Georgia Technology Authority

Project Planning, Scheduling, and Control – Student Guide

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Preface for Students

About the Student Guide

This Student Guide is designed to supplement the presentation on **Project Planning, Scheduling, and Control**. It includes

- **PowerPoint slides**
  The PowerPoint presentation highlights the key points, concepts, illustrations and diagrams associated with the course. This guide contains a grab of each slide in that presentation.

- **student learning objectives**
  The presentation is divided into a number of lessons. Each lesson is then further subdivided into a number of topics. A topic is stand-alone piece of instruction that has a specific, demonstrable learning objective. You should begin each lesson by taking a moment to review the objectives.

- **supplementary notes**
  Supplementary notes appear with each slide, adding detail to what has been covered in the presentation. It is recommended that you review these notes following each presentation.

Lesson 1: Definition of Project Work

Topic 1: Introduction to Project Time and Cost Management

Topic 2: Defining a Project Deliverable

Topic 3: Work Breakdown Structures

Topic 4: Producing and Using a Project Deliverable

Student learning objectives

After completing this lesson, you should be able to

- explain the basis of time and cost management and describe what elements are key to project planning
- describe how a work breakdown structure is used as an input to developing a project plan
- use a work breakdown structure and define work deliverables

Topic 1: Introduction to Project Time and Cost Management

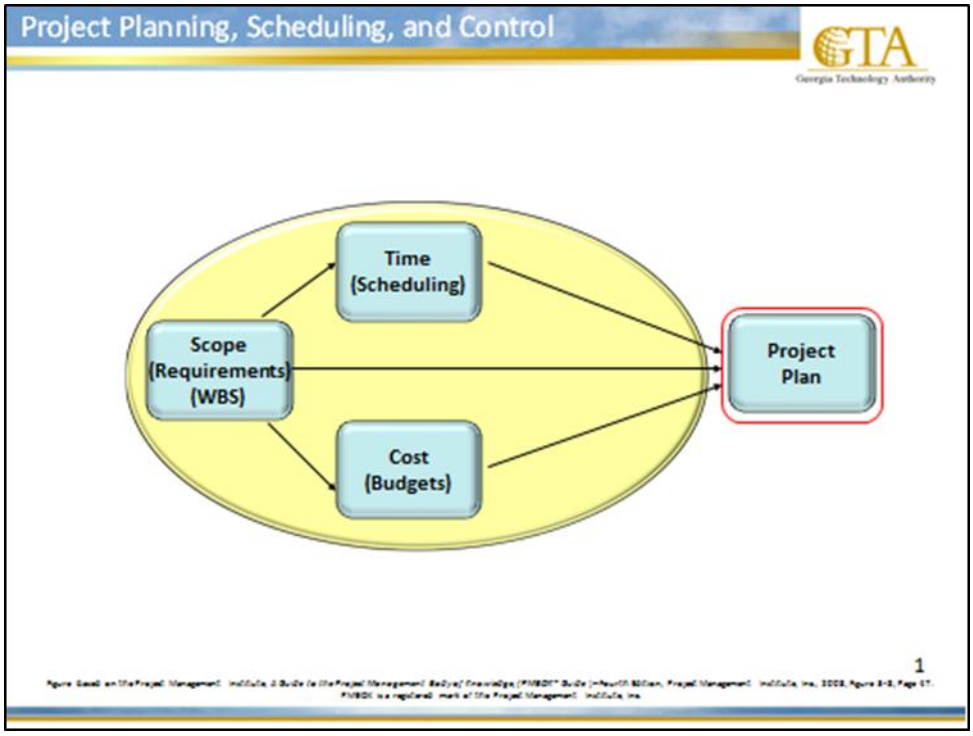

Figure based on the Project Management Institute, *A Guide to the Project Management Body of Knowledge, (PMBOK® Guide) – Fourth Edition, Project Management Institute, Inc., 2008.*
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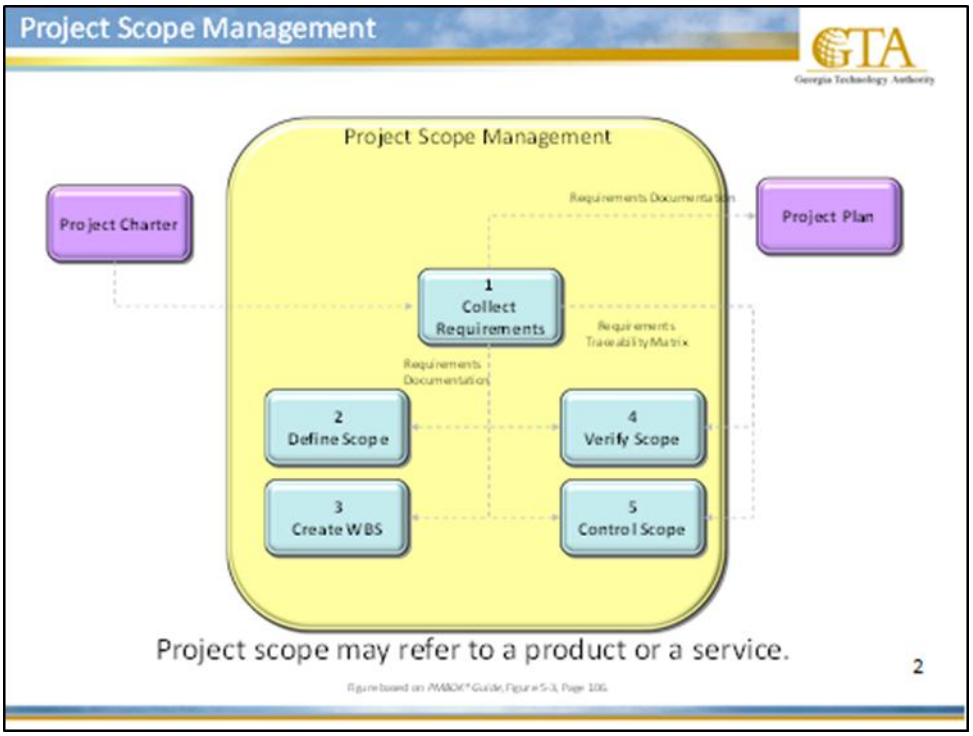
A project team is likely to deal with some or all of the following in the course of a typical project:

- scope, cost, and schedule objectives
- contract terms and conditions
- resource assignments

However, project managers continually face balancing the triple constraint – project scope, time, and cost – when planning any project. Project quality depends on the balance between these three constraints. High quality projects deliver required results within scope, on time, and within budget.

Scope, time and cost plans are all part of the project management plan; the formal, approved document used to guide both project execution and project control. (To view a sample Project Management Plan, see Tools & Templates handout.)

Topic 1: Introduction to Project Time and Cost Management (cont'd)



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Sequence of Activities:
Collect Requirements →Define Scope →Create WBS → Verify Scope →Control Scope

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Project scope management is made up of a number of processes that define and control what work is included in the project. These definitions are taken from the *PMBOK® Guide*. Scope Management processes includes the following:

- **Collect Requirements** is the process of defining and documenting stakeholders' needs to meet the project objectives.
- **Define Scope** is the process of developing a detailed description of the project and product.
- **Create WBS** is the process of subdividing project deliverables and project work into smaller, more manageable components.
- **Verify Scope** is the process of formalizing acceptance of the completed project deliverables.
- **Control Scope** is the process of monitoring the status of the project and product scope and managing changes of the scope baseline.

Topic 1: Introduction to Project Time and Cost Management (cont'd)

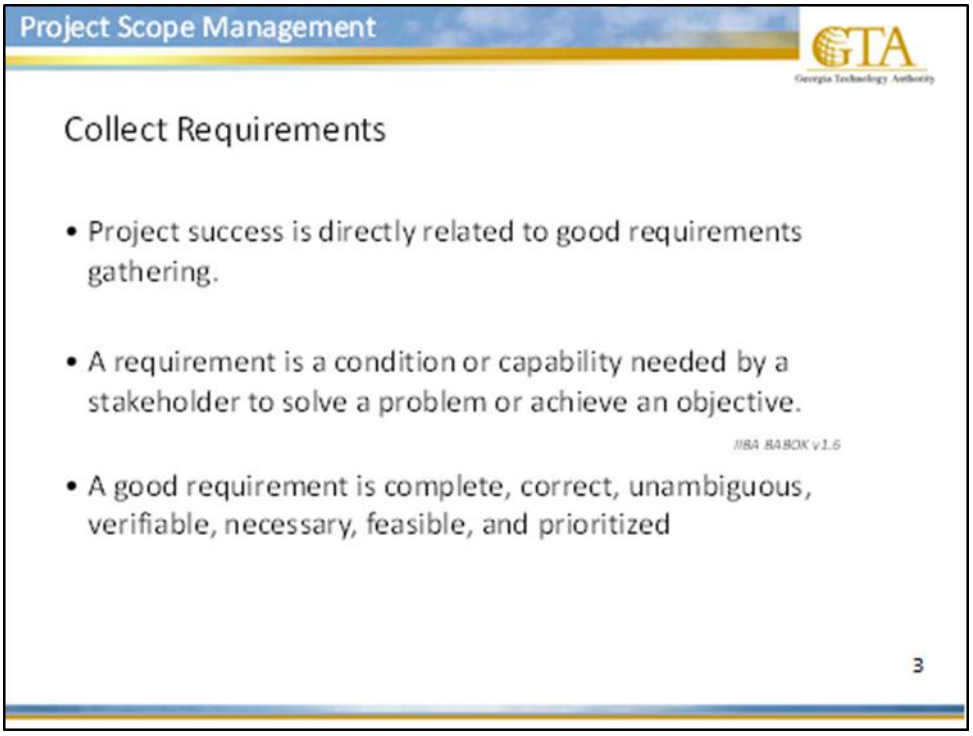
Project scope may refer to a product or a service. **Work breakdown structures (WBS)** are one of the most important tools in project management and are issued in the project planning phase. The WBS presents a definition of the project scope in the form of work packages.

If the initial requirements of a project change as it progresses, this represents a change in the scope of the project. Similarly, if there are any changes to the project work regardless of how small or large, or whether they were specifically requested or not, these also represent a change in project scope.

