

Managing The Implementation Of The Hospital-Based Electronic Medical Records

Jakov Crnkovic

School of Business, University at Albany (State University of New York)
(518) 442-5318
yasha@albany.edu

Dorothy Urschel

School of Business, University at Albany (State University of New York)
(518) 442-4916,
dmurschel@yahoo.com

Abstract

This paper is a case example of managing the implementation of a hospital-based electronic medical record system (EMR) project. We present and discuss several project management techniques to manage *time¹ and budget constraints*. The project is depicted as a network diagram, calculating all parameters for the project using the Critical Path Method (CPM) and with appropriate data. The PERT probabilistic modeling framework is used to predict probabilities of project completion before an imposed deadline. Based on these conclusions and the nature of IT projects (problems with rework and feed-back loop issues) we included and discussed GERT modeling technique and Monte Carlo simulation. The limitations of PERT/CPM methodologies are discussed. We show that most of these limitations can be traced back to an explicit or implicit assumption within the PERT/CPM modeling framework. Apart from time management, this EMR project is discussed based on available resources, including the crashing options, using the cost-time trade-offs. In conclusion, despite limitations, PERT/CPM remains valuable in managing these types of projects.

Keywords: Project Management, PM techniques, Excel applications, Teaching IT related courses, Electronic Medical Records

Introduction

An electronic medical record is usually a computerized legal medical record created in an organization that delivers care, such as a hospital and doctor's surgery². EMR is typically a part of a local stand-alone health information system (there have been many attempts at standardization, but none is finalized and widely accepted). EMR should help in storage (opening possible privacy issues) and retrieval of medical records. Only one-quarter of office-based physicians reported using fully or partially electronic medical record systems (EMR) in 2005³, but less than 10% of those have a "complete EMR system", with all four basic functions deemed minimally necessary for a full EMR: computerized orders for

¹ An extended abstract of this case, which is dealing only with managing EMR project time was accepted for the presentation at the Western Decision Support Systems Conference, Lake Tahoe, NV, April 2010.

² http://www.providersedge.com/ehdocs/ehr_articles/Electronic_Patient_Records-EMRs_and_EHRs.pdf

³ National Center for Health Statistics: Electronic Medical Record Use by Office-Based Physicians:, United States, 2005 Retrieved July 24, 2006

prescriptions, computerized orders for tests, reporting of test results, and physician notes⁴.

There were many attempts to introduce the Electronic Medical Record (EMR) system in hospitals and other health care providers. The New York State Department of Health has mandated the implementation of EMRs in all hospitals that exceed a certain bed capacity⁵. The policy is motivated by evidence that shows that EMRs reduce medical and nursing errors. A deadline for implementation has been imposed and failure to meet the deadline is punishable.

Apart from the project duration limitation, EMR project has to contend with certain budgetary restrictions. Project manager was able to estimate costs for individual activities, when working at a regular pace, and also the higher costs if crashing is required.

For using the Project Management (PM) manual techniques or software packages, data showing the resources (costs for people and materials) would be very valuable, but unfortunately, project team was not able to get all necessary information for the case. As mentioned above, costs were aggregated on the activity level and no details were provided. Also, having in mind history of implementing similar projects in the company (our hospital), the project team wanted to get information about the general knowledge of PM methods and their usage in the information systems department; this information was never made available.

Based on available data, project team discussed possible approaches and methodologies⁶. Reviewing the PM literature and software market, team was able to start planning for the EMR project implementation.

This case will be used to help the process of decision making in our hospital using Project Management (PM) methodologies. Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) are two project management methodologies that arose independently in the 1950's (initial idea of PM history dates to the 19th century). Over the years the methodologies have been combined, and the resulting methods are typically referred to as PERT/CPM. There is strong software support for the area, particularly for CPM technique. Since the case is in the area of applied IT, after solving the problem using both of these methods for project management, we are discussing elements of Graphical Evaluation & Review Technique (GERT).

The educational purpose of the case is to help student understand methodologies and their usage for effective and efficient decision making. Applying several PM techniques to solve this case allows users not only to compare outputs, but has additional value which can be used in managing other IT projects, particularly projects in System Analysis and Design.

⁴ CDC's National Center for Health Statistics: More Physicians Using Electrical Medical Records Retrieved July 27, 2006

⁵ For the anonymity we will treat the hospital as "our" hospital. Also, all numerical data in all tables are fictitious.

⁶ Using the project principles and project management approach is common daily activity in many companies and governmental offices. For more details, please refer to the last section of this paper: References and Further Readings.

Independently of the applied methodology, the ultimate goal is to produce a realistic schedule making the best multi-criteria decision based on limited time and resources, with the fixed budget and with the request to eliminate possible penalties for being late. Based on the type of the project, it is necessary to maintain the high quality of task executions (which may introduce rework for some activities).

Our hospital has already had to abandon one EMR project. There are 25 weeks for our project to be completed. The deadline is fast approaching and there is a \$250,000 fine for being late. Activity supervisors collected data for task durations in their domains. Data are presented in the Table 1.

Table 1: Collected data for optimistic, typical and pessimistic expected durations (in weeks) for all tasks

Activity	Optimistic duration (o)	Typical (or most likely) duration (t)	Pessimistic duration(p)
A	2	3.5	8
B	2	3.5	14
C	1	4.5	5
D	1	2	3
E	2	3	10
F	3	4	11
G	1	2	3
H	4	5.5	10
I	2	3	4

The project management team has been charged with these tasks:

1. Display the project graphically.
2. Estimate the time to completion, if no unexpected delays occur.
3. Determine the earliest start and finish time for all activities (to be used in the initial scheduling)
4. Determine the latest start and finish times for all activities that will permit completion by the estimated completion date (to be used in "last chance" scheduling).
5. Identify critical "bottleneck" activities where any delays will necessarily delay overall project completion.
6. For non-critical activities, determine the amount of delay (slack) that can be tolerated without delaying project completion.
7. Given uncertainties in estimating durations, determine the probability of project completion by the deadline (and thereby avoiding the \$250,000 fine).
8. Manage possible needs for re-work because of latency or sub-standard quality of execution of certain activities?
9. If a decision is made to expedite project completion, determine the least costly way of proceeding.
10. Discuss the limitations of the analysis.

Case Description

We begin by cataloging all required activities, their precedence relationships, and their estimated durations. Using the table 1, we will construct input data for the CPM technique by calculating the expected durations for all activities using the data from Table 1 and applying the formulas from the PERT technique⁷. Table 2 presents activity descriptions, predecessors and results from the previous calculations.

For ease of presentation we will grant deterministic status to these durations and later we will discuss the PERT approach.

Table 2. Project Activity List (with added descriptions and calculated expected duration times)

Activity	Description	Immediate Predecessor	Estimated Duration (weeks)
A	Hardware and Network Upgrades	none	4
B	Design of Custom Applications	none	5
C	Installation of Core EMR	A	4
D	Installation of Custom Applications	B,C	2
E	Training - Hospital Staff	D	4
F	Training – Physicians	D	5
G	Integration Test	E,F	2
H	Shadow Use	G	6
I	Embed PACS (Picture Archiving and Communication Systems)	G	3

The next step is to use one of the traditional PM methodologies and get the initial results ("baseline"). Since the number of tasks is small and the relationships between them are very simple, there are many techniques to solve this problem:

1. To use a simple algebraic procedure: draw a sketch and find all possible paths; then select the longest one to be the Critical Path (CP) and its duration will be the Critical Time (CT),
2. To make a Gantt chart and calculate the CT, critical activities (CA), and based on them the CP
3. To draw a network diagram for the problem and apply Critical Path Methodology (CPM)
4. To use suggestion #3 and to implement it in an Excel spreadsheet (convenient for What-If analysis)⁸
5. To use a PM software package (if available)⁹

⁷ All PERT approaches use the weighted average of optimistic (o), typical (t) and pessimistic (p) durations for each activity or task. To calculate expected or estimated duration for each activity we can use the known formula:
 $d = (o + 4t + p) / 6$

⁸ This approach is very practical, not only for teaching purposes, particularly if there is no PM software available in the company or a Campus wide

The traditional PM approach

We will assume that readers are quite familiar with the CPM solution. Because of that, we will skip ideas 1 to 3 and briefly present solution #4. This model will be then expanded to answer more questions from the list of issues given above. In the same time, this will be the base model for developing the PERT and GERT models. We will use an Excel spreadsheet to draw a network and use some Excel functions to ease the calculations. Enter the project table (Table 2) in the Northwest area of a spreadsheet.

Name	Duration
ES	LS

Figure 1: A graphical symbol used to present an activity node with four data: Name, Duration, Early Start (ES) and Late Start (LS).

A simple notation will represent activities in nodes (see Figure 1). We start by creating a rectangular range of four cells for each node. To be more visible, we paint the cells of each node in selected color (designer may use different colors according to groups of activities, to get a color coordination). The upper two cells --Name and Duration (Figure 1)-- are filled by transferring the existing data from the entered table using simple linking with the appropriate cells in the table. Please note that task durations might result from a calculation made in this or some other worksheet. The bottom half of the range (cells named ES and LS in the Figure 1) will be prepared later. Activities (nodes) are connected with **arrows** (or arcs) using the drawing tools provided in Excel (from the Shapes icon)¹⁰. Each node may have zero or more incoming and/or outgoing arrows. All classic

methods of project management require a project to have **only one** beginning and **only one** ending node—**Start** and **Finish** with the durations of zero (designer may wish to add them to the chart making the network more compact). The network indicated in Figure 2

