Project Management for Engineering Professionals

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Introduction

One of the most important tasks for modern engineering personnel is to support with their technical expertise various projects they are assigned to. There are many Project Management processes and tasks engineers are involved in; for example:

- Preparation of Project Scope
- Technical support of permitting process
- Preparation of estimates
- Participation in Project scheduling process
- Procurement of equipment and materials
- Participation in Project meetings
- Submission of project updates
- Participation in Project closeout (lessons learned)

The active role that modern engineers are playing in managing of projects makes their education in this area extremely important. Engineers should not be Project Management experts, but they need to know its basic principles, processes and tools in order to become a valuable member of the project team and a contributor into the project success.

By the same token, Project Managers (PM's), not being technical experts, need to have a basic business knowledge to fully appreciate complexity and importance of engineering tasks related to the Project, and have a clear understanding of their impact on Project budget, scope and schedule.

Project teams where managers are a little bit engineers and engineers are a little bit project managers have everybody fully engaged in the project and working towards its successful completion.

This course is designed to educate engineers in Project Management. There are similar courses to provide PM's with a basic technical knowledge.

Main Concepts

Let's start with a definition of the project. As indicated in footnote 1 below, "The main characteristics of the Project are:

- Temporary endeavor undertaken to create a unique product or service
- Having a definite beginning and a definite end"[1].

For example, buying a car is a Project because the process has a temporary nature and is bringing the result, which is unique for the buyer (it happens rarely). Car maintenance activity such as oil change is not a Project because while being a temporary process, it is not unique (happens on continuous basis).

[1] URL: science.energy.gov./~/media/opa/powerpoint/Final_Module_1.ppt

At the same time, if a car owner, who always took the car a to a repair shop for an oil change, at some point decides to do it himself, it will become a Project for him, because he never did it before and the whole process is unique for him. Now he needs to find out what kind of oil filter to use, how to drain oil, where to dispose it, etc.

For you, this course is a Project as well. Let's see why it is the case. First of all, it is unique for you, because you never read it before. Secondly, it definitely has a beginning and an end. So, it has all the characteristics of the Project. For a better understanding of this concept, try to remember all the tasks you performed recently and choose the ones that may be considered projects.

The main goal of every PM is to meet so called "Triple Constraint", consisting of:

- Time
  Example: Need to buy a car by summer
- Cost
  Example: Car shouldn't cost more than $15,000
- Scope
  Example: Need a 4-door red Ford Focus with automatic transmission and a/c

Very often, quality is used as the 3rd constraint instead of scope.

There is an old PM's joke saying that while 3 constraints exist, only 2 may be met. For example, if you do work on the Project fast and cheap, scope (quality) will suffer, or if you perform a high quality work fast, it will not be cheap, etc.

But seriously speaking, meeting all these constraints is critical for the success of the Project. As you noticed, safety is not one of the constraints. The reason for that is the fact that safety is above any constraints, it is paramount. No work should be ever done if there are even slight safety concerns associated with it.

The last comment on the triple constraint is associated with different priorities that managers and engineers have while working on the Project. For a PM, cost is the most important constraint; whereas, the engineer is more concerned about quality of the work performed and the fulfillment of scope requirements. This difference in opinion provides required checks and balances for the Project. That's why one person should never combine both project management and engineering functions.

The last main project component that needs to be defined is a Work Breakdown Structure (WBS), which is rightfully considered as a cornerstone of Project Management. It is supporting:

- Project planning
- Estimating
- Scheduling
- Risk Management
- Project Control

In a nutshell, WBS is a "family tree" of all the tasks to be performed in the course of the project. It is obtained by splitting of project work into smaller more manageable components (decomposition). WBS should include:

- All necessary work
- No unnecessary work

It should be detailed enough for a Project Manager to manage and control the project. WBS may be presented in:

- Graphical format
- Tabular format

Example of WBS in graphical format is shown in Fig. 1 for the construction component of the Project.

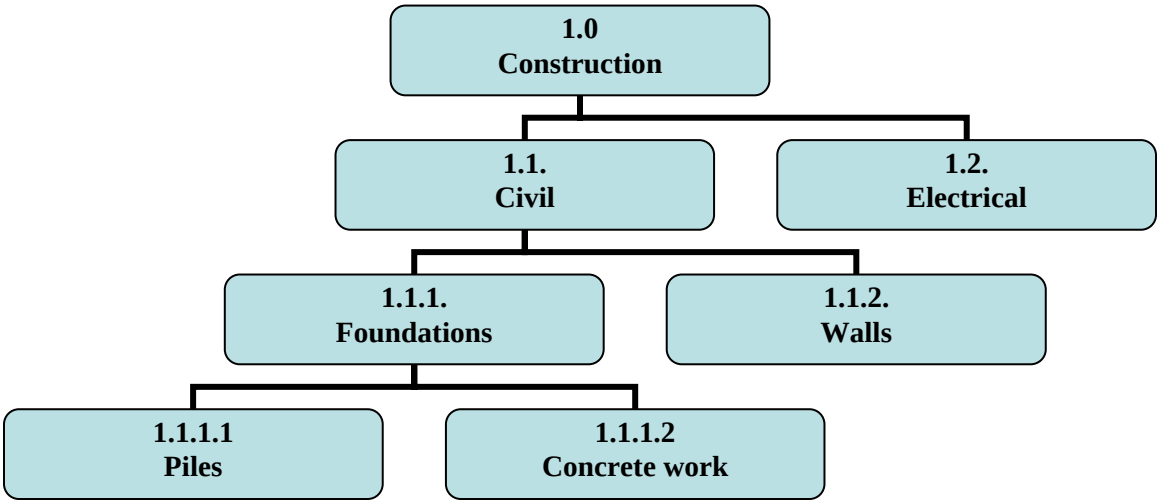


Fig. 1. Example of Work Breakdown Structure (WBS)

Estimating

Estimating is one of the key activities of Time and Cost Management. "Estimate" may be defined as an expected, forecasted likely result of any project component. There are two main types of estimates: cost estimate which serves as a basis for a Project Budget, and time estimate which is a basis for a Project Schedule.

There are two main inputs into these estimates which should be clearly distinguished:

- Effort: A number of man-hours, man-days etc. required to complete a task
- Duration: The number of working or calendar days over which the task will be done

Effort depends on the nature of the task, its level of complexity, etc. Duration depends on the number of resources assigned to fulfill the task. For example, let's assume that our task is to paint an 800 feet long fence and the effort required to do it is 40 man-hours. How long will it take to complete the task depends on number of people assigned to perform it:

- If 2 painters are assigned, it will take 20 hours
- If 4 painters are assigned, it will take 10 hours, etc.

Both of these numbers represent a productive time spent on performing the task.