Scope changes can make a project larger or smaller. They can also affect the timeline and cost of the project. These changes in scope are commonly referred to as **scope creep.** In a nutshell, **scope creep is the change or growth of project scope**.

Scope creep occurs most frequently during the later stages of a project, such as programming and testing, rather than during the earlier stages, such as design. This is a result of the project team gaining more knowledge of any early problems and developing solutions to them.

Topic 1: Introduction to Project Time and Cost Management (cont'd)

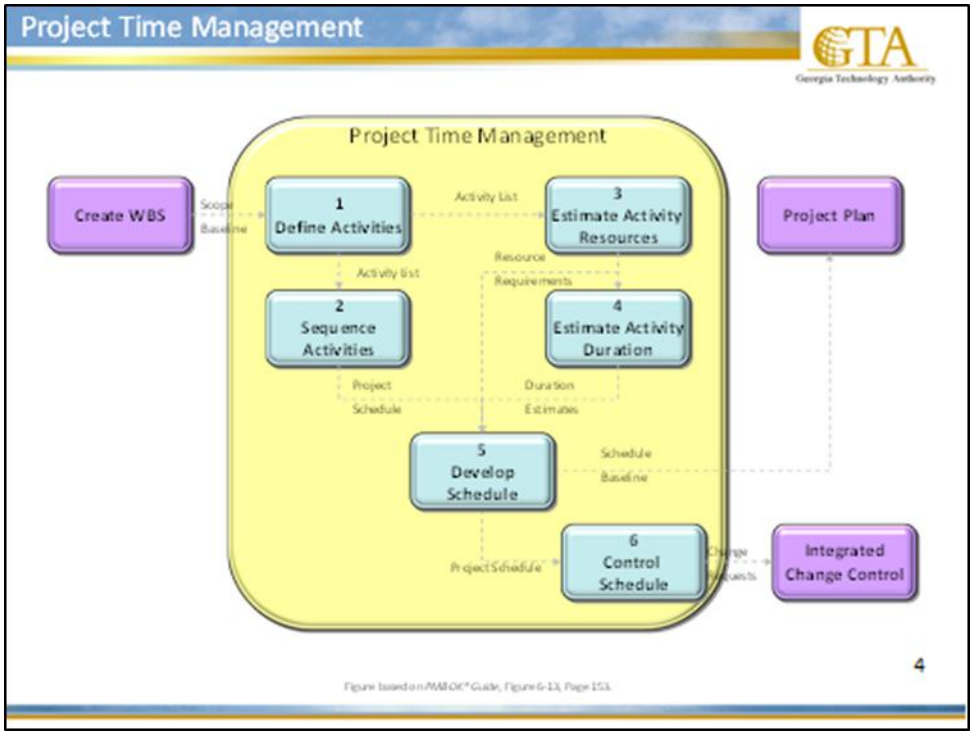


Collecting requirements is essential to the success of the project. According to the International Institute of Business Analysis *Business Analysis Body of Knowledge, v1.6*, a requirement is "a condition or capability needed by a stakeholder to solve a problem or achieve an objective". Requirements are the building blocks for development of the WBS, schedules, test cases, and ultimate customer expectations. Requirements should be elicited, validated, specified, and verified.

The project manager must understand that characteristics of a good requirement are:

- **Complete:** the requirement gives a detailed description of what is needed.
- **Correct:** the requirement should be appropriate to meet the goals of the project and accurately describes the stakeholder's expectation.
- **Unambiguous:** the requirement should be written so that all readers arrive at a single consistent interpretation.
- **Verifiable:** the requirement should be testable.
- **Necessary:** the requirement must be necessary to support at least one of the project goals.
- **Feasible:** the requirement must be possible to achieve for a reasonable cost.
- **Prioritized:** the requirement must be put in a priority ranking.

Topic 1: Introduction to Project Time and Cost Management (cont'd)



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Project Time Management:
Define Activities →Sequence Activities → Estimate Activity Resources → Estimate Activity Durations →Develop Schedule →Control Schedule

Planning is a project manager's major responsibility. If project planning is performed correctly, then it is conceivable that the project manager will work him/herself out of a job because the project can run itself. However in reality, this is highly unlikely. Few projects are completed without some conflict or trade-off for the project manager to resolve.

The stable elements of planning in any project are cost and time. Project time management includes those processes needed to accomplish timely completion of a project. Project time management processes include the following:

These definitions are taken from the *PMBOK® Guide*. Project time management processes include the following:

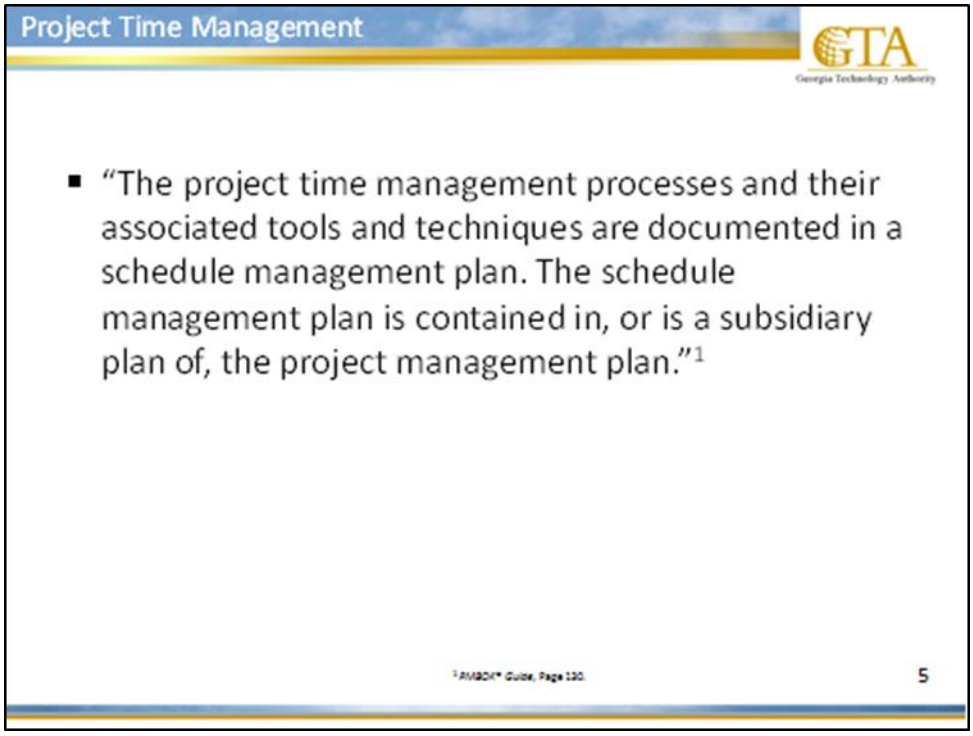
- **Define Activities** – identifying the specific actions to be performed to produce the project deliverables
- **Sequencing Activities** – identifying and documenting relationships among the project activities
- **Estimate Activity Resources** – estimating the type and quantities of material, people, equipment, or supplies required to perform each activity
- **Estimate Activity Duration** – approximating the number of work periods needed to complete individual activities with estimated resources
- **Develop Schedule** – analyzing activity sequences, durations, resource requirements, and schedule constraints to create the project schedule
- **Control Schedule** – monitoring the status of the project to update project progress and managing changes to the schedule baseline

Topic 1: Introduction to Project Time and Cost Management (cont'd)

On some projects, particularly smaller ones, the processes of activity sequencing, activity duration estimating, and schedule development are so tightly linked that they are viewed as a single process that can be performed by an individual over a relatively short period of time.

All well-managed projects, including large government projects, adhere to the time management processes of activity definition, activity sequencing, activity resource estimating, activity duration estimating, schedule development, and schedule control.

Topic 1: Introduction to Project Time and Cost Management (cont'd)



This planning effort sets out the format and establishes criteria for the development and control of the project schedule.

The main task of the planning effort is to define the project scope. This is achieved using a **work breakdown structure (WBS)**, which is a deliverable-oriented hierarchy of decomposed project components that organizes and defines the total scope of the project.

The project time management planning function produces a developed project schedule and schedule management plan that is contained in, or is a subsidiary plan of, the project management plan.

This schedule management plan may be formal or informal, highly detailed or broadly framed, depending on the needs of the project.

Topic 1: Introduction to Project Time and Cost Management (cont'd)

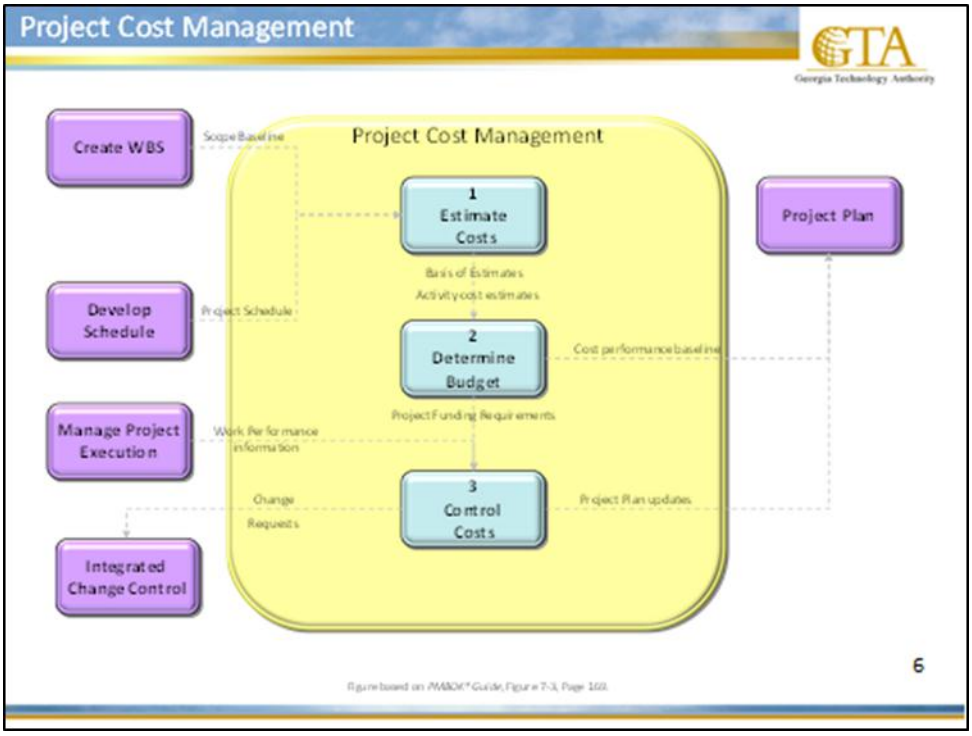


Figure based on the Project Management Institute, *A Guide to the Project Management Body of Knowledge, (PMBOK® Guide) – Fourth Edition, Project Management Institute, Inc., 2008.*