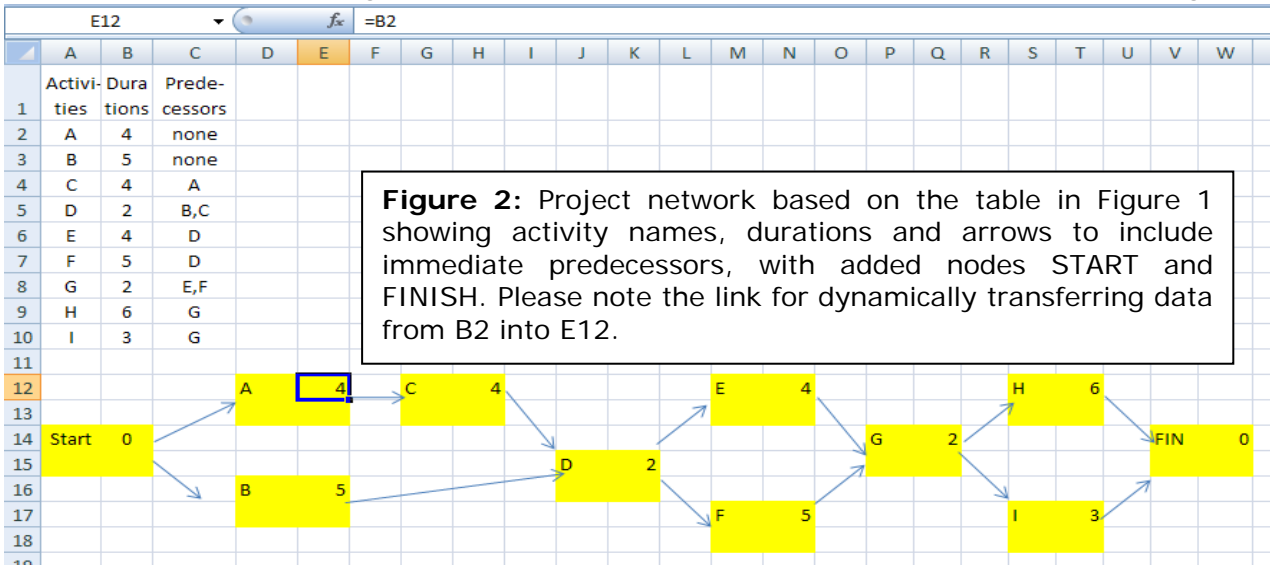


Figure 2: Project network based on the table in Figure 1 showing activity names, durations and arrows to include immediate predecessors, with added nodes START and FINISH. Please note the link for dynamically transferring data from B2 into E12.

⁹ For a list of commonly used PM software packages please see the Appendix A

¹⁰ Those arrows are drawings and they are not carrying any functionality in this example. The major inconvenience of this technique is that the project manager must create an original network for every project (actually, there is a small chance for reusing some of existing networks, but designer must be very careful in that attempt). Big projects can be subdivided into subprojects which can be reused (“Lego cubes” idea)

was created using the explanation above.

We use the CPM algorithm to calculate ES and LS and to find PM information.

Early Start (ES) signifies the point in time at which a given activity may start (assuming that all immediate preceding activities have been completed). Using this estimate will expedite manual solution since the user does not need to recalculate from the Start node every time. The ES should be entered into the lower right-hand square using the formula (see Figure 3) which is based on data from the immediately preceding node: its duration + its ES (there must be an arrow linking the two activities). If there are two or more immediate predecessors, ES will be the **maximum** ES of all directly preceding activities (see formula for activity D in the Figure 3). The value for ES in the finish node represents CT = 23.

The unused lower right-hand place of every node range (Figures 1 and 3) is reserved for the **Latest Start (LS)**. Latest Start indicates the latest possible time at which an activity may start without extending CT. We assume that the project manager will try to finish any given project as quickly as possible. This will make the **LS** for the **Finish** node equal to **ES**. The LS for any activity is calculated by subtracting the current activity duration from the LS of its immediate successor. Problems arise when there are two or more immediate successors; in this case, we calculate the **minimum** LS, for all outgoing arrows.

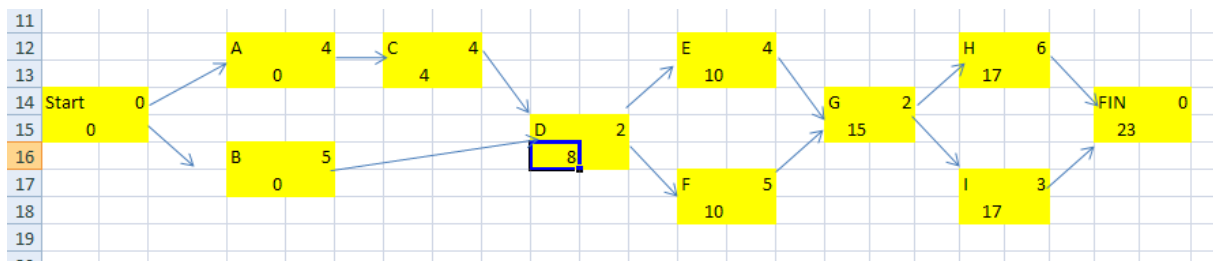


Figure 3: Calculating ES. Formula for ES in the node D (in the cell) J16 is
 =MAX(D17+E16,G13+H12)

Slack is the time available between ending one task and beginning the next (immediate follower) and must be non-negative ($S \geq 0$). Slack or $S(\text{task})$ is defined as the difference between LS and ES:

$$S(\text{task}) = \text{LS} - \text{ES}.$$

If the slack value for an activity (node) is = 0, this activity is defined as **critical** (obviously, any delay in any critical activity will create the project's delay).

Finally, Figure 4 presents the complete solution after calculating ES, LS and Slacks for all nodes and showing Critical Activities (CA). Based on CAs, designer needs to present CP(s). In this case, CP is A-C-D-F-G-H with CT=23 weeks (as indicated earlier).

Please note: when using a model like one presented in Figure 4, always try to use cell addresses in ALL formulas and for transferring the input and output values. This approach will offer possibilities to answer many What-If questions. For example, if a designer changes a duration for any activity in the input range (B2:B10), Excel will automatically recalculate the project outputs: slacks and CA's (later, for a PERT model will recalculate project variance). More than that, the change(s) can be applied even after the planning phase,

during execution, to find alternative critical path(s) if some activities take longer or shorter times. One of requirements for today's PM is to manage the project after planning it!

This approach is helping us to solve the first five of the posted questions.

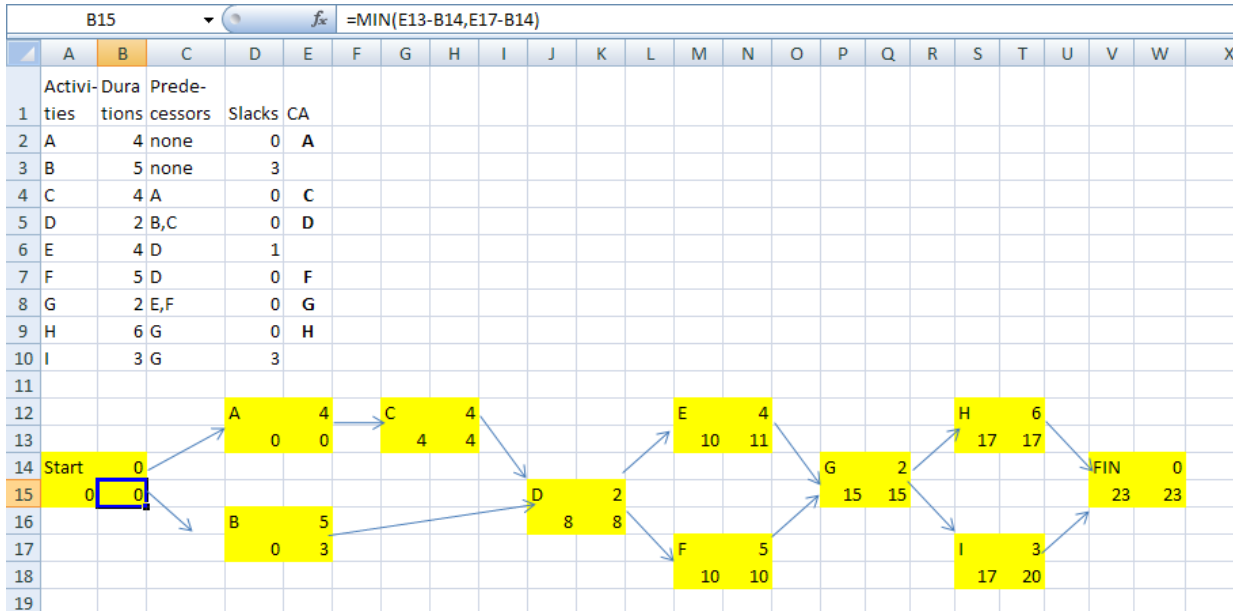


Figure 4: Completed CPM diagram with calculated slacks. Formula bar shows the last formula to be entered in the network for calculating the LS in the node A. To find if the activity A is the CA, we used the formula: `=IF(D2=0, B2, " ")` and this formula can be copied ("filled") down for all activities

The next table presents initial results:

Estimate the time to completion, if no unexpected delays occur.	CT = 23 weeks
Identify critical or "bottleneck" activities where any delays will necessarily delay overall project completion (noted as CA).	CA: A, C, D, F, G and H, creating the Critical Path (CP): A-C-D-F-G-H
Determine the earliest start (ES) and finish time for all activities (to be used in the initial scheduling).	Values in the lower left cell in each node in Figure 5
Determine the latest start (LS) and finish times for all activities that will permit completion by the estimated completion date (to be used in "last chance" scheduling).	Values in the lower right cell in each node in Figure 5. Please note: activities in nodes with slacks may start before the LS, but it will not shorten the CT

We created a project network and baseline plan, but, for smaller projects, designer will also create a Gantt chart. Using the ES, activity durations and slacks, designer may plot a Gantt chart using the Excel chart options (from the Input tab). This chart is presented in the Appendix B, Figure B2. It is placed there to allow reader to make easier comparison with Detailed Gantt chart from the Microsoft Project software, Appendix B, Figure B1.

With the sixth question (from the list of nine) designer in fact starts the management process for this project. Since there are activities with slack, one idea is to take advantage of the slacks in activities B, E and I using a possible reallocation of resources FROM these activities (making them "longer") TO critical activities (to make them "shorter"). For example, designer may extend activity B for up to three weeks, E for up to one week, and I for up to three weeks. This will make all activities critical (and make the project manager very worried), but will release resources from those activities. Obviously, during the PM process, designer should not use all slacks if the goal is to shorten the CT! In a real situation, the question is: how and what resources to re-allocate from those activities to make some of the other activities shorter (practically, what to use for possible reallocations: people, equipment or money?). If designer will expand activity B for 2 weeks, activity A will shorten for one week; similarly, expanding the activity I by 2 weeks could shorten H by 1 week, and the new CT=21 and the new plan will leave only E to be the non-critical activity! All other ideas to shorten the CT, like "crashing", need all data about costs. Using available data, we are discussing crashing in the section: *Decision making based on costs*.

The previous discussion generated sufficient information (based on fixed activity durations) to reach the question 7: to use uncertainties in estimating durations to determine the probability of project completion by the deadline. The CPM method applied above assumed fixed durations for all activities and there is no room for any probability issues.