To calculate an actual duration, we need to take into consideration non-productive time as well, such as time off work, weekends, holidays, etc.

For example, let's calculate the duration of performing the task based on the following assumptions:

- 2 painters start work on 8:00 A.M. Thursday
- Painters are working 8 hours a day, there is no work on weekends

How long does it take to finish the task in this case?

Solution:

- Each painter will work 20 hours, or 2.5 days
- If work starts on 8:00 A.M. Thursday, it will be completed on 12:00 P.M. Monday

If we wanted the work to be completed by the end of the day of Friday, painters would need to work 10-hour days instead of 8.

Main Estimating Techniques

There are two main estimating techniques:

1. Top-down estimates, which are based on previous experience of performing a similar task, or working on a similar project.

   For example, we want to estimate how much we may expect to pay the dentist for the crown. A top-down estimate in this case may be based on the following logic:

   Two years ago, I've paid the same dentist $600 for the crown. That's what I expect to pay this time.

   To be more precise, we may want to adjust this cost for inflation during a two-year period. Assuming 4% inflation rate per year, the final top-down estimate for dental work is:

   $$\$600 \times 1.04 \times 1.04 = \$648.96 \approx \$650.00$$

2. Bottom-up estimates, which are based on:

   - splitting the task, project, etc. into smaller components
   - estimating each component
   - adding them up to obtain the total estimate

   For the same example with the cost of the crown, the bottom-up estimate may be prepared as follows:

   Crown work may be split into the following components:

   - Cost of dentist time, based on current rates:
     2 hours x $150/hour = $300
   - Cost of assistant time, based on current rates:
     2 hours x $40/hour = $80
   - Current cost of lab work and materials:
     1 crown x $400/crown = $400

   Estimated total cost: $300 + $80 + $400 = $780

   As we can see, the bottom-up estimate in this case is significantly higher, which may be important for us to plan our personal budget properly.

Comparison between Top-down and Bottom-up Estimates:

1. Top-down estimates:

   - Are based on historical data
   - Are using experience and intuition of a single contributor
   - Are less accurate
   - May be prepared in a relatively short time
   - Are prepared during the initial stages of the project

- May be made more accurate by choosing a more comparable previous project

2. Bottom-up estimates:

- Are based on splitting the project into components and estimating them separately
- Are using specific data for unit costs, durations, etc.
- May require involvement of numerous contributors
- Are more accurate
- May take a relatively longer time to prepare
- Are prepared during the advanced stages of the project
- May be made more accurate by continuously updating the estimating database

Types of Cost Estimates based on the Levels of Accuracy

1. Order of magnitude or study:

- Technique: top-down
- Accuracy: – 50 to + 50%
- Project phase: feasibility studies, concept
- Application: comparison of several options, financial forecast

2. Budget or conceptual:

- Technique: bottom-up
- Accuracy: – 30 to + 30%
- Project phase: preliminary design and engineering
- Application: justification for project budget

3. Detailed or definitive:

- Technique: bottom-up
- Accuracy: – 10 to + 10%
- Project phase: detail design and engineering
- Application: Forecast for budget at completion

The following examples illustrate what each level of accuracy means:

- Order of magnitude estimate of $100,000 means that actual cost is expected to be no lower than $50,000 and no higher than $150,000
- Budget estimate of $100,000 means that actual cost is expected to be no lower than $70,000 and no higher than $130,000
- Detailed estimate of $100,000 means that actual cost is expected to be no lower than $90,000 and no higher than $110,000

It is important to mention that accuracy for each type of estimate may be negative as well. So, an estimated number may be hypothetically higher than a real cost, not necessarily lower. And despite popular belief that spending less money than budgeted amount is always good, it is not necessarily true, because extra funds could be redirected somewhere else to provide a better return on investment or they would not be acquired to begin with.

Let's illustrate this thought with a simple example:

You need to remodel your kitchen. Estimating the work you plan to do at $30,000, you took a home equity loan for that amount at 5% for 1 year. When work was done 6 months later, you've found out that actual cost of it was $20,000, which seems nice until you factor in an interest (roughly $250) you've paid on extra $10,000 ($30,000 - $20,000), which you would not need to borrow if original estimate was more accurate.

For a multi-year construction project, depending on its budget, this extra interest paid because of an inaccurate estimate may amount to hundreds of thousands or even millions of dollars wasted. So, the Project Manager finishing the project significantly under budget may be reprimanded rather than praised.

The overall impact of estimating errors may be defined as follows:

- Project delays and cost overruns
- Unrecoverable revenue losses
- Project failures
- Lost of client trust
- Scope and quality reduction
- Legal repercussions
- Increase in operation and maintenance costs
- Repercussions against personnel

The following steps may be taken to increase quality of estimates:

- Create extensive historical database
- Learn from previous project experience
- Expand personal knowledge
- Use reliable data as input to estimating
- Include all necessary project components working on bottom-up estimates
- Achieve cooperation from other contributors into the estimating process
- Use estimating software

Scheduling

Another key activity of Time Management besides estimating is Project Scheduling which is the development of planned dates for performing project activities and meeting milestones[2]. Milestone, in its turn, is a significant point or event in the project.
Here are the following views of the Project Schedule:

- List or table of start and finish dates for all activities.
- List of milestones
- Milestone chart
- Gantt chart
- Network diagram

All these formats of the schedule provide a different level of detail and serve specific purposes, with the list of milestones being the least detailed and the most used for reporting, while the network diagram provides the most amount of information and is used for actual management of the Project. To familiarize ourselves with the different views of the Project Schedule, let's consider a simple example of procurement of a power transformer. The list of activities for such project may be presented as follows:

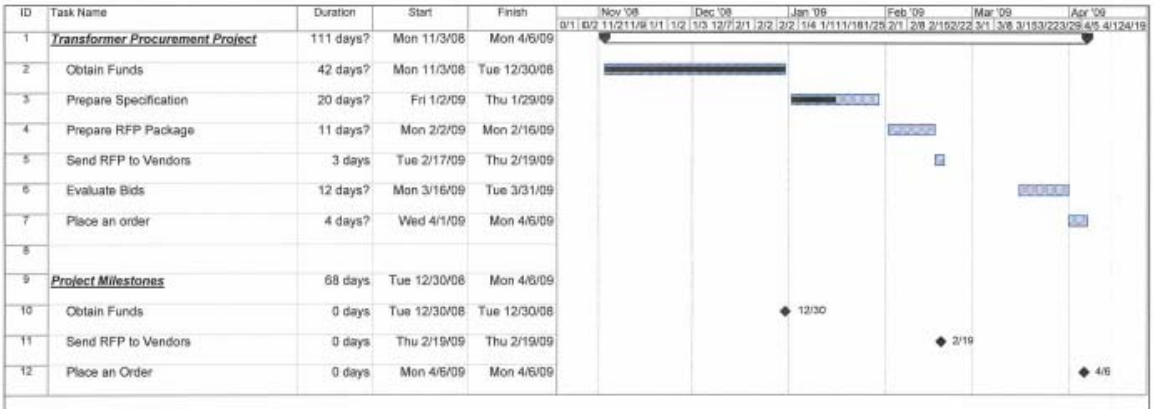
	Activity	**Start Date**	**Finish Date**
1	Obtain funds	11/3/08	12/30/08
2	Prepare Specification	1/2/09	1/29/09
3	Prepare RFP package	2/2/09	2/16/09
4	Send RFP to vendors	2/17/09	2/19/09
5	Evaluate bids	3/16/09	3/31/09
6	Place an order	4/1/09	4/6/09