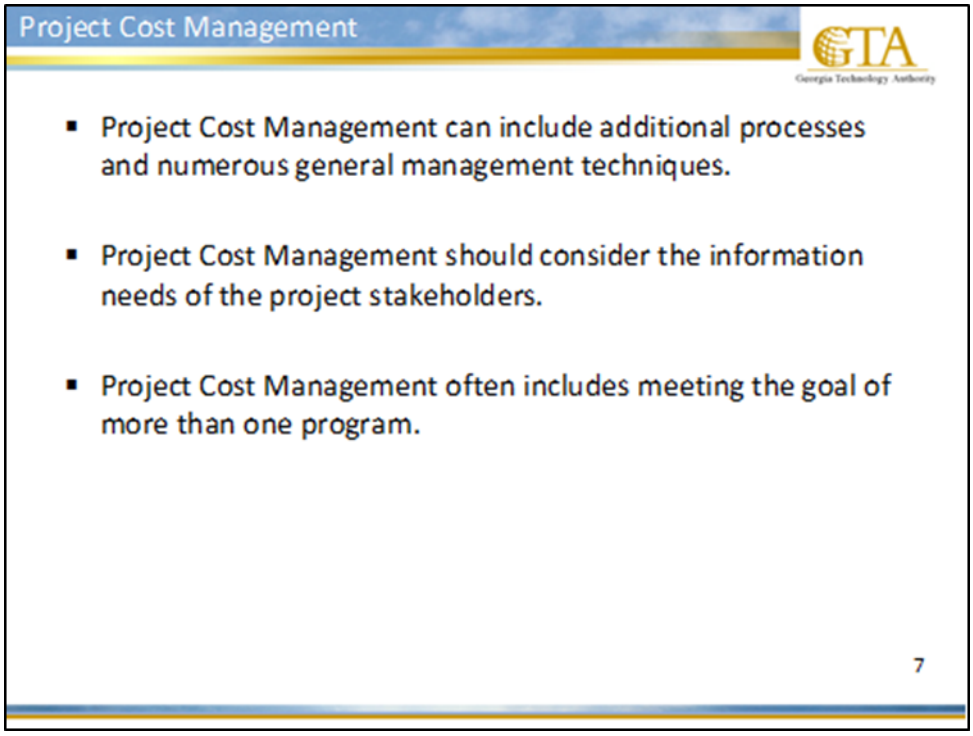
Sequence of Activities:
Cost Estimating → Cost Budgeting → Cost Control

Project cost management includes the processes involved in planning, controlling, and managing costs so that a project can be completed within the approved budget. It can be broken down into the following three processes:

- **cost estimating** – developing an approximation of the costs and resources needed to complete project activities
- **cost budgeting** – aggregating the estimated costs of individual activities or work packages to establish a cost baseline for the total project
- **cost control** – influencing variations in the factors that create additional costs and controlling changes to the project budget

Project cost management is mainly concerned with the cost of the resources, labor, and equipment required to complete project activities. It should also consider the effect of project decisions on the cost of using the product. For example, limiting the number of design reviews can reduce the cost of the project at the expense of an increase in the customer's operating costs.

Topic 1: Introduction to Project Time and Cost Management (cont'd)



In many application areas, the work of predicting and analyzing the prospective financial performance of the project's product is done outside the project.

In other application areas, such as capital facilities projects, project cost management also includes this work.

When these predictions and analyses are included, project cost management encompasses additional processes and numerous general management techniques, such as **return on investment**, **discounted cash flow**, **earned value** and **investment payback analysis**.

Project cost management should consider the information needs of the project stakeholders. Different stakeholders measure project costs in different ways and at different times. For example, the cost of an acquired item can be measured when the actual cost is incurred, or the actual cost can be recorded for project accounting purposes.