But, in this model, the values used for the CMP were in fact expected values based on triple estimates prepared for the PERT calculations¹¹ and there is enough data for PERT analysis.

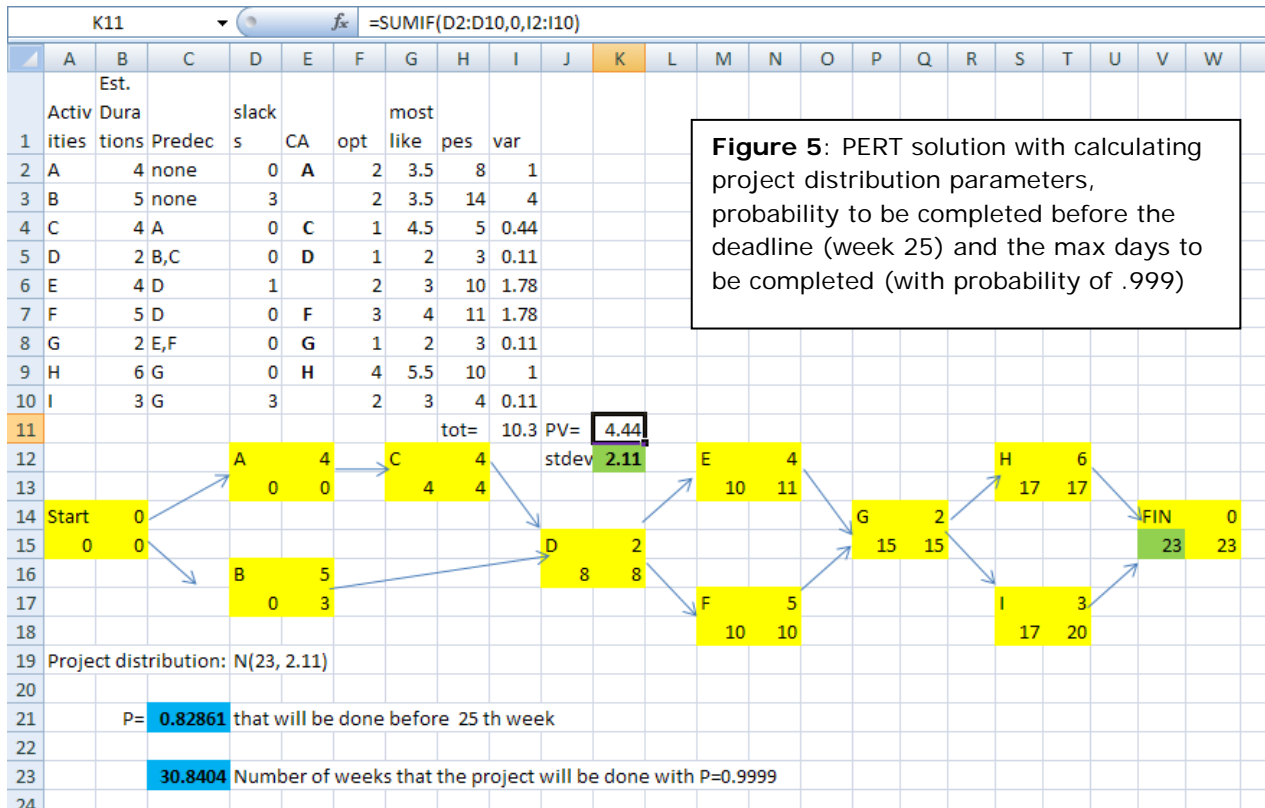
PERT input and output data and solutions are in the Figure 5. Using the project variance (defined as the sum of variances of all critical activities, PV=4.44) we argue that the project follows Normal distribution: N(23,2.11), with the mean of CT=23 and the standard deviation of 2.11.

In cells C21 and C23 we are using Excel built-in functions for the Normal and Inverse normal cumulative distribution, showing that there is 83% chance that the project will be done before week 25, while the project will be done before 31 week with a probability of 99.99%. This way we answered the seventh question.

Please note that typically software packages do not cover these probabilities and will prepare neither project variance¹² nor the appropriate probabilities to be used for the decision making.

¹¹ The PERT approach assumes Beta distribution which is usually approximated by the Normal distribution. This distribution has two parameters: the mean and the standard deviation. Mean is the CT, while the standard deviation is square root of the project variance. Project variance is the sum of variances of critical activities. Variance for the duration of each activity is given by the formula $V(\text{activity}) = ((p-o)/6)^2$, calculated in Figure 5. Note: designer may choose different weights (instead of: 1, 4, 1) when calculating the weighted average for estimating the activity durations.

¹² For example, in Microsoft Project, the term **variance** is used for DIFFERENCE! It has module (under Toolbars) to calculate expected time based on triple estimate, but does not calculate any statistics (variances, probabilities, max duration) for the PERT method.



To provide some additional information, designer could create CPM models by replacing expected durations with

- optimistic values, with CT=12
- pessimistic scenario, with CT=41, or
- using typical durations, CT=21.5.

Simulation experiments when using the same data typically show smaller probability that the project will be completed before given date (week) in this case. More than that, PERT makes three simplifying assumptions:

- The mean critical path is taken to be the longest path through the network. Although this might not be the case, the error in critical path length arising from this assumption is likely to be small
- The activities are assumed to be statistically independent. This greatly simplifies the calculation of project duration variance. The assumption will be violated if the circumstances that delay one activity also delay other activities¹³.
- The project duration random variable is assumed to be normally distributed. Since project duration is the sum of independent random variables (activity durations for activities on the mean critical path), we can invoke the Central Limit Theorem to justify this assumption. As the number of activities increase, the assumption becomes increasingly plausible.

¹³ Which is often not a case in IS projects and it makes PM of those projects more challenging.

All previously reached information could be used for decision making about timeline, but it leaves a space for some critics to say that, majority of PM packages **should not be used at all** since the time management can be planned without checking the appropriate resources!

After preparing these additional PM scenarios, the members of the management team may make an argument that the best approach will be to try the most optimistic plan (with CT=12) and to allow re-work for certain nodes (with assumed probabilities based on the historical data). If necessary, it means to organize a new model with loops for re-doing selected activities. Also, if the upper management or stakeholders will ask a question: what if some activity needs to be re-worked, designer will need to make a new model. Traditional PM approaches do not support these options and they are often seen as typical shortcomings of currently applied PM techniques.

Because of that we introduce **Graphical Evaluation & Review Technique (GERT)**. The new model (based on the existing model presented in Figure 4) will introduce selected ideas from GERT approach. After creating a new model, to implement it, we will run Monte Carlo simulation and discuss selected outputs. Let us first present a brief introduction into GERT methodology.

Description of the GERT technique

As stated above, traditional PM models do not offer solution for relatively common problems in managing the IT and production projects. Among others, the problems are: need for reworking and branching (based on decision made in previous activity), or the possibility of taking several paths to reaching the succeeding activity with given probability. Classic models (based on CPM) do not allow "revisiting" the previous nodes in the case when tasks need to be re-examined or reworked.

The simplest solution for at least some of those issues seems to be to allow additional time for selected tasks or to add extra time to the Finish node (to put a duration >0 for the Finish node). In the model, it will make all activities have a slack (known as "buffering"). This will extend the project time. Designer could identify the critical activities and critical path(s) using the given value for duration of the Finish node (CA will have a slack equal to that value). But, the problem is not solved: now, the project is planned be to ALWAYS longer (even when the re-work will not be necessary).

Nicholas (2004)¹⁴ identifies 5 major challenges for the traditional PM methodologies:

1. All immediate predecessor activities must be completed before a given activity can start
2. No activity can be repeated and no "looping back" to predecessors is permitted
3. The duration time for an activity is restricted to Beta distribution for PERT and to a single estimate (deterministic) for CPM.
4. The critical path is always considered the longest even though variances include the likelihood of other paths being longer
5. There is only one terminal event and the only way to reach it is by completing all activities in the project.

¹⁴ Nicholas, J.M. Project management for business and engineering: principles and practice. Elsevier, Boston (2004)

PM concepts which allow conditional branching, rework and looping use the common name: **Graphical Evaluation & Review Technique (GERT)**.

When a project is presented in the GERT environment, designer may apply the Monte Carlo simulation to estimate the major characteristics of the model and these outputs will be used for managing the project. After reviewing the challenges, it is fascinating that many IT projects can be easily identified as good candidates for GERT modeling.

Developing a program to execute the GERT model

To be able to prepare a GERT version of our model, it is necessary to select one or more activities we would like to consider for re-work or to introduce possible feed-back loops in some points (nodes). Project manager should apply his or her own experience or consult literature when making those selections.

This discussion could lead into two areas:

- a) What about quality? It is possible to assume that the highest quality will be produced if all activities are prepared "slow" (e.g. using the pessimistic durations), but IT projects' experiences will tell us that this is not always true! Also, in this case it means that the project will be late 16 days, forcing the hospital to pay huge penalty!
- b) What if we make all durations stochastic? After choosing the appropriate probability distributions for all (or just selected tasks), we need to change our model. One model is Figure 6, where we use random numbers from Excel to create variable durations of activities. After that, to be able to collect information we create a program for Monte Carlo simulation¹⁵ and run selected number of simulations¹⁶.

Our presented model addresses the solution of the PM projects using the CPM, elements of the theory of probability and Monte Carlo simulation. We implemented this model using Microsoft Excel and Visual Basic for Application (VBA). This is the most convenient approach because of availability of the software and the knowledge of typical users who will need to develop and execute appropriate types of models in their PM practice.

For this case study we are proposing a simple GERT method to estimate network characteristics such as the project time. Presented method starts with a design of a stochastic network. After running a set of Monte Carlo simulations, program generates outputs. The PM manager will need to validate the model and to analyze outputs and compare initial information with results based on the traditional PM techniques.

The first model simulates activity durations based on data from the PERT analysis (Figure 6). Let's assume that each duration uses the most-likely value $\pm 2 \cdot SD$ for the appropriate node. Sign + or - is decided based on a random number from the Uniform distribution: $U(0,1)$ using built in Excel function `Rand(?)`. For example, if this random number is < 0.50 , sign is negative. All results are in Figure 6. After many simulations (using different seed values), the probability that the project will be completed before the week of 25 is 80%, and the project will be completed with 99.99% before week 31.3. We applied very simple statistical analysis. The purpose of this simulation is model validation (results are statistically close to PERT outputs). In this model all durations were generated using the random

¹⁵ We are presenting an implementation using Excel and VBA code. The code is available from authors upon request, free of charge for educational purposes. It is possible to use Crystal Ball, @Risk or some other similar package for this simulation. Please note that simulation packages tend to be expensive.