If we are interested just in major milestones, the above mentioned list may be compressed into the following:

	Activity	**Date**
1	Obtain funds	12/30/08
2	Send RFP to vendors	2/19/09
3	Place an order	4/6/09

A Gantt chart for our example, which shows duration of activities as horizontal bars is shown in Fig. 2. The black line in the middle of the bar shows completion of the task. The corresponding milestone chart is shown in Fig. 2 as well.

[2] URL: science.energy.gov./~/media/opa/powerpoint/Final_Module_3.ppt



ID	Task Name	Duration	Start	Finish
1	***Transformer Procurement Project***	111 days?	Mon 11/3/08	Mon 4/6/09
2	Obtain Funds	42 days?	Mon 11/3/08	Tue 12/30/08
3	Prepare Specification	20 days?	Fri 1/2/09	Thu 1/29/09
4	Prepare RFP Package	11 days?	Mon 2/2/09	Mon 2/16/09
5	Send RFP to Vendors	3 days	Tue 2/17/09	Thu 2/19/09
6	Evaluate Bids	12 days?	Mon 3/16/09	Tue 3/31/09
7	Place an order	4 days?	Wed 4/1/09	Mon 4/6/09
8				
9	***Project Milestones***	68 days	Tue 12/30/08	Mon 4/6/09
10	Obtain Funds	0 days	Tue 12/30/08	Tue 12/30/08
11	Send RFP to Vendors	0 days	Thu 2/19/09	Thu 2/19/09
12	Place an Order	0 days	Mon 4/6/09	Mon 4/6/09

Fig.2. Gantt and Milestone Charts

And finally, Fig. 3 shows a Network Diagram for the same transformer procurement project:

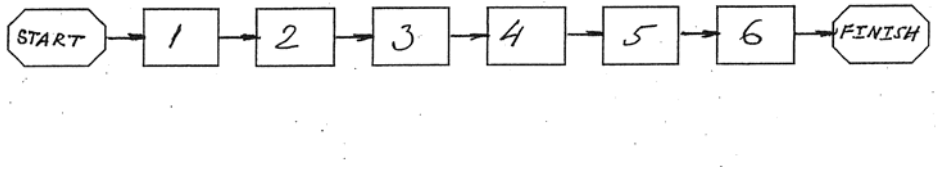


Fig. 3. Network Diagram

Where:

1 - Obtain funds;
2 - Prepare Specification;
3 - Prepare RFP package;
4 - Send RFP to vendors;
5 - Evaluate bids;
6 - Place an order

Typical network diagram activity box is shown in Fig. 4.

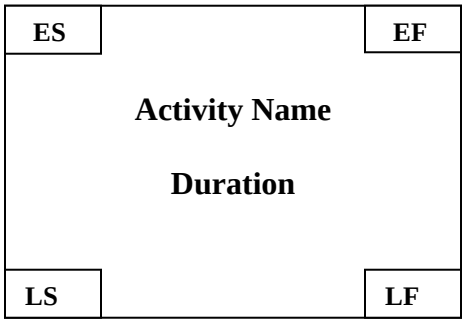


Fig. 4. Typical Network Diagram Activity Box,

Where:

ES – Early Start: Earliest an activity can start
LS – Late Start: Latest an activity can start without delaying project completion
EF - Earliest an activity can finish based on early start
LF - Latest an activity can finish without delaying project completion

As an example, Fig. 5 shows the 1st box of network diagram built for the transformer procurement process, which is "Obtain Funds".

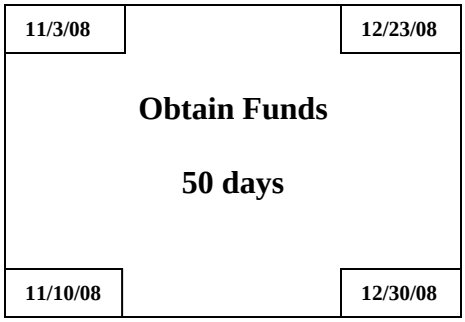


Fig. 5. Network Diagram Activity Box "Obtain Funds".

The main concepts of a network diagram may be formulated as follows:

- It is always drawn left to right to reflect sequence of work
- It consists of boxes representing activities, and arrows showing relationships between them
- It may be used to:
  - Calculate the critical path – shortest time to complete all the work in the project
  - Optimize the schedule

There are two main schedule optimization techniques:

- Schedule Crashing:
  - Adding resources: Workers, Equipment, etc.
  - Working overtime
  - Using better technology (for example, the use of fast curing concrete will allow to have the foundation ready for equipment installation earlier than in the case of using standard concrete)

- Schedule Fast Tracking:
  - Changing schedule logic (for example, performing activities in parallel instead of sequentially: starting construction without design fully completed, performing civil and electrical construction in parallel, etc.)

Use of each of these techniques will eliminate or reduce schedule slippage and bring the Project back on track. On the negative side, possible results from application of both techniques are:

- Higher cost
- Increased risk

Scope

Scope may be defined as work that should be performed to deliver products or services the Project intends to provide. It is usually formulated at the very beginning of the Project in the Scope Statement; a comprehensive document which includes the following critical project characteristics:

- Project objectives
- Major deliverables
- Description of work to be performed
- Exclusions
- Assumptions
- Risks

Typically, the scope has a tendency to change in the course of the Project. It is very important to distinguish the following types of scope changes:

- Controlled changes to project scope, justified by objective needs, accompanied by project cost and schedule adjustment.

  Example: Adding pile driving to the original scope to build a house because of discovered high water table.

- Scope Creep – uncontrolled unjustified scope changes made without cost and schedule adjustment

  Example: Adding a fireplace to the original scope to build the house without increasing the budget

Controlled scope changes are acceptable as long as they are properly documented and accounted for. They may lead to requests for budget increase and schedule extension. Scope creep should be avoided. It may lead to project failure.

