longest path in the project. The expected time of the last event in the project ($T_E$) is calculated and the standard deviation ($\sigma_{TE}$) for critical activities in each path for each of the four iterations is also calculated. The average expected time ($T_E$) and the average the standard deviation ($\sigma_{TE}$) were calculated using the "average" function, as shown in Fig. 6. As shown in the figure, for a scheduled time ($T_S$) = 45 days; for example, the probability (Prob.) to complete the project in this duration equals 83.91% and the risk associated with this probability = 100 – Prob. = 100 – 83.91 = 16.09%.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 39 | $T_E = \mu =$ | 43.916392 | | | |
| 40 | | Iteration 1 | Iteration 2 | Iteration 3 | Iteration 4 |
| 41 | $\sigma =$ | 1.118034 | 0.971825 | 1.118034 | 1.118034 |
| 42 | $\sigma av. =$ | 1.0936659 | | | |
| 43 | *Example:* $T_S =$ | 45 | | | |
| 44 | $z =$ | 0.9908036 | | | |
| 45 | *Prob.* = | 0.8391093 | | | |
| 46 | *Risk* = | 0.1608907 | | | |

Fig. 6. The Probability and Risk Calculation Sheet for Example 3

## Conclusions

Spreadsheets are becoming increasingly popular for use as a powerful tool in teaching and are considered among the earliest software innovations that had a profound effect on the widespread use of personal computers. Among the strong features of spreadsheets are their intuitive cell-based structure and the simple interface that is easy in education. Underneath the structure and the interface is a host of powerful and versatile features that can be utilized in teaching, from data entry and manipulation to a large number of powerful functions. In this paper, several spreadsheet applications are developed for use in teaching construction management concepts.

For the purpose of illustration, three of these spreadsheet applications are then presented. The three examples demonstrate the simple and powerful data management features of spreadsheets and its capability in solving complex construction management problems. Students will better understand the concept because they developed the model and can easily visual the results. In addition, the developed spreadsheets, as such, represent a transparent methodology that allows for quick what-if analysis regarding cost estimation, optimum markup estimation, and risk analysis. Finally, the availability of Excel makes it a powerful tool in developing application at school and at work after graduation.

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