¹⁶ Simulation results when using the Crystal Ball are in the Appendix B.

numbers. Obviously, a similar idea could be used if designer would like to keep duration of selected activity fixed and simulate durations for other activities.

Depending how the model is created, it could be also used for a stochastic model for rework, making it closer to the main GERT idea.

Figure 8 presents the case with reworking two activities: B and E. Formula for rework is based on assumption about the frequency of reworking and the extra time required for the rework. No surprise, the simulated CT is longer (24.33 weeks after all runs), giving the smaller chance that the project will be completed on time (62%) and the chance for 99.99% finalization is happening a week later (week of 32.3).

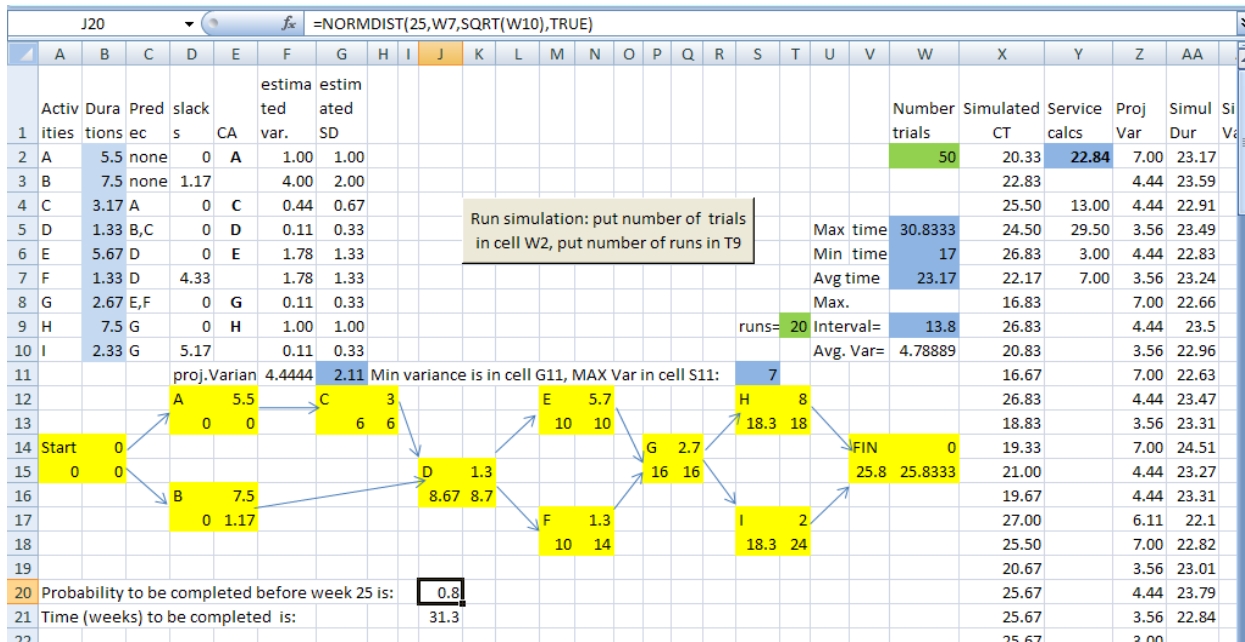
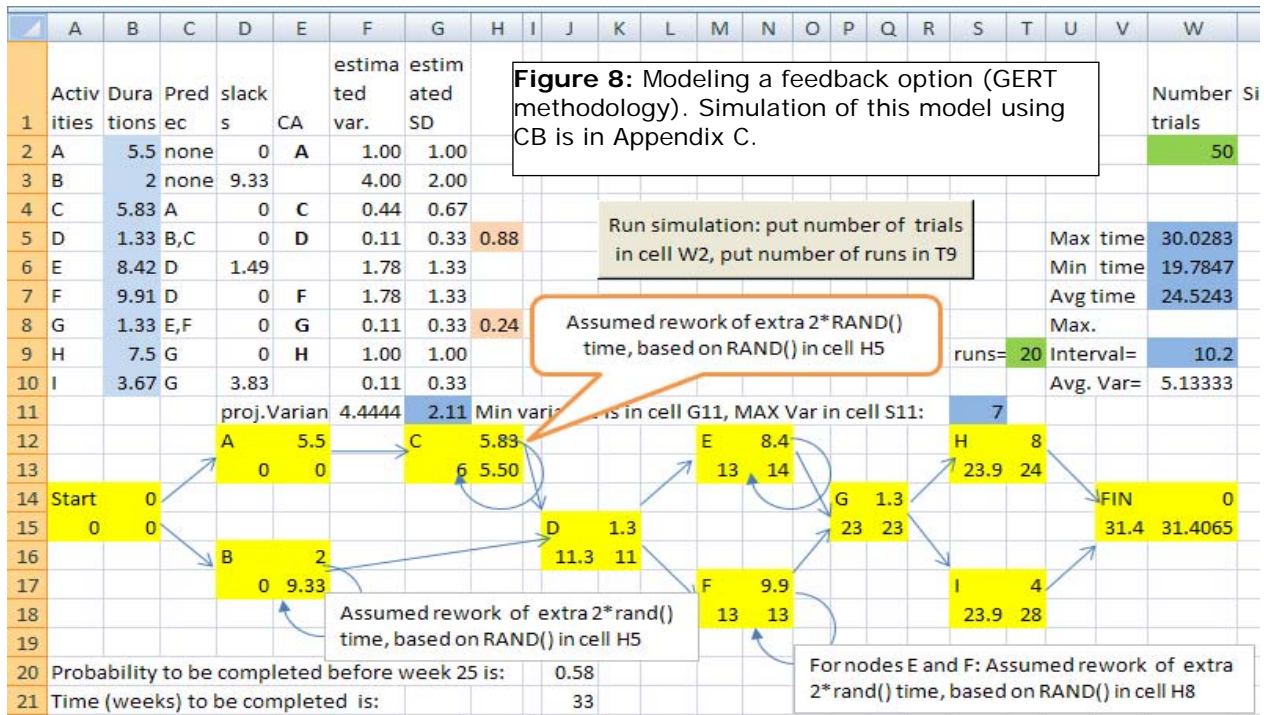
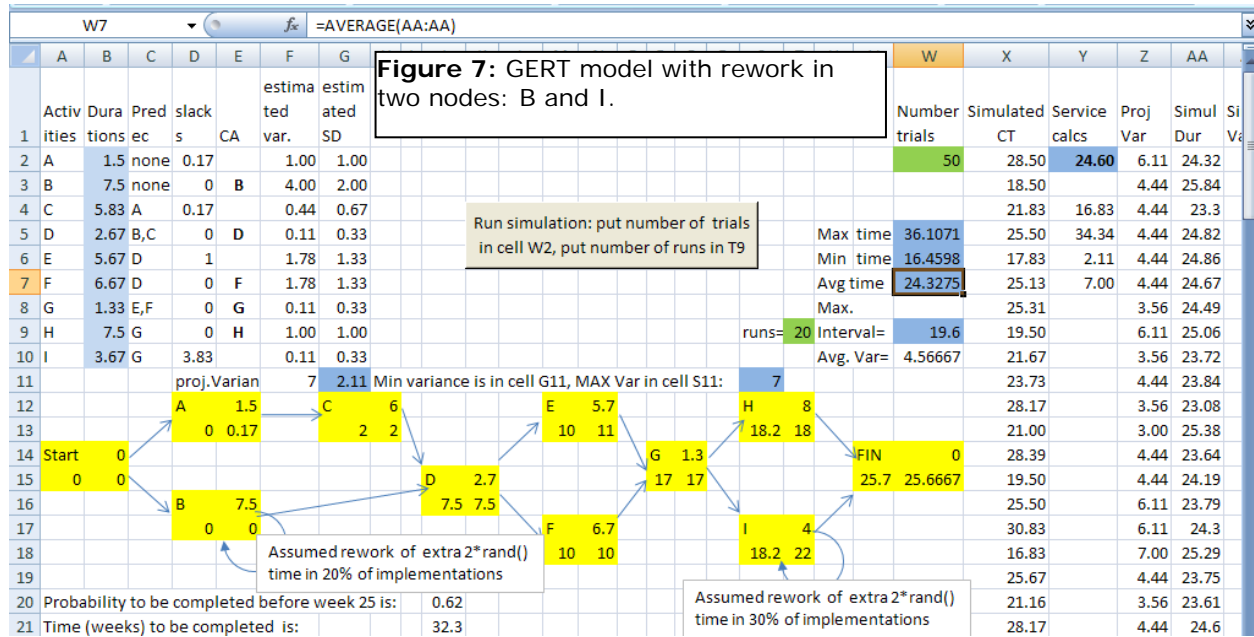


Figure 6: Simulation model for the PERT analysis. Model is used to validate its quality. After running 20 simulation runs (each with 50 trials) output results are compatible with the results from the theoretical PERT. Like in Figure 6, we use the function NORMDIST. In the model, two adjustments were made: since the minimum values for B and E using the suggested formula $\pm 2 \cdot SD$ may lead to the duration(s) for these activities to be below zero, we put the optimistic durations for the minimum values in these nodes.

Similarly to the rework model, Figure 8 presents the model with feedback loop. Let us assume that there are problems with the quality of work in the node D, and also some issues about the quality of training in the node G. It means that project manager needs to organize rework of preceding activities B and C for D and E and F for G. This way, if there are known probabilities when the problems will occur, a feedback loop model could be realized as a special case of a rework model. This EMR problem does not offer conditional branching¹⁷ since all presented activities must be executed and we cannot demonstrate this GERT

¹⁷ The need for the conditional branching is present mostly in production and marketing projects. For example, new product is being tested at five sites and after successful completion at three of them, process can go on to the next node (while the other tests will be completed or stopped). In this case project manager must have appropriate conditions and/or probabilities to be able to run this model.

technique subtype using this project. We defer the discussion of how the estimates are obtained until later in this case. The activities are depicted in a network diagram (Figure 1). We choose an Activity on Node format (as opposed to an Activity on Arc format, which was popular when PERT/CPM first came to prominence). Observe that we are assuming simple precedence relationships in the network diagram. That is, we cannot start an activity until all immediate predecessor activities have finished.