Procurement Process

The Project Engineer is very often involved in the procurement of equipment, materials, design and engineering services, construction services, etc. Because of this, it is important for us to discuss the procurement process in a greater detail. There are several procurement options which we need to know and understand their pros and cons.

The first one is procurement from "Sole Source", which exists when there is only one Vendor providing certain type of services or products. For example, we need to buy a new car and want only Focus manufactured by Ford, which in this case is a Sole Source for our procurement task.

Advantages of sole source:

- Simplicity of Vendor's selection process
- Minimum time spent to obtain necessary services or products

Disadvantages of sole source:

- Vendor's control over market, possibly leading to high costs for the services

The second option is procurement from "Single Source", who is the Vendor providing services or products available from other Vendors as well, but he is chosen because of business reasons:

- Need to shorten procurement process
- Desire to standardize products or services
- Possibility to obtain better price through partnership

For better understanding, let's consider again that we need to buy a new car and are looking for a 4-door compact sedan, which may be Ford Focus, Toyota Corolla, Honda Civic, etc. Let's assume that, once again, we want a Ford Focus, but for some objective reasons such as: we had good previous experience with Ford product, Ford service station is located across the street from our house which is a real time saver, our cousin is working in Ford dealership and will give us a discount, etc. In this case Ford will be a Single Source for our procurement activity.

Advantages of single source:

- Simplicity of procurement process
- Less time and effort is required for Owner to obtain required products or services

Disadvantages of single source:

- Without necessity to compete, Vendor may reduce quality of provided products or services
- Lack of guarantee of getting the best price

Because of the aforementioned deficiencies of using sole or single source procurement options, buying from multiple sources (shopping around) is the more favorable option which consists of:

- Requests for proposals (RFP) or quotes (RFQ) from multiple Vendors from an approved list
- Evaluation of obtained Vendor bids
- Selection of successful bidder
- Placement of a purchase order for products or services

It is important to emphasize that we have to use only approved Vendors who have a proven record, provided quality products in the past, etc. By doing so, we are reducing our chances to get a "lemon". For example, when buying a car, we will most likely not pursue manufacturers we never heard of before and have no idea about their safety and quality record.

Advantages of multiple sources:

- Vendor's selection is justified
- Owner is paying a fare price for services or products
- Because of competition, Vendors have incentives to keep quality of products or services at the required level

Disadvantages of multiple sources:

- Procurement process is very lengthy
- Owner's personnel involvement is very extensive

Contract Management

After a provider for services or equipment is selected through the procurement process described above, a corresponding contract should be prepared and signed by all involved parties. Because a Project Engineer is usually involved in the preparation of the contract, it is important for him/her to understand what types of contracts exist and what the main advantages and disadvantages of each type of contract are.

One of the most popular types of contracts is "Lump Sum" whose main principle is:

- Contractor provides specified services for a fixed price to be paid by Owner upon completion of work

The typical example of a lump sum contract is hiring a Builder to construct you a house for a predetermined price, let's say $200,000 by the end of 2012 (expected completion date is almost as important as the asking price is, or Builder will work on your house when it is convenient for him instead of when you need it).

Advantages of a lump sum contract:

- Risk is shifted to Contractor
- Less supervision and control by Owner is required
- Easy to forecast expenses

Going back to the example of you ordering the house on a lump sum basis, the advantages mean that you know how much it will cost ($200,000) and may arrange for a financing, and you may hope that the Builder understood what was required from him when he gave you a fixed price for his services and now he has to deliver you a house without bothering you with problems he may find while keeping the price at the agreed amount.

Unfortunately, it rarely works like that because a lump sum contract has the following disadvantages as well:

- Very tight quality control by Owner is required

  One of the most effective ways for a Builder to make money on your house is to "cut corners". For example, if vinyl siding is not clearly included in the contract, you may end up with painted walls instead. Or, if you expect to see a fireplace, but it is not spelled out in the contract, you will never see it. Or, if a quality of carpeting is not defined, you will get the cheapest one, etc. So, if you want to get what you had in mind, you need to watch closely what the Builder does.

- Owner will end up compensating Contractor for risk included in a lump sum

  If Builder does not have the information about the land where your house is supposed to be built on (for example, type of soil, water table, etc.), or he does not know how difficult it may be to obtain all the permits from a local municipality, he may assume the worst possible case and include a corresponding risk into his asking price. If things go better than the Builder expected, he will pocket the profit.

- Possible cost overrun because of Contractor's change orders

  This is by far the most efficient way for the Builder to extract extra cash from the Owner (you). For example, during the course of construction you find out that you are not getting your beloved fireplace because it was never included in the contract. But you really want it and agree on a change order. Now the Builder will ask for extra money in addition to the original $200,000, and this "extra" may be much higher than the amount it would cost you to have a fireplace, if you've included it into the contract from the very beginning (for example, instead of total $203,000 you would end up paying $208,000).

- Lack of flexibility to cover unforeseen events

  For example, you had a very heavy snowfall at the end of October and now the Builder wants extra money for snow removal. This is because it never happened before in this area so he never included cost for that in his asking price. You may argue that it is part of the Builder's risk, but the result probably will be some sort of payment after lengthy negotiations between you and the Builder.

Taking all pros and cons of a Lump Sum Contract into consideration, it may be recommended for application only when requirements for services are clearly defined.

Another popular type of contract is "Unit Price" whose main principles are:

- Work is broken into various components
- Fixed price is defined for each unit of work and paid to Contractor

The typical example of "unit price" contract is hiring a contractor to pave a driveway in front of your house and paying him a fixed price for each square yard of pavement.

Advantages of unit price contract:

- Cost directly depends on amount of work
- Less reasons for contractor's change orders

It seems to work fine for a "driveway" example. However, you need to watch very closely the quality of preparatory work performed by the Contractor before a driveway is covered with an asphalt: was a thick enough layer of gravel provided; was there a necessary layer of sand underneath the gravel; was sand and gravel of required quality etc.?

So, one of the disadvantages of a "unit price" contract is:

- Thorough Owner's supervision is required

Another disadvantage of "unit price" contract is the fact that it can't cover non-quantifiable work. For example, if you need to hire a plumber to replace a water heater in your house, it is difficult to split this type of work into components. That's why a "lump sum" contract is a much better option in this case.

Taking all pros and cons of a Unit Price Contract into consideration, it may be recommended for application only when work is easily quantifiable.

The 3rd popular type of contract that we want to discuss is "Time and Materials" or "Cost Plus". Its main principle is:

- Contractor is paid for actual labor and material expenses based on predetermined rates

Any of the above mentioned tasks (building the house and paving the driveway) may be performed on a time and material basis. However, it is important to understand the pros and cons of this approach.