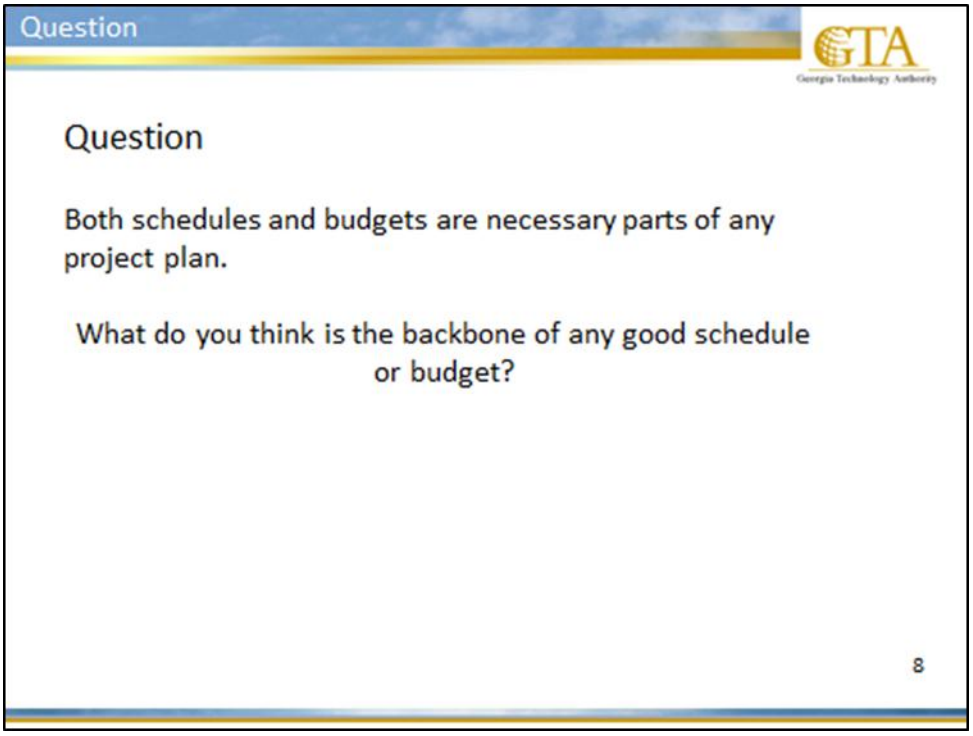
Representative bodies in large governments generally assign funds to programs rather than individual projects. Each project must be funded by one or more of these programs.

It is **generally** possible that a single project can contribute to the goals of more than one program. This is particularly common in transportation infrastructure projects. A road-widening project could be combined with pavement rehabilitation or seismic retrofitting, for example, even though each individual piece of work would be budgeted as a separate program.

A **program is a group of related on-going projects that are managed in a coordinated way**.

Similar situations are common wherever new facilities are budgeted separately from rehabilitation. It **generally** makes sense to have a new contractor perform both the new work and the rehabilitation at a particular location, as this minimizes the overhead cost and the disruption to the occupants of the facility.

Topic 1: Introduction to Project Time and Cost Management (cont'd)



Topic 2: Defining a Project Deliverable

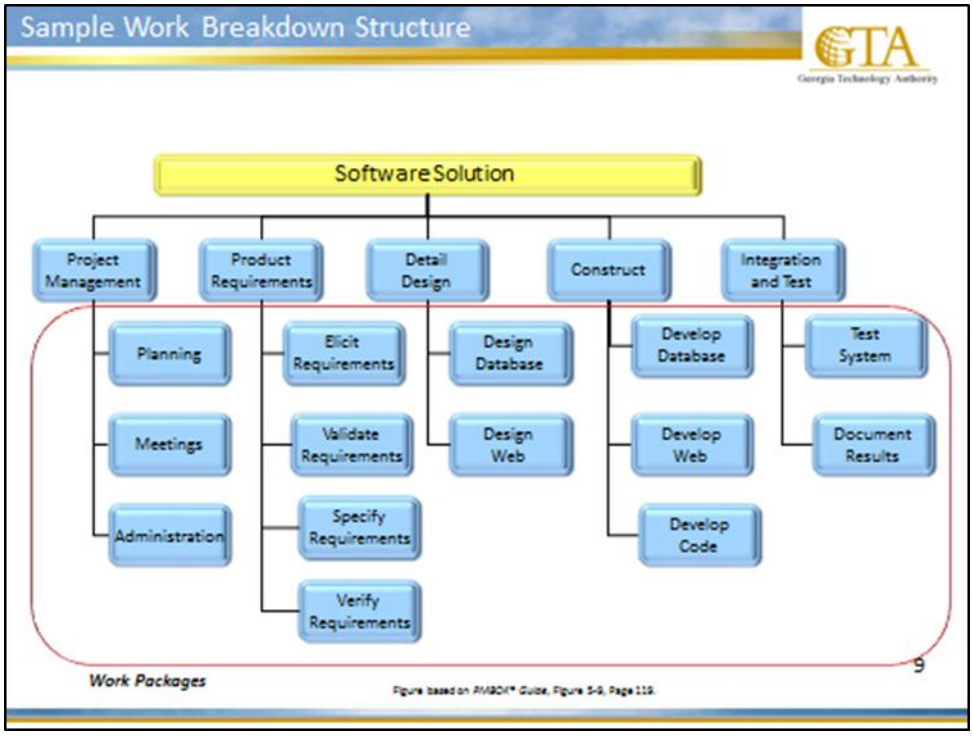


Figure based on the Project Management Institute, *A Guide to the Project Management Body of Knowledge, (PMBOK® Guide) – Fourth Edition, Project Management Institute, Inc., 2008.*

Objective of the WBS

The **work breakdown structure (WBS)** is a deliverable-oriented hierarchy of decomposed project components that organizes and defines the total scope of the project.

It is a representation of the detailed project scope statement that specifies the work to be carried out in the project. The elements of the WBS assist stakeholders in viewing the end product of the project. The work at the lowest-level WBS component is estimated, scheduled, and tracked.

A **deliverable** is any measurable, tangible, verifiable outcome, result, or item that must be produced to complete a project or part of the project.