Current Problems Facing The Project

We turn to question #8 and consider how we could expedite project completion, and what that might cost. In other words, we want to perform a time-cost trade-off analysis. There are two reasons why this type of analysis is worthwhile. Our superiors might not be reassured by the approximately around 80% probability of project completion before the Health Department's deadline (and \$250,000 fine); they may ask us to accelerate the project and increase the probability of meeting the deadline. In addition, even if we decide to proceed "normally" at the outset, early unforeseen delays could cause us to change our plan in mid-project. In that case an existing formal analysis of time-cost trade-offs would allow us to rapidly institute cost-efficient adjustments to our project.

The project manager was not able to disaggregate those costs by resources, particularly to make a split between human and material costs. Because of that, we have to assume that we cannot reallocate resources as indicated in the previous discussion about managing the plan before starting the project since we do not have all needed data about resources.

We will use CPM method to explore the most efficient ways to "crash" the project. Crashing an activity refers to taking special costly measures to reduce the time for completion of an activity below its normal value. Examples of costly measures include bringing in extra staff or equipment, and paying overtime. Crashing the project refers to crashing a number of activities in order to reduce project completion time below its normal value. CPM assumes a linear time-cost relationship for each activity.

A representative graph for this relationship is illustrated in Figure 9.

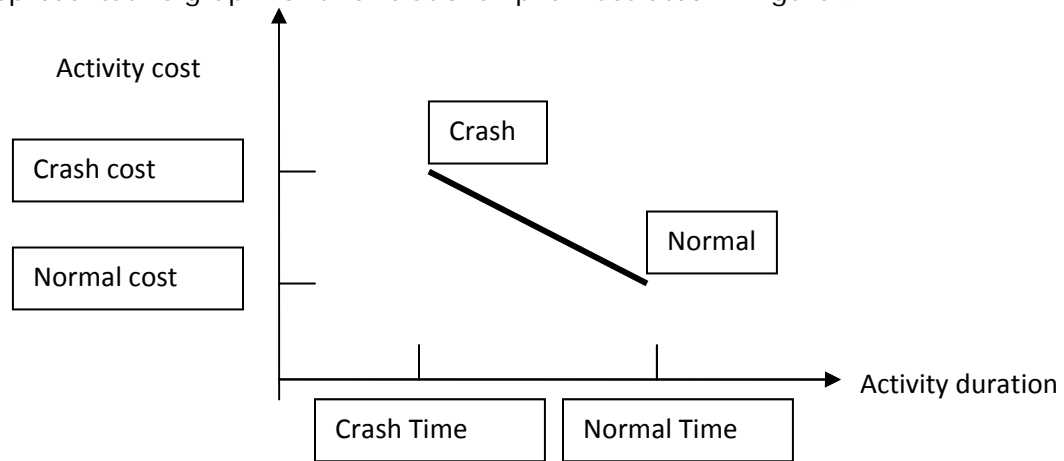


Figure 9: Graphical representation of Time-Cost Trade-off of Crashing an Activity

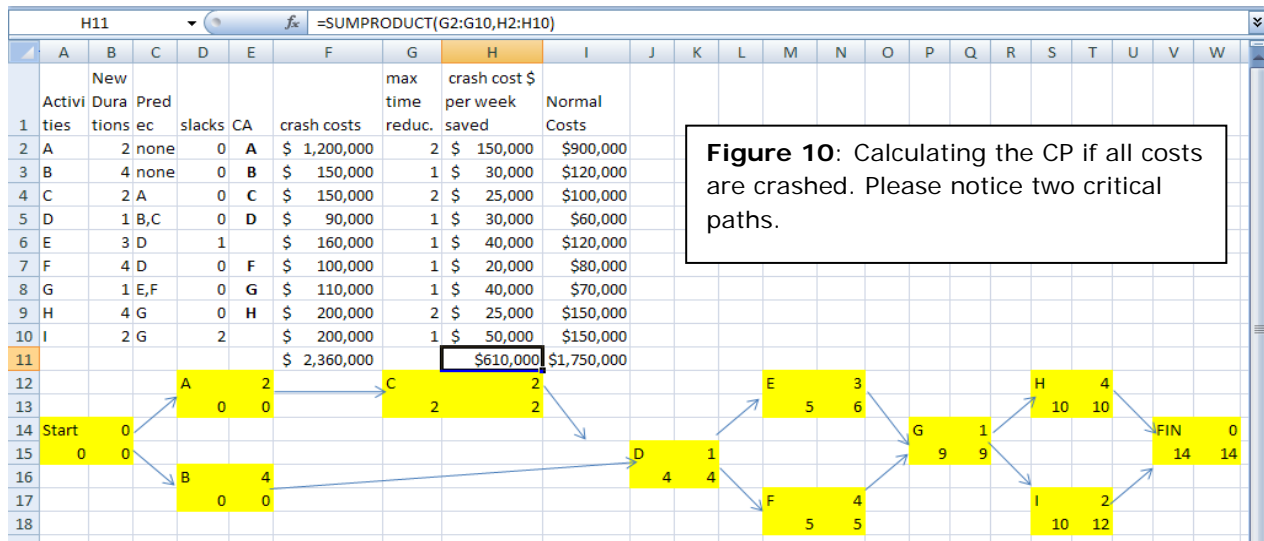
The Normal point gives the time-cost pair associated with performing the activity normally. Similarly, the Crash point gives the time-cost pair associated with fully crashing the activity (reducing its duration to its minimum possible value). CPM assumes that we can obtain accurate estimates of these two points from the activity supervisors. CPM also assumes a continuous linear relationship, where proportionality and divisibility hold. In other words, we can partially crash anywhere along the depicted line segment. These simplifying assumptions greatly aid our analysis.

Note: This assumption about linearity may not be applicable in many cases. For example, it could be difficult to change or update contracts with workforce, or to extend a rental agreement or to change the transportation plan.

In Table 3 we collected the time-cost estimates for each activity (supplied by activity supervisors). We can use the CPM with the crash durations and then find the fully crashed critical path. It turns out (Figure 10) that there are two critical paths with a length of 14 weeks. Thus, the fully crashed project has an estimated duration of 14 weeks and a cost of \$2,360,000 while the normal project's time and costs are 23 weeks and \$1,750,000, respectively. Considering our previous analysis on probability of completion by deadline, and the magnitude of the fine that we face (\$250,000), we cannot justify the additional cost (\$610,000) of fully crashing the project.

Table 3: Time-Cost Trade-off Data for Project Activities.

Activity	Time (weeks)		Cost (\$)		Maximum Time Reduction (weeks)	Crash Cost (\$ per week saved)
	Normal	Crash	Normal	Crash		
A	4	2	900,000	1,200,000	2	150,000
B	5	4	120,000	150,000	1	30,000
C	4	2	100,000	150,000	2	25,000
D	2	1	60,000	90,000	1	30,000
E	4	3	120,000	160,000	1	40,000
F	5	4	80,000	100,000	1	20,000
G	2	1	70,000	110,000	1	40,000
H	6	4	150,000	200,000	2	25,000
I	3	2	150,000	200,000	1	50,000
Total Costs			1,750,000	2,360,000		



In the figure 10, there are two activities (E and I) with slacks. If project manager will completely crash all activities, but not to crash E and I, there are savings of $40,000 + 50,000 = 90,000$ making the additional cost to be 520,000 (still much more than eventually to be late and pay the fine).

A partial crashing time-cost trade-off analysis is still worthwhile for the reason mentioned previously; unexpected setbacks early in the project may force us to crash the remaining project, or some of the remaining activities. We need a method to select the most cost-efficient choice of activities to crash. There are at least three alternatives. For most projects of any complexity this problem is best formulated and solved using linear programming methods. The second idea is to use the marginal cost analysis with our Excel template and the concept of What if Analysis. The third idea is a simulation option and it is presented in the Appendix D.

A partial crashing time-cost analysis starts with first crashing the activities with lower marginal costs. In our case, "cheaper" crashing will be to crash activities in the order: F (20,000 extra costs per week), C and H (25,000), B and D (30,000), E and G (40,000), I (50,000) and A (150,000).

Figure 11 shows step-wise crashing for this case, following the idea to crash the cheaper activities first.

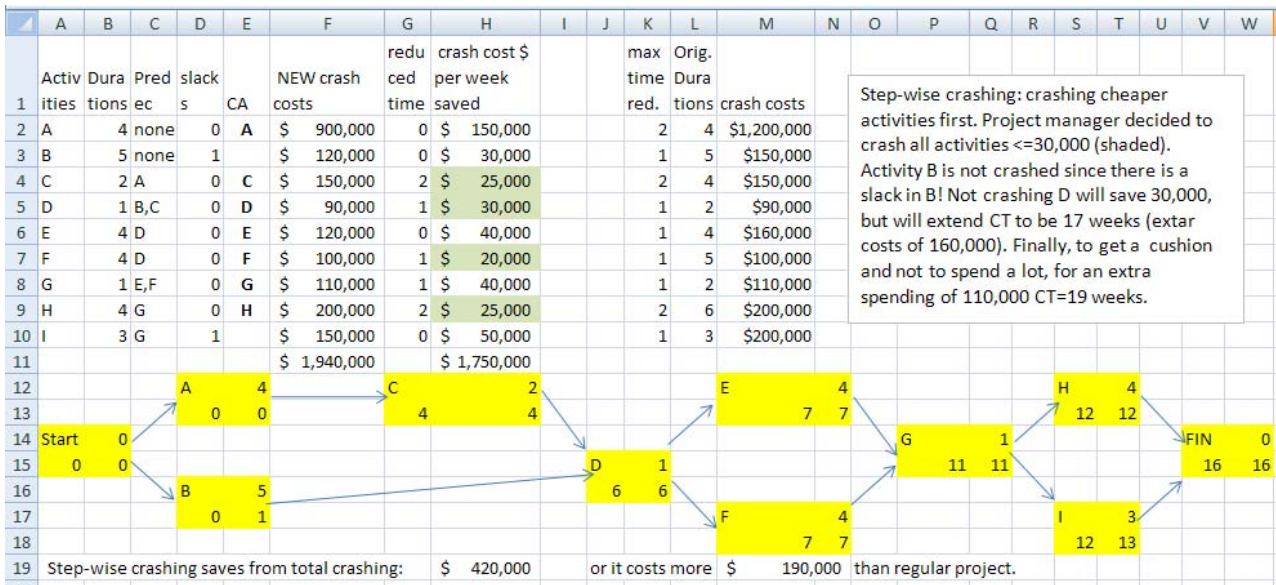


Figure 11: Step-wise Crashing. Check how much more it costs comparing to the regular costs!