Advantages of Time and Materials (T&M) Contracts:

- Easy to cover unforeseen events
- Less reasons for contractor's change orders
- Less reasons for contractor to "cut corners"

However, this approach has the following clear disadvantages as well:

- Difficult to forecast expenses
- Risk is shifted to Owner
- Very thorough Owner's supervision is required

Let's discuss these pros and cons in a greater detail using the example of building the house. If you hire a Contractor to do the work on "T&M" basis, you do not need to worry about paying premium for adding a fireplace to the original scope, or negotiating with the Contractor extra payment for unexpected snow removal, because you are paying for time and materials actually spent by Contractor to do any work on your house as well as necessary equipment he used to do it. However, you do not know how much the whole house will cost you and as a result may have difficulties in arranging proper financing to pay for it.

The second problem is a completion date. Contractor does not have an incentive to finish work earlier (remember, the more time he spends, the more you pay). So, you need to watch continuously what they do to ensure that they work effectively.

The 3rd problem is a quality of materials. Unfortunately, with "T&M" arrangement, Contractor has an incentive to inflate material prices, use lower quality components but charge you for high quality ones, etc. Again, it will be your mission to watch closely what the Contractor does, check invoices for materials obtained from the suppliers, etc.

So, as a result, with a "T&M" Contract, you as an Owner should spend much more time than you would do with both Lump Sum and Unit Price contracts to ensure that you will get what you wanted when you needed it and that you pay a fair price for it.

So, why does someone want to use "T&M" contracts if there is so much extra work involved? The reason for that is perhaps the lack of clear scope for the project, lack of complete design documentation, etc. It is very difficult to have a low risk lump sum contract if we can't describe **precisely** what we want to get. If the Contractor has to guess what he has to do, he will definitely add sufficient risk to his quotation and we'll end up overpaying for his work.

If, at the same time, the components of this work are not easily quantifiable, we can't use a unit price contract either. That's why when the Owner's requirements for services are not clearly defined, a "T&M" contract may be recommended.

In reality, you may have a situation when it is prudent to use all three types of contracts on the same Project. For example, you want to build a house with a detached garage and a paved driveway into the garage, but you have a completed design package for the garage only. As far as the house is concerned, you have a good idea what you are looking for but nothing to substantiate it. The same situation exists with a driveway. You understand how it should be built, but do not have any technical design documentation for it and do not even know how long it is going to be because the property key plan is not done.

Under these circumstances, you are better off having a lump sum contract for all the work associated with the garage, unit price contract for the paved driveway, and time and materials contract for the house itself. Needless to say, you will have a lot of work supervising the Contractor, but this multiple contract arrangement is probably your best chance to have your project successfully completed.

Risk Management

Every project has a lot of uncertainties. No matter how extensive your planning was, you always run into problems when you start actual work. Some of these problems could be anticipated, some not, but not accounting for them in your Project Budget and Schedule may lead to Project failure. First of all, let's discuss what we can do with anticipated problems which are called Project risks, starting with their definition.

Each risk may be defined as "The combination of the probability of an uncertain event and its consequences: either positive (opportunity), or negative (threat)" [3]. The main activity in risk management is risk planning which involves:

- Risk identification
- Risk analysis
- Risk response planning

Risk identification is the first activity in the risk planning process; it answers the following main question: "What may go wrong?" The following may be used as sources for answers:

- Historical data:
  Example: "*On my last trip to Florida, I've had flight delays*"

- Expert interviews:
  Example: *"My friend told me not to use this text book; it is too complicated"*

- Brainstorming
  Example: "*Preparing for grandma's anniversary celebration, family members discussed possible problems*"

The second step in risk planning is Risk Analysis which is answering the following main questions:

- How likely for this event to happen? Probability
- If it happens, how bad will it be? Impact

There are two main techniques to perform risk analysis. The first one is a qualitative technique which is based on the following equation and definitions:

Risk level = F {Probability x Impact}:

- Low probability, low impact = low risk
- High probability, high impact = high risk
- Low probability, high impact, or, high probability, low impact = medium risk

[3] URL: w*ww.wsdot.wa.gov/publications/.../**ProjectRiskManagement**.pdf*

For a better understanding, let's consider the following real life example:

Description: You have a job interview tomorrow 200 miles away from your home. You decided to drive there. You car is 15 years old and has 150,000 miles driven. What is the level of risk for you not to have this interview?

Answer: The risk of your car breaking down on your way to the interview is high. If it happens, you most likely will not make it to the interview on time. So, impact is high as well.

Conclusion: risk level for you not having the interview is high.

The results of qualitative risk analysis may be presented as a Risk Matrix; similar to the one shown in the Fig. 6 [4].