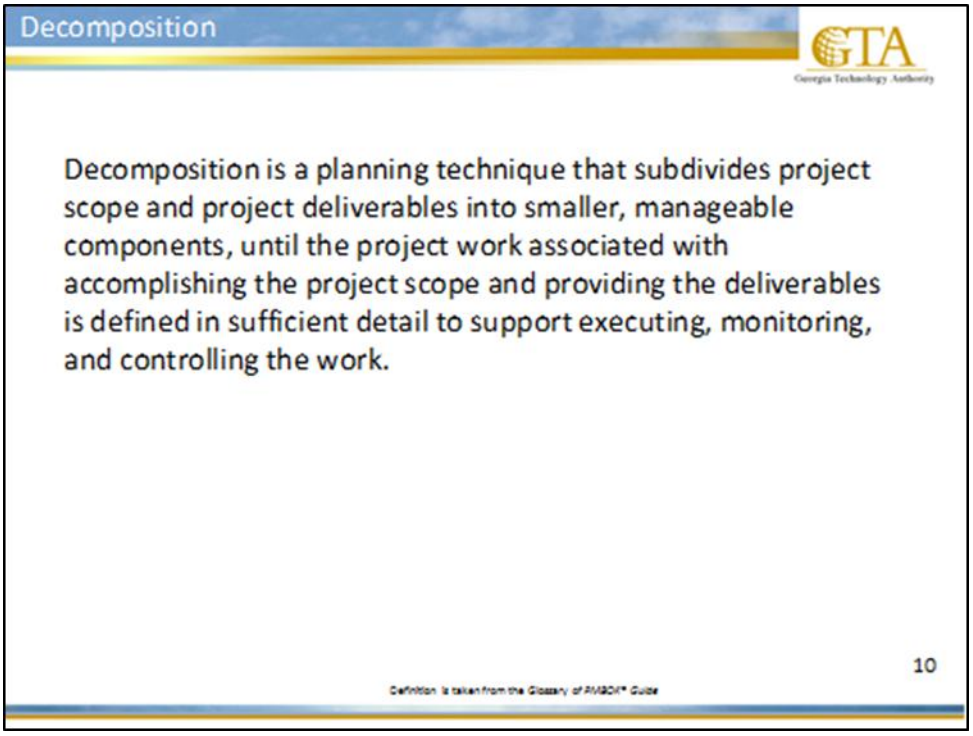
Deliverables are linked to **milestones** in that a milestone is any significant event in the project, usually completion of a major deliverable.

A **work package** is a deliverable at the lowest level of the WBS, and can be used to help evaluate accomplishments. Work packages should be natural subdivisions of effort, planned according to the way the work will be done. However, when work packages are relatively short, little or no assessment of work-in-progress is required and the evaluation of status is possible mainly on the basis of work package completions.

The longer the work packages, the more difficult and subjective the work-in-process assessment becomes, unless the packages are subdivided by objective indicators such as discrete milestones with pre-assigned budget values or completion percentages.

To get a correct balance for defining a work package, the **80-hour rule of thumb** can be used. It identifies work packages where the duration of activities when possible be between 8 and 80 hours. Anything that exceeds this is not a single activity and should be further decomposed when possible.

Topic 2: Defining a Project Deliverable (cont'd)



Defining Deliverables through Decomposition

Decomposition involves subdividing the major project deliverables or sub deliverables into smaller, more manageable components until the deliverables are defined in sufficient detail to support development of project activities (planning, executing, controlling, and closing).

Decomposition involves the following major steps in identifying a deliverable:

- Identifies the **major deliverables** of the project, including project management and its associated activities. These deliverables should identify the entire scope of the project, nothing should be omitted.

  The major deliverables should always be defined in terms of how the project will actually be organized. For example, the phases of the project life cycle may be used as the first level of decomposition with the project deliverables repeated at the second level.

- Deciding whether **adequate cost and duration estimates** can be developed at this level of detail for each deliverable.

  Note, however, that the meaning of adequate may change over the course of the project. Decomposition of a deliverable that will be produced far in the future may not be possible.

Identifying the Deliverable's Components

The components of the deliverable need to be described in terms of tangible, verifiable results in order to allow performance measurement.