Observe that it is never beneficial to crash activity 1. This marginal cost crash analysis could prove very useful to us. Even though we plan to run our project in a normal mode, we have a range of contingency plans available to us should unexpected problems arise. For example, if delays occurred early in the project we would know to immediately crash F by one week,

and then crash H by two weeks if needed. In the process of crashing, it is necessary to observe the slacks. Project manager does not want to crash duration and to have slacks!

Scenario Summary							
	Current Values:	tep_wise_ALL	Step-wise-1	Step-wise-2	step-wise-3	step-wise-4	step-wise-5
Changing Cells:							
A_150	0	2	0	0	0	0	0
B_30	0	1	0	0	0	0	0
C_25	0	2	0	1	2	1	2
D_30	0	1	0	0	0	1	1
E_40	0	1	0	0	0	0	0
F_20	0	1	1	1	1	1	1
G_40	0	1	0	0	0	0	1
H_25	0	2	0	1	2	1	2
I_50	0	1	0	0	0	0	0
Result Cells:							
New_Crash_cos	\$ 1,750,000	\$ 2,360,000	\$ 1,770,000	\$ 1,820,000	\$ 1,870,000	\$ 1,850,000	\$ 1,940,000
CT	23	14	22	20	18	19	16
Total_slacks	7	3	6	4	2	4	2

Figure 12: Summary of running several step-wise scenarios. The first two scenarios: Current value is without crashing and step-wise-ALL is with crashing all activities, while others are with crashing the cheaper activities first. Step-wise-3 looks very promising (CT=18 weeks representing the savings of 5 weeks with extra spending of only 120,000). In this and in all other cases project manager must pay special attention to the row Total_slacks to check the CPM model that they are not planning to crash an activity and to produce a slack in it. Please note that existing slacks in scenario step-wise-3 are in activities B and I, which are not crashed.

Using the Scenario Analysis option from Excel we created the next Figure 12. Using this approach project manager can prepare several alternatives (scenarios) to present to the board. Obviously, there are many possibilities and the approach should be step-wise.

Discussion about some of the limitations of our analysis

Finally, we turn to the 10th task, addressing the limitations of our analysis. We will critique the PERT/CPM methods that we have used and consider modifications that may improve our analysis. Recall that even our very first application of PERT/CPM PM, construction of a network diagrammatic representation of the project, involved a simplifying assumption. We assumed a simple form of activity precedence relationships; an activity could not start until its immediate predecessors were finished. Our modeling did not permit more subtle relationships, such as overlapping activities or lags between activities. More sophisticated precedence diagramming methods (PDM) can be used, but that increases the complexity of traditional analysis. Obviously, the simulation and GERT approaches introduced in this case study will allow making those types of models.

PERT activity duration estimation methods are very approximate. There are problems at

many levels of the process. The optimistic, pessimistic, and typical estimates (o, p, and t estimates) provided by activity supervisors are very subjective. Moreover, they are inherently difficult estimates for supervisors to make. We are asking supervisors to give us the extreme values of a continuous probability distribution. These values correspond to extreme events that are undoubtedly outside the realm of the supervisors' experience. Even the most likely estimate is more difficult than it appears. Most people are better able to use their experience to estimate the median of a distribution, as opposed to the distribution's "peak" (most likely value). In addition to these problems of estimating o, p, and t, the PERT mean and variance formulas are very rough approximations. Modified estimation methods have been developed. In one such modification supervisors are asked to supply the 10th, 50th (median), and 90th percentile values of the activity duration distribution. These are easier estimates for supervisors to make, but the resulting approximation formulas for mean and variance are more complex.

PERT methods for estimating overall project length are open to criticism on many fronts. The three simplifying assumptions - mean critical path, statistically independent activities, and normality - are the genesis of the problems. As we saw in our analysis, the mean critical path may not turn out to be the actual critical path. PERT uses it anyway, and we hope that the error introduced is small. For the EMR project the error turned out to be small (recall in the most pessimistic scenario the critical path changed, and that added a week to project length). However, the PERT modeling framework gives us no guidance on the possible magnitude of this error. Empirical studies have shown that it is typically small, but this error can be very large. That is not reassuring.

The second simplifying assumption, statistical independence of activities' duration, is also a problem. Consider, for example, delays due to adverse weather or interruption of input (labor and materials) supply. It is easy to see that these events could adversely impact more than one activity, and that independence would no longer hold. Recall that independence simplified the calculation of project length variance. Without independence we not only need estimates of activities' covariance, but we can be certain that project length variance will be higher. What is the consequence of underestimating project length variance? When we standardize our normal distribution, and calculate a z-score corresponding to the deadline date, underestimation of variance gives overestimation of the z-score; overestimation of probability of project completion before the deadline follows. As an alternative to PERT methods, we used simulation methods to estimate the project length distribution. Our output from a simulation runs supported the expectation that PERT overestimates the probability showing when the project will be completed before deadline. That is why we reduced our estimate for EMR completion by deadline from 83% to 80%. Simulation methods are the main alternative to PERT methods for this particular problem. Of course, that fundamentally changes the nature of our work from an analytic framework to a simulation or hybrid framework.

As mentioned earlier, probably the biggest issue is that PERT/CPM methodology implicitly assumes that resources are available for all activities in both normal form and crashed project scheduling. However, it is not unusual for various activities to require some of the same resources, and that these resources may be limited (not just constrained by cost). That presents a new dimension to project decision making; resources must be allocated

across activities. Traditional PERT/CPM methodology does not address this and appropriate software packages manage time without explicitly requiring inputs for resources.

The CPM time-cost trade-off analysis also has limitations. The estimates for fully crashed activity times and costs are subjective. In addition the assumed linear and continuous time-cost relationship often does not hold. As crashing progresses, costs are likely to increase (not be constant as linearity suggests). It is also unlikely that the continuity/divisibility assumption holds; labor, in particular, is not fully divisible. Some of these problems can be overcome with modifications to a linear programming approach to crashing decisions (not presented in our paper).

Several times in the paper we discussed the educational values and underlined the ideas of connecting several areas of IT and business education. We hope the readers will find it to be very interesting and useful.

In summary, we have illustrated the use of PERT/CPM, GERT and simulation methods in the case of implementation of an Electronic Medical Record project. Although the methods have limitations, their application brings a formalism and discipline to our endeavor. Adding support from Excel wizards for scenario analysis and Pivot tables and our VBA programs we enriched the traditional approaches and brought them closer to contemporary decision making. PERT/CPM provides useful, albeit very approximate, estimates that are useful in our project management decision making.

Appendices

Appendix A: Introduction to PM Software market¹⁸

The PM software market is an aggressive one with a variety of vendors offering specialized PM packages and PM options for existing enterprise solutions. A short list would include: Project Scheduler; Fast Track; MS Project 2000-2007 (in this paper we use version 2007); ProjectTrak; Welcom; Artemis; and Primavera (Artemis and Primavera are considered the "high end" packages).

The list of Open-source software products is equally diverse, including: PHProjekt (an internet-based groupware suite, www.phprojekt.com); DotProject (www.dotproject.net); MrProject (a part of GNOME, <http://mrproject.codefactory.se>); Project/Open (internet-based "Project-ERP" with an emphasis on project collaboration and finance, www.project-open.com); Gantt-Project (written in Java for all OS, <http://ganttproject.sourceforge.net>).

There are also proprietary internet-based packages like Project.Net (www.project.net), eProject (www.eproject.com) and Projectplace (www.projectplace.com). For more details, please see vendor Web sites.

¹⁸ In Gido and Clemens: *Successful Project Management*, Thomson, 2006, on the page 421 authors refer us to the web page: www.pmi.org/ for the comprehensive list of PM software vendors and consultants

Appendix B: Solving the EMR case using Microsoft Project

Microsoft Project has user friendly Input (user need to enter data for durations in a form of table, as CPM or PERT model and add other input values like resources and costs, if available). More than that, user can create a specific calendar for the project and/or individual calendars for specific people. Then, PM software generates many views: Gantt, Network, Resources, Costs... Figure B1 presents two Gantt charts for the EMR case with applying different calendars. Please note that the standard calendar is applied in the upper part of the figure (in this calendar Thanksgiving holiday and weekends have 2 days off) and modified calendar (free day is only Sunday and only one not-working day for Thanksgiving) in the lower part of the screen. The selection of these two calendars is interesting to compare with manually generated data of having CT=23 weeks. Now, manager can see what 23 weeks means in reality! Chart B2 is prepared using Excel chart option to compare with upper charts. It is easy to create, but not helpful enough for decision making.

Microsoft Project software offers many very useful outputs, particularly when designer enters resources and costs. In addition, newer versions (2003 and 2007) offer possibilities for “virtual” management using Internet connections applied to the group work and also allows the project manager to manage multiple projects using the same or different team members, allowing manager to manage more than one project, but also project team members can work on more than one project. The 2007 version gives additional very good reports¹⁹ presenting them in Excel format with charts and Pivot tables. Previous versions had only static reporting options (generating only Print Preview type or outputs)²⁰. User can enter triple estimates to get PERT-like inputs (using special toolbar), but, as mentioned earlier, calculations use CPM technique and computations for probabilities and PERT distributions are missing.