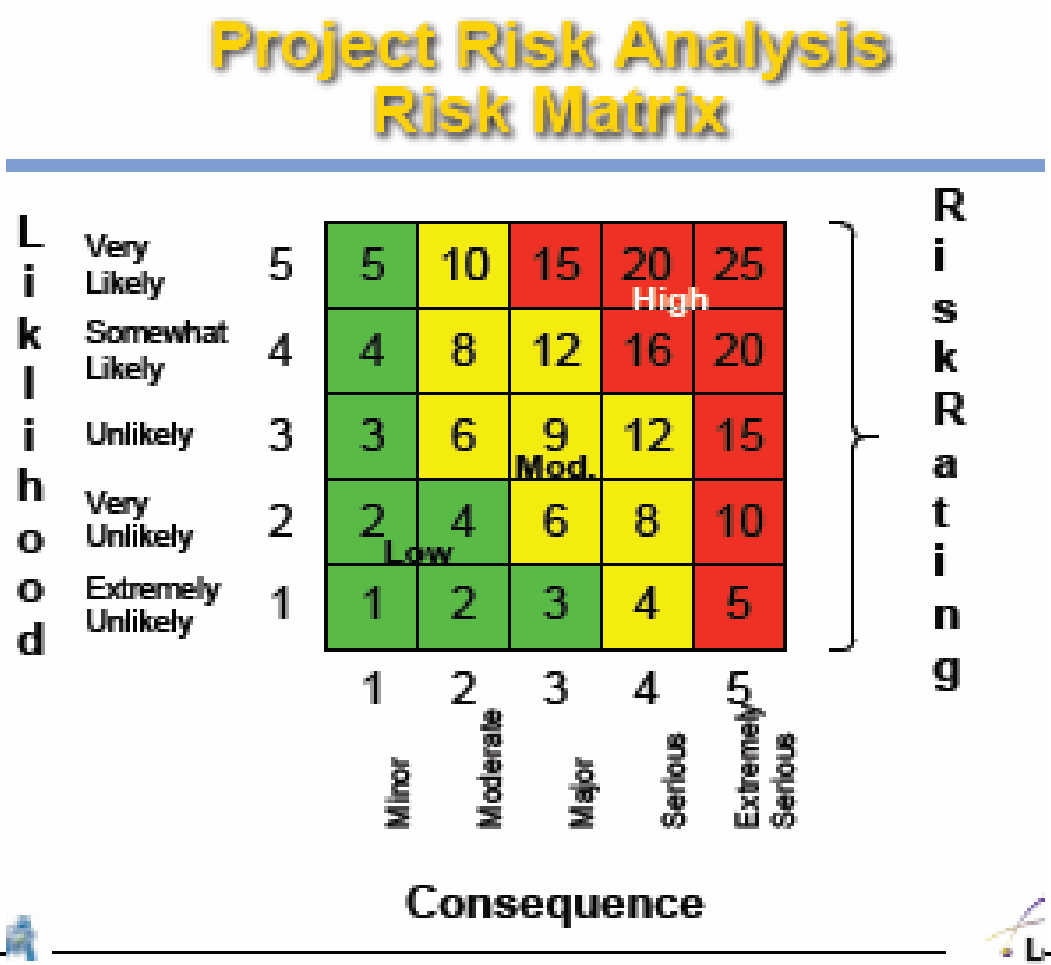


Fig. 6. Example of Risk Matrix

[4] URL: www.lanl.gov/orgs/d/d5/documents/case.pdf

The second technique for risk analysis is a quantitative technique, which is based on the following equation:

Cost of risk = probability x impact

Let's consider the following example:

Description: Car assembly plant's transformer substations are fed by two 138 kV cable lines. The probability of both of them failing and being out of service at the same time is 0.2% for any given year. If it happens, loss of revenue for the plant is $100M. What is the annual cost of risk?

Answer: Cost of risk = 0.002 x $100,000,000 = $200,000

As we can see, the quantitative technique provides a much more definitive answer than the qualitative one does. Unfortunately, the exact information about probability and impact of every risk event is rarely available. That's why a qualitative technique is used much more often than a quantitative one.

Usually both risk identification and a qualitative risk analysis are performed during a brainstorming session, where all project team members and invited experts generate all possible risk events (identification) and assign risk levels to each of them (analysis). The outcome of this brain storm should be a Project Risk Matrix; similar to the one shown in Fig. 6.

After the risk matrix is created, the main question becomes: what to do about the risks? Here are the following standard responses to risk events:

- Avoid the risk – take another path

  In the job interview example, risk avoidance may be taking the train to the interview

- Mitigate the risk – take steps to reduce either probability of risk, or impact, or both

  In the job interview example risk mitigation may be:

- Renting a car
- Leaving one day earlier

- Transfer the risk – transfer or share the risk with another party (buy insurance, for example)

  In the job interview example, risk transfer may be joining an auto club which will help you with the car if it breaks down; i.e. repair it, rent you a car, etc.

- Accept the risk – take no action to reduce probability or impact of the risk

  In job interview example, risk acceptance may be driving your car and hoping for the best

As a rule of thumb low risk events may be accepted, while high risk events always require an action. Medium risks are handled on a case-by-case basis.

Let's discuss how risks may be handled at a Project level:

- For budget risks:
  - Create contingency funds
  - Review adequacy of initial contingency funds at key points in the Project Life Cycle and initiate change if needed
- For schedule risks:
  - Add time buffers to the Project schedule
  - Review adequacy of initial schedule buffers at key points in the Project Life Cycle and initiate change if needed

As we mentioned before, risks are the anticipated problems ("known unknowns"). However, there are events which may not even be foreseen; these are called contingencies ("unknown unknowns"). For example, for a car trip to the interview, a contingency may be a collision with another car which will prevent you from getting to the interview on time. Should you do anything about contingencies? It is a Project Manager's call, but usually it is a good practice to include in the budget some extra contingency funds (5% - 10% of the total) to cover events which you can't even imagine. It is difficult to include extra float in the schedule to cover contingencies (not only we do not know what they are, but we have no idea what kind of delay they can cause). Hopefully having extra money in the budget will help the project manager to accelerate the Project if needed.

Speaking of risks, we need to remember that there are always events typical for specific industries. For example, for utility companies, the following main sources of risks may be noted:

- Licensing and Permitting:
  - Local residents resistance to the project
  - Site restrictions: wetlands, height, noise, etc.
- Site conditions:
  - Presence of underground obstructions
  - High water table
- Technical problems:
  - Detail design discovered problems not foreseen during feasibility studies
- Equipment issues:
  - Vendor's delays with delivery of equipment
  - Equipment quality issues

- Contractor performance:
  - Contractor's deviation from specifications
  - Production delays
  - Workmanship quality issues

- Personnel issues:
  - Lack of qualified resources

Project Communications

Communication is an extremely important component of Project Management representing a process of exchanging information among project team members, stakeholders, senior management, etc. There is an opinion that 70% to 80% of the Project Manager's work is to provide effective communication between all the players involved in the Project. Here are the following types of communications:

- Oral:
  - Personal conversations
  - Phone calls
  - Voice mail
  - Meetings
  - Presentations

- Written:
  - Handwritten notes
  - Faxed messages
  - E-mail
  - Formal reports
  - Business letters

- Body language:
  - Posture
  - Face expressions

Project meetings are the most effective way to disseminate information, give people the opportunity for face-to-face conversations, obtain performance reports, set goals, etc. Usually they have numerous attendees (10 to 15 people or more) who may spend several hours on meeting participation instead of fulfilling their direct duties and working on the project. Some of these people are coming to the meeting from different locations, which can make their loss of time even more painful. That's why it is very important to make these meetings efficient and productive. The following suggestions may help to accomplish this goal:

- Start on time
- Use teleconferencing
- Plan in advance
- Have an agenda

- Limit number of participants to key people
- Develop action items and assign people to work on them
- Keep meetings short
- Follow-up the meeting with written minutes and distribute them among participants

In a day-to-day project management it is suggested to use personal contact as a mean of communication rather than e-mails and voice mails. It would help to obtain an immediate response and avoid confusion or a misunderstanding that may eventually lead to project failure.

Project Baseline and Control

For each Project, there is an approved Project Plan which includes primarily the following components:

- Budget
- Schedule
- Scope

This project plan is called a Project Baseline. The most important of the Project Manager's responsibilities on the project is to keep all its parameters inside the boundaries defined by the baseline. To ensure that at any point in time the Project is moving in the right direction; is being completed below budget; and is ahead of time with the scope fully implemented, the Project Manager should use Project Control which represents monitoring of actual project performance to define deviations from the project plan and choose corrective actions, if needed.

Project Control is critical for the success of the Project and should start as early in the Project life cycle as possible. Uncontrolled or poorly controlled projects usually fail. The best analogy for project control is an Olympic sport called Curling, whereby teams consisting of four players slide stones (eight for each team) across a sheet of ice towards a target area (see Fig. 7a). The main goal for the team is to get each stone as close to the center of the target as possible. To have it accomplished, each of the team members has a specific function. One, called the "curler", is releasing the stone towards the target (see Fig. 7b), which is similar to project initiation. If nothing else is done, there is still a small chance that the stone lands in the center of the target.

However, to increase probability of success, other team members called "sweepers" (see Fig. 7c) accompany the stone as it slides down the sheet, using the brooms to alter the state of the ice in front of the stone to change its path, speed, etc. to ensure that the target is hit.

That's exactly what Project Control is supposed to provide: continuous monitoring of the Project's path to completion and correcting it, if necessary. And like in curling, the Project should be controlled from the very beginning, because the more time the Project Manager has to work on corrective actions and implement them if needed, the more chances the Project will hit the target.

Fig. 7a.[5]

Fig. 7b.[6]

Fig 7c.[7]

Fig. 7. The Main Principles of Curling

[5] Reproduced from: http://upload.wikimedia.org/wikipedia/commons/2/28/Brier_045.jpg

[6] Reproduced from http://en.wikipedia.org/wiki/File:Curling_Canada_Torino_2006.jpg,
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[7] Reproduced from http://en.wikipedia.org/wiki/File:Olympic_Curling,_Vancouver_2010_crop_sweeping.jpg
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Project Control is a complex process which includes the following main components:

- Monitoring of performance
- Developing and analyzing progress reports for cost, scope and schedule
- Identifying variances, their causes and impacts
- Evaluating options for corrective actions
- Selecting the most appropriate actions and implementing them
- Controlling project changes
- Initiating baseline changes as needed

Because of this complexity, the Project Manager has to have Project Control personnel helping him with this extremely important function, which requires a lot of effort but brings undeniable benefits as follows:

- Better Project performance:
  - On time and within budget
  - According to specifications and expectations
- Effective communication of project status to stakeholders
- Having early warnings for problems
- Learning from experience

Performance Measurement

One of the most important tasks of Project Control is to obtain accurate data on Project performance, because this information is a basis for Project status analysis which in its turn determines if Project is proceeding as planned or corrective actions are needed.

For every Project it is recommended to obtain the following performance data on a regular basis:

- Progress Data – What has been accomplished as of today?
- Effort Data – How much resource time has been spent to achieve this progress?
- Change Data – Type of change, cause and impact
- Expense Data – Costs of human resources, facilities, equipment, etc.

To collect this data, the following main types of reports are used:

- Status
- Progress
- Forecast

These reports should include the following data:

- Task completions (full or percent complete)
- Actual effort
- Cost data and issues

How often these reports should be collected depends on the length and phase of a specific Project. Frequency of reporting may be weekly, bi-weekly, monthly, quarterly, etc. For troubled projects, even daily reports may be needed.

Earned Value Analysis (EVA)

Now that we have Project performance data, the next question is how to analyze them. It is not enough, for example, to find out only how much money are already spent on the Project. What is more important is to understand what was accomplished. For example, just knowing from a cost report that 50% of the Project Budget is spent at a certain moment does not give us any idea how good or bad the Project is performing. If we completed 50% of all the work, we are doing fine. If only 30% of the work is done, the project needs significant improvement to avoid failure.

One of the most effective techniques to analyze Project performance is Earned Value Analysis (EVA). Instead of just answering the question "What performance results are we currently getting?", EVA will allow us to understand if our money was worth these performance results.

EVA is using three main metrics which are listed below. For each metric, the following information is included:

- definition,
- question that each metric is answering
- real life example to show how a specific metric is determined

The first metric, which is very important but hard to obtain because it is based on performance measurement, is:

- Earned Value (EV) or Budgeted Cost of Work Performed (BCWP) :
  "The sum of budgets for fully and partially completed work packages" [8]

  Question: "How much was budgeted for the amount of work done?"

  Example: A crew should install 10 wooden poles for an overhead electrical line with a budget of $5,000. After 2 days, 3 poles are installed. What is EV?
  Solution: EV = ($5,000/10) x 3 = $1,500

The second metric, which is much easier to obtain because it is based on project schedule and cash flow which always should be available, is:

- Planned Value (PV) or Budgeted Cost of Work Scheduled (BCWS):
  "The sum of the budgets for all work packages, planning packages, etc. scheduled to be accomplished (including in-process work packages)" [8]

[8] URL: evm.nasa.gov/glossary.html

Question: "How much work should be done by certain date? How much did we plan to spend as of certain date?"

Example: A crew should install 10 wooden poles for overhead electrical line with a budget of $5,000 in 5 days. What is PV after 2 days of work?
Solution: PV = ($5,000/5) x 2 = $2,000

And the third metric, which is easily obtainable because it is usually based on actual invoices, is:

- Actual Cost (AC) or Actual Cost of Work Performed (ACWP)":
  "The costs actually incurred and recorded in accomplishing the work performed within a given time period" [9]

  Question: "How much money have we actually spent?"

  Example: After 2 days of work on the installation of wooden poles, the Contractor submitted the invoice for $2,500. What is AC?
  Solution: AC = $2,500

Using main EVA metrics, we may obtain several derived ones. The most important ones are shown below, including their meaning for the Project status.

- Schedule Variance SV = EV – PV
  SV = 0 – on schedule
  SV > 0 – ahead of schedule
  SV < 0 – behind schedule

- Schedule Performance Index SPI = EV/PV
  SPI = 1 – on schedule
  SPI > 1 – ahead of schedule
  SPI < 1 – behind schedule

Using main EVA metrics from the previous example, the corresponding derived metrics may be calculated as follows:

From the previous example, EV = $1,500; PV = $2,000;
SV = $1,500 - $2,000 = - $500 – Behind Schedule
SPI = $1,500/$2,000 = 0.75 – Behind Schedule

- Cost Variance CV = EV – AC
  CV = 0 – on budget
  CV > 0 – under budget
  CV < 0 – over budget

[9] URL: evm.nasa.gov/glossary.html

- Cost Performance Index CPI = EV/AC
  CPI = 0 – on budget
  CPI > 1 – under budget
  CPI < 1 – over budget

Again, based on main EVA metrics from the previous example, the derived metrics may be calculated as follows:

From the previous example, EV = $1,500; AC = $2,500;
CV = $1,500 - $2,500 = - $1,000 – Over Budget
CPI = $1,500/$2,500 = 0.60 – Over Budget

Forecasting at Completion

Besides understanding the current Project status, it is even more important for the Project Manager to envision how the Project baseline values will look like at its completion. In order to have this information, the PM needs to prepare a forecast at completion which may be done using the following principle approaches:

- Extrapolation based on statistical analysis of the work performed using EVA:
  - How will we end the Project if things will go the same way as before?