¹⁹ Please note: reporting and some other features are not available with the “60 days free” or trial version of the program

²⁰ It was one of the common critiques of the program earlier

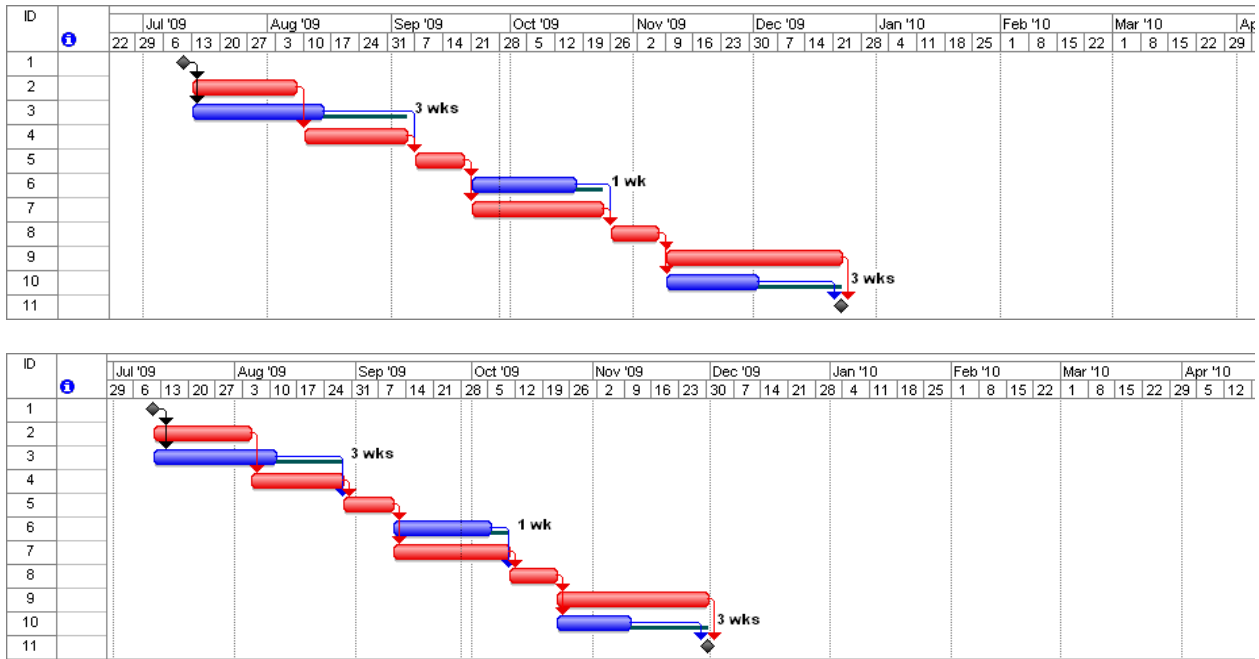


Figure B1: Detail Gantt charts for the EMR case generated by Microsoft Project for two different calendars

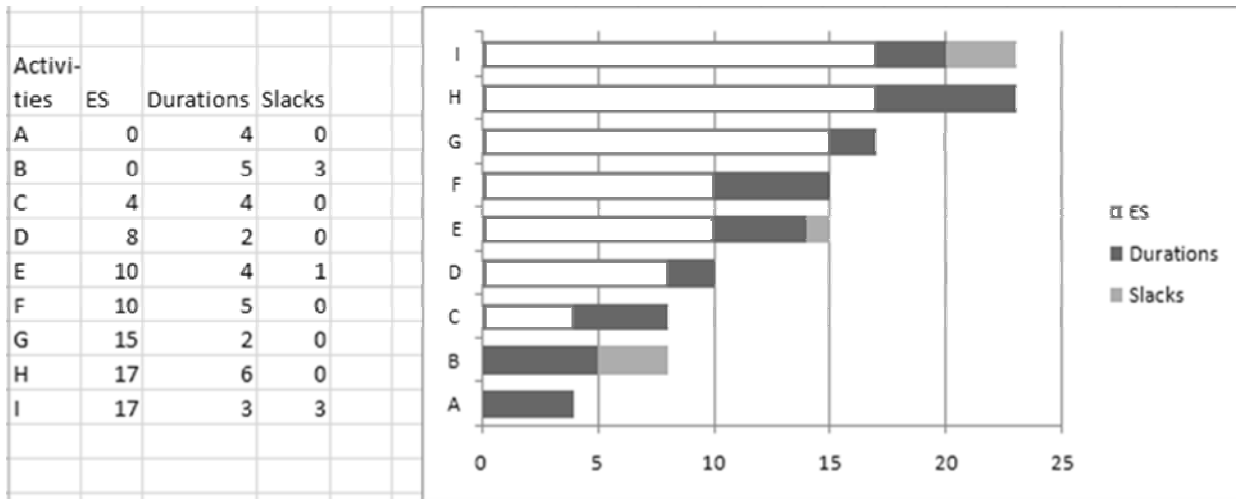


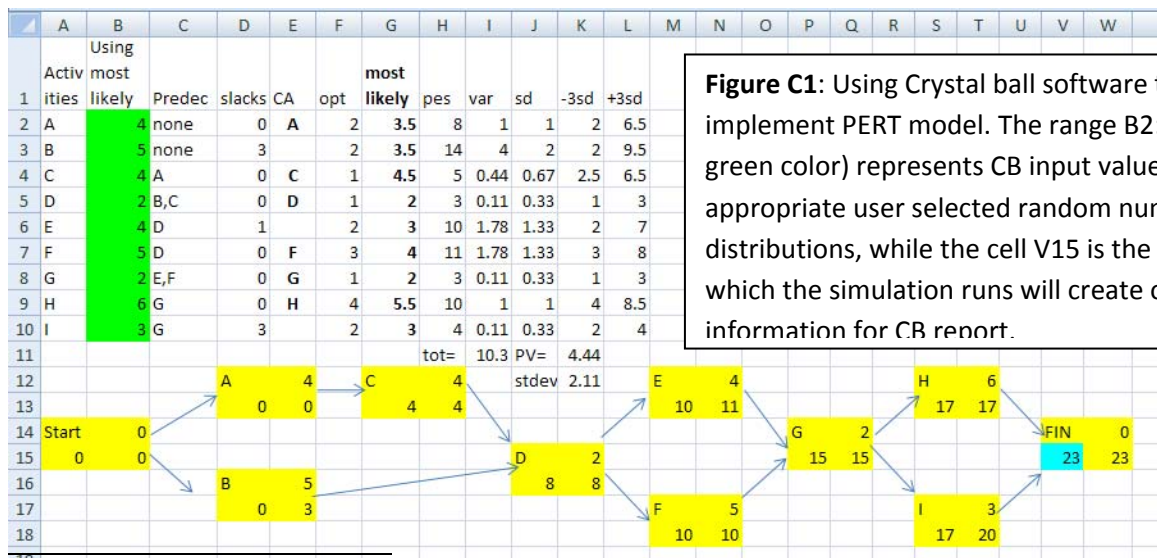
Figure B2: Gantt chart for the EMR case based on the manual CPM solution and created using the Chart option from Excel. This chart is made in three steps: highlight the data, select Insert and from the Chart menu select Stacked bar. Note: each activity starts at the end of its ES bar (for the starting activities ES=0) and critical activities do not have any slack (slack is 0 and it cannot be presented in the figure). This chart use the “raw” data for PM (from week 0 to week 23).

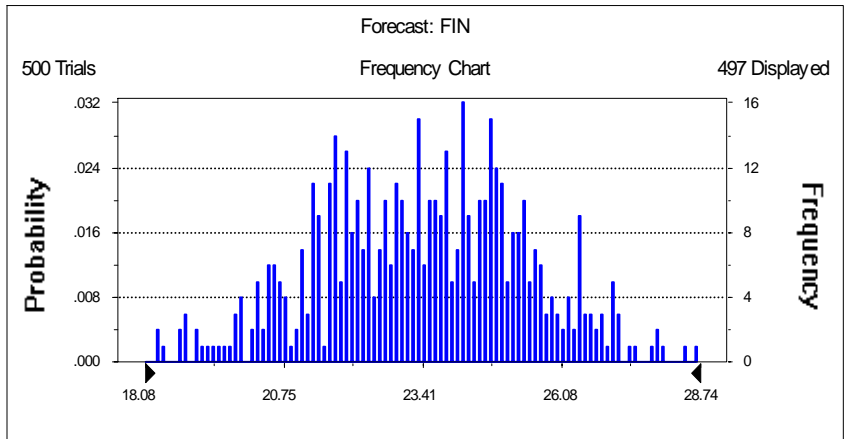
Appendix C: Implementing GERT model of EMR case Using Crystal Ball

When realizing GERT processes it is very common to utilize a simulation methodology²¹ and the use of a simulation package CrystalBall (CB) is very convenient for modeling GERT PM problems. Those models include stochastic variables and designer needs to prepare characteristics for probability distributions for input variables, selection of the number of runs, and discussion of the results. For the first example we are using Normal distribution and parameters from the PERT approach, and we expect results similar to PERT outputs. Excerpts from CB design are presented in Figure C1, while parts of reports are in Figure C2. We will use the PERT data and normal distribution for each activity: we use the PERT variance to calculate the standard deviation (SD) and then we selected interval: the most likely value +/- 3* SD. If the value: task duration's most likely value -3*SD is less than the optimistic time we will put the optimistic time duration as a lower limit in the simulation run. (Please locate this for activities A and B having big SD).

If a project manager has more detailed information about activity durations and the Beta²² distribution cannot be applied, designer can choose from a variety of built-in distributions in CB or even use empirical distribution if desired. When applying the GERT procedure, designer may wish to model a system with a feed-back loop. Let us assume that, dealing with activities D and G, designer found problems. In this case rework will be needed for an activity or activities immediately preceding activities D and G and could be estimated by adding extra duration for those activities. In this situation, designer needs to select probabilities p(node) for occurrence of the problem and how much time should the rework take? Assume that the problems for B and C occurs with p(D), and in that case durations should be longer. Similarly, using p(G), training activities (E and F) should be expanded or not. Designer may wish to run two separate random numbers for p(D) and p(G) which may generate situations with none, one or both reworks.

Possible CB design is in Figure C3, with results in Figure C4.





Percentile	Value
0%	17.75
10%	20.74
20%	21.71
30%	22.26
40%	22.92
50%	23.49
60%	24.10
70%	24.62
80%	25.12
90%	25.96
100%	29.62

Figure C2: Partial results from CB simulation for the PERT problem. Please note that FIN value is <25 in almost 80% of runs, and the project will be 100% completed within 29.62 weeks.