- Re-estimating including the following activities:
  - Look at what has occurred
  - Determine the cause
  - Analyze if the cause will lead to similar variances in the future
  - Reassess staffing, methods, estimates, technology, etc. to compensate for negative variances to date
  - Forecast the outcome and update the Project plan

We will concentrate on the extrapolation approach (the most popular out of the two) because it may be done as often as we have updated project performance information available; and therefore, the ability to calculate updated EVA metrics which enables us to react swiftly on detected problems and develop corrective actions accordingly. Re-estimating requires much more time and effort and may be done only a couple of times during the course of the Project.

With that said, let's start with the following main definitions related to cost and time forecasting at completion using EVA:

- Main definitions for the cost forecasting process:

  - BAC: Budget at Completion. "The total planned budget" [10] for the Project

[10] URL: evm.nasa.gov/glossary.html

  - EAC: Estimate at Completion. "The estimated total cost for all authorized work"[11]
    EAC = BAC/CPI
  - CVAC = BAC – EAC – Cost Variance at Completion, forecasted final cost variance
  - For the overhead line construction example:
    BAC = $5,000. EAC = $5,000/0.6 = $8,333
    CVAC = $5,000 - $8,333 = - $3,333
    So, the Project will cost $3,333 more than budgeted

- Main definitions for the time forecasting process:

  - SAC: Schedule at Completion. Planned duration of the Project
  - ESAC: Estimated Schedule at Completion:
    ESAC = SAC/SPI
  - SVAC = SAC – ESAC – Schedule Variance at Completion, forecasted final schedule variance
  - For the overhead line construction example:
    SAC = 5 days. ESAC = 5/0.75 = 6.67 days
    SVAC = 5 – 6.67 = – 1.67 days
    So, the Project will be completed 1.67 days later than scheduled

Corrective Actions

Now, after forecasting at completion is done, the PM needs to decide if a projected outcome of the Project requires corrective actions, which may be defined as a documented plan for executing the future project work to bring the expected project outcome in line with the project management plan. The main goal of the corrective actions is to eliminate the cause or the impact of schedule or budget slippage through:

  - Identification of slippage
  - Determination of its cause
  - Evaluation of alternatives (accept or change the baseline values: budget, schedule, scope, etc., take action to reduce or eliminate)
  - Acting

The following corrective actions may be suggested:

- For schedule slippage:
  - Crash: Add resources, work overtime, etc.
  - Fast track: Change the sequence of tasks (perform tasks in parallel, for example)
  - Maximize the use of the most effective resources
  - Use progressive technology
  - Expedite certain intermediate deliverables and approvals

[11] URL: evm.nasa.gov/glossary.html

  - Reduce the scope by putting off some features or functions of the product, getting corresponding approval from the stakeholders, etc.

- For budget overruns:
  - Use cheaper supplies
  - Explore trade-off possibilities (with client approval):
    - Scope reduction
    - Delaying of Project completion date
  - Improve productivity

Let's practice in forecasting at completion through EVA and development of corrective actions using the following case study:

Description:

Public School #23 needs to replace wallpaper in all class rooms by September 1st. The total amount of wallpaper to be installed is 1,000 yd^2. To do the work, the school Principal hired a Contractor to perform all the work in the months of July and August (60 days) for a total of $25,000. When the Principal checked the work progress after 15 days, he found out that 200 yd^2 of wallpaper were installed and the Contractor submitted an invoice for $4,500.

Question:

What information about the Project can the Principal obtain out of this report and what does he need to do to correct the situation, if required?

1. Forecasting at Completion using EVA:

   - The following data may be obtained from the performance report:

     - Cost Analysis:

       - EV = ($25,000/1,000$yd^2$) x 200 yd^2 = $5,000
       - AC = $4,500
       - CV = EV – AC = $5,000 - $4,500 = $500 – under budget
       - CPI = EV/AC = $5,000/$4,500 = 1.11 – under budget
       - BAC = $25,000
       - EAC = BAC/CPI = $25,000/1.11 = $22,522
       - CVAC = BAC – EAC = $25,000 - $22,522 = $2,478

       Conclusion: Installation of wallpaper will cost $2,478 less than planned.

     - Schedule Analysis:

       - PV = ($25,000/60 days) x 15 days = $6,250
       - SV = EV – PV = $5,000 - $6,250 = - $1,250 – behind schedule

- SPI = EV/PV = $5,000/$6,250 = 0.8 – behind schedule
- SAC = 60 days
- ESAC = SAC/SPI = 60/0.8 = 75 days
- SVAC = SAC – ESAC = 60 – 75 = - 15 days

Conclusion: Installation of wallpaper will be completed 15 days later than scheduled

2. What corrective actions are needed?

Obviously we have no concerns about getting over budget; however, steps should be taken to correct schedule slippage. Let's come up with several possible solutions starting with a comparison between current and required productivity of wallpaper installers:

So far, 200 yd^2 of wallpaper were installed in 15 days, which gives us a productivity of: 200 yd^2 / 15 days = 13.33 yd^2 / day

To finish on time in the remaining 45 days, 1,000 – 200 = 800 yd^2 of wallpaper should be installed with a productivity of 800 yd^2 / 45 days = 17.77 yd^2 / day

So, a required increase in productivity is 17.77 – 13.33 = 4.44 yd^2 / day. How can we achieve it?

The following recommendations can be made:

- The Contractor needs to increase productivity by:
  - Using more resources
  - Working overtime
  - Apply more progressive technology (for example, fast drying glue)

- The Project Manager (School Director) should assess Project status in another 15 days and decide what to do next to finish on time

- In order to have a successful project, no more than an extra of $2,478 may be spent to expedite the work

Conclusion

This course presented an overview of modern practices in effective management of technical projects and engineering professionals' participation in this process to enable you to:

- Describe the Project Engineer's involvement in Project Management
- Provide a definition of the Project
- List components of triple constraint
- Know what WBS is for and how it is obtained
- Understand the difference between effort and duration
- Describe the main estimating techniques
- List the types of Cost Estimates
- Describe views of the Project Schedule
- List project schedule optimization techniques
- Define Scope and scope "creep"
- Describe the Project Engineer's involvement in a procurement process
- List procurement options and types of contracts in technical projects; their advantages and disadvantages
- Describe risk identification, analysis and response processes
- List the main sources of Risk in utility company Projects
- Describe the types of project communications
- Explain how to make meetings productive
- Define project baseline
- List the main components of project control
- Use Earned Value Analysis to forecast Project outcome