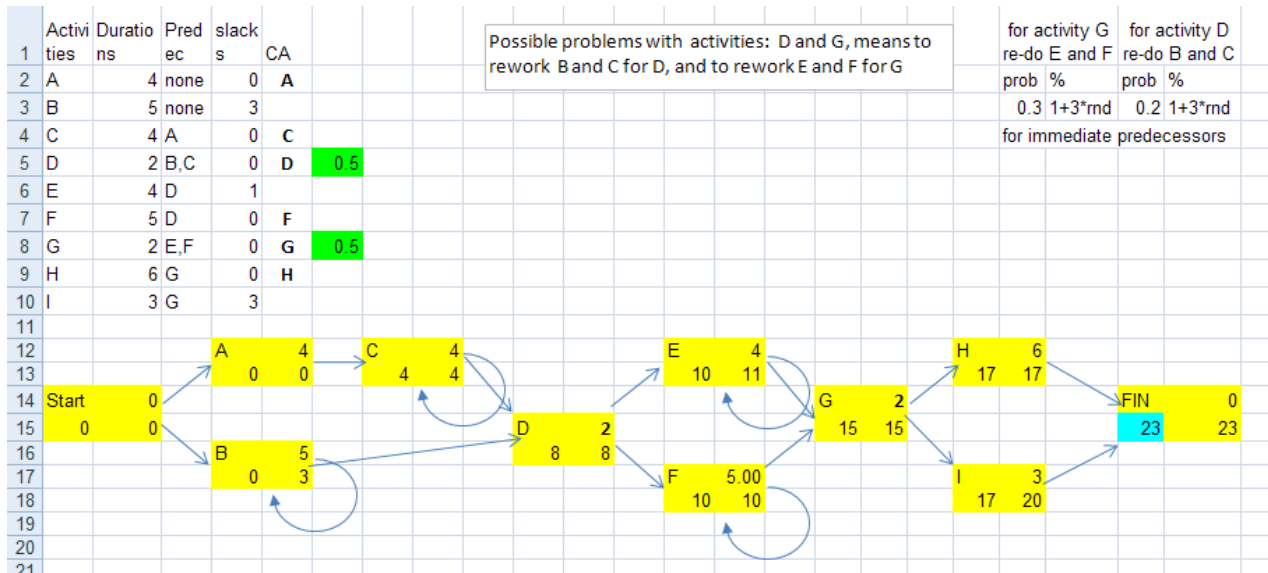


Figure C3: Creating a model for GERT approach based on Figure 9 (from the main text) where the activities B, C, E and F need rework. Durations for those activities are functions of random numbers and our assumption (see in the upper right hand side corner). For example, formula in cell B3 for the activity B (with estimated duration = 5) is =IF(F5<0.3,5*(1+3*F5),5) Input cells for CB simulation are F5 and F8 (green color, with Uniform distribution U(0,1)), while the output cell is V15.

Figure C4 (right): Partial results from CB simulation for the reworking problem. Please note that FIN value is <25 in only about 57% of runs and the project will be 100% completed within 42.75 weeks (what is almost two weeks longer then the most pessimistic CT).

Percentile	Value
0%	23.00
10%	23.00
20%	23.00
30%	23.00
40%	23.00
50%	24.14
60%	25.59
70%	26.95
80%	29.79
90%	33.12

Appendix D: Using Simulation Method for Conducting Step-wise Time-cost Analysis

In the discussion about the time-cost analysis using the scenario approach from Excel (or doing it manually) we noticed that there are many options to be evaluated. The simulation approach will do "all" those calculations in a fraction of time. The idea is that the random numbers will "pick-up" all possible combinations and we will have to organize good outputs to be able to compare them. The model is based on the Figure we developed and executed (VBA program) and we used the Pivot Table option from Excel to present the results. The next figure (Figure D1) presents the base for simulation runs. After clicking the button and entering the number of runs (we tried using 500 runs and it took approx 1 minute to generate outputs), program will prepare output that looks like the Figure D2. This output is input for the Pivot table generated to help manager to identify options more quickly.

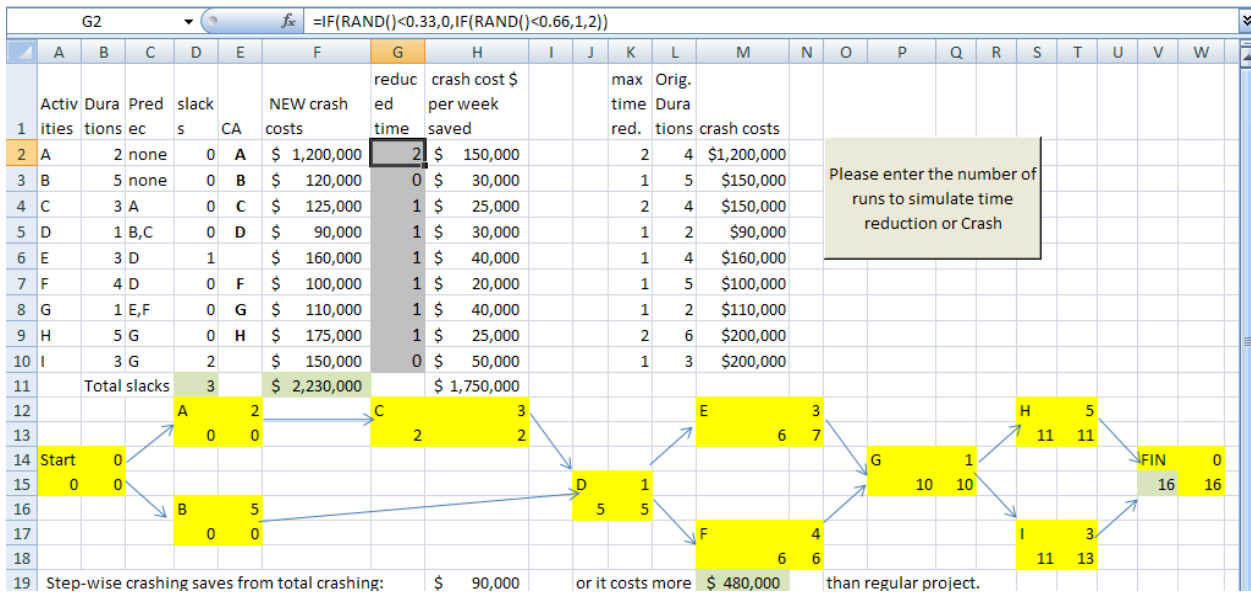


Figure D1: Starting sheet for the simulation process

CT	Tot.slacks	Total costs	Crashing costs	crashed A	crashed B	crashed C	crashed D	crashed E	crashed F	crashed G	crashed H	crashed I
2	19	\$1,900,000.00	\$150,000.00	0	1	2	1	0	0	1	0	0
3	21	\$1,830,000.00	\$80,000.00	0	1	1	0	0	0	0	1	0
4	18	\$2,190,000.00	\$440,000.00	2	1	0	0	1	1	0	2	0
5	20	\$2,015,000.00	\$265,000.00	1	0	1	0	0	0	1	0	1
6	16	\$2,065,000.00	\$315,000.00	1	0	2	1	0	1	1	1	0
7	19	\$2,165,000.00	\$415,000.00	2	0	1	0	0	0	1	0	1
8	18	\$2,055,000.00	\$305,000.00	1	0	2	0	1	0	1	1	0
9	19	\$1,945,000.00	\$195,000.00	0	1	0	1	0	1	1	1	1

Figure D2: Output sheet from the simulation process

One selected Pivot table view based on data in Figure D2 is in the Figure D3.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Tot.slacks	(All)												
2														
3	Min of Crashing costs	Tot.Costs												
4	CT	\$1,770,000	\$1,780,000	\$1,795,000	\$1,800,000	\$1,805,000	\$1,810,000	\$1,815,000	\$1,820,000	\$1,825,000	\$1,830,000	\$1,835,000	\$1,840,000	\$1,845,000
5	14													
6	15													
7	16													
8	17													
9	18													
10	19													
11	20								\$70,000	\$75,000				\$95,000
12	21			\$45,000	\$50,000	\$55,000					\$80,000	\$85,000	\$90,000	\$95,000
13	22	\$20,000	\$30,000				\$60,000	\$65,000	\$70,000	\$75,000				\$95,000
14	23				\$50,000									
15	Grand Total	\$20,000	\$30,000	\$45,000	\$50,000	\$55,000	\$60,000	\$65,000	\$70,000	\$75,000	\$80,000	\$85,000	\$90,000	\$95,000

Figure D3: Initial Pivot output with highlighted 3 minimum values for selected CT.

Using the Pivot output, manager can manipulate data by eliminating options which are not candidates at all. For example in the Figure D3, locate cells E14, H13, K12, L12, M12, N12, N13; those options are expensive for the amount of time saved, so they will not be considered! After cleaning data (using Conditional formatting and manually using the strikethrough), project manager will use the pivot table, as in Figure D4. We decided to keep more than just one solution for the min of crashing costs options, since PM needs to check which tasks should be crashed. For example, the difference of 50,000 +/- 5,000 is not crucial if it will be more convenient to crash activity to spend a bit more. In the figure D4 we can see the total costs values for these three selections to be 1,795,000; 1,800,000 or 1,805,000. Using the data from the simulation we can see which activities should be crashed in which case, and they are F and H, C and H or C and D respectively (all for one week). Now, project manager needs to decide. Without going too much into details, it looks like the best idea to is go with F and H, not only to save 5,000 but, since those two activities are nearer to the end of the project, maybe we will even not need to crash them if everything else goes well!

Figure D4: "Cleaned" Pivot table output with highlighted 3 minimum values for selected CT. Note that we eliminated CT=23 (for this CT there is no need to crash) and several more expensive options if they do not improve the CT!

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Tot.slacks	(All)													
2															
3	Min of Crashing costs	Tot.Costs													
4	CT	\$1,770,000	\$1,780,000	\$1,795,000	\$1,800,000	\$1,805,000	\$1,810,000	\$1,815,000	\$1,820,000	\$1,825,000	\$1,830,000	\$1,835,000	\$1,840,000	\$1,845,000	\$1,850,000
5	14														
6	15														
7	16														
8	17														
9	18												\$135,000	\$140,000	\$145,000
10	19									\$105,000	\$115,000	\$120,000			\$145,000
11	20						\$70,000	\$75,000	\$95,000		\$115,000		\$135,000	\$140,000	\$145,000
12	21			\$45,000	\$50,000	\$55,000			\$95,000	\$105,000		\$120,000	\$135,000		\$145,000
13	22	\$20,000	\$30,000				\$70,000	\$75,000	\$95,000		\$115,000	\$120,000			\$145,000
14	Grand Total	\$20,000	\$30,000	\$45,000	\$50,000	\$55,000	\$70,000	\$75,000	\$95,000	\$105,000	\$115,000	\$120,000	\$135,000	\$140,000	\$145,000

Acknowledgments

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References And Further Reading

Directly used references are placed in footnotes in the text. The next list represents further readings (in alphabetical order):

1. CPMM Quick Guide, Web: <http://projectmanagement.cornell.edu/>, accessed in October 2009
2. Enterprise Project Management Office (EPMO) link: <http://www.da.ks.gov/kito/ITPMM.HTM> , accessed in October 2009
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Note: Readers can get the Excel spreadsheets with macros used in this text by sending a request to yasha@albany.edu (please put a note in the subject line: EMR_case)