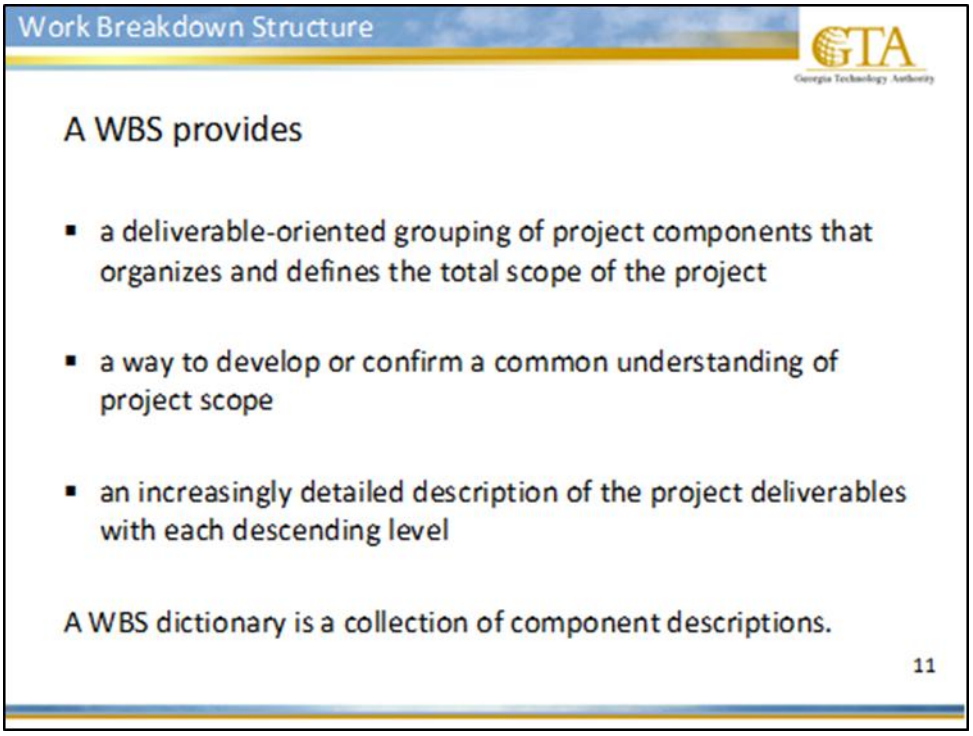
Topic 2: Defining a Project Deliverable (cont'd)

As with the major components, each deliverable's components need to be defined in terms of how the work of the project will be organized and accomplished.

Tangible, verifiable results can include services, as well as products. For example, status reporting could be described as weekly status reports.

In summary, project deliverables must be defined in sufficient detail to support development of project activities. By decomposing major project deliverables into components and naming them, it is possible to create a series of activities that can be estimated, scheduled, and tracked. These activities are known as work packages, and are the lowest level component of a WBS.

Topic 3: Work Breakdown Structures



Work Breakdown Structure

A WBS is a deliverable-oriented grouping of project components that organizes and defines the total scope of the project. Any work not in the WBS is outside the scope of the project.

It is used to develop or confirm a common understanding of project scope. Each descending level within the WBS shows an increasingly detailed description of the project deliverables.

A WBS is normally presented in the form of a chart. The WBS should not, however, be confused with the method of presentation. Simply drawing an unstructured activity list in chart form does not make it a WBS.

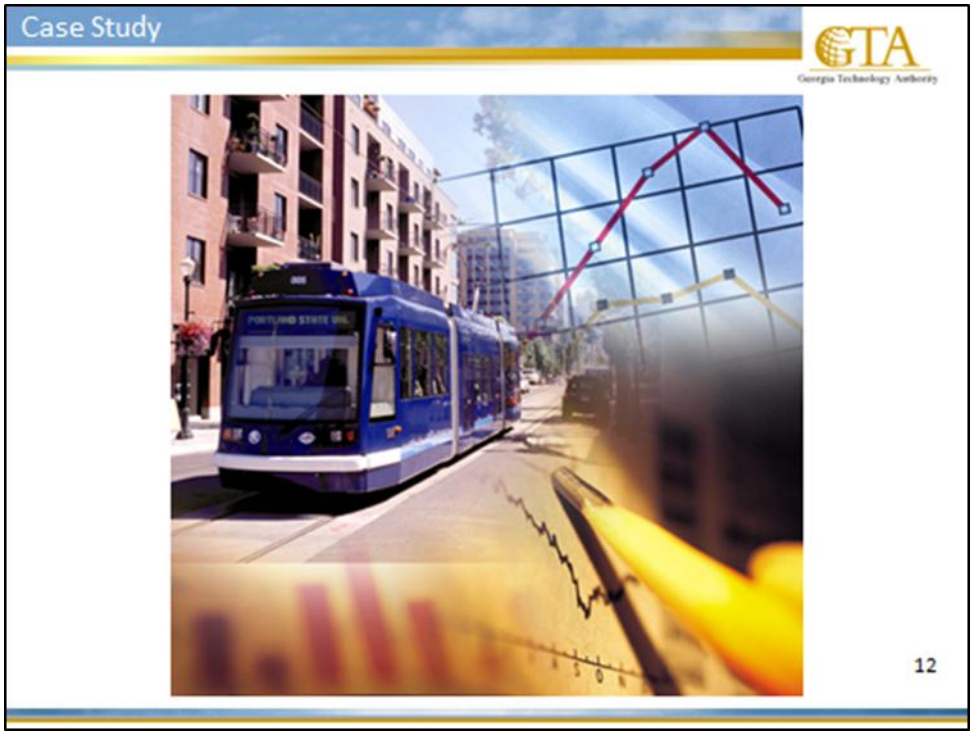
Each item in the WBS is usually assigned a unique identifier, which is used to provide a structure for a hierarchical summation of costs and resources. The items at the lowest level of the WBS may be referred to as work packages, particularly in organizations that follow earned value management practices. These packages can be decomposed further, if necessary, into activities. The activities can then be sequenced and estimated to create the project schedule.

Work component descriptions are often collected in a WBS dictionary.

A WBS dictionary will typically include

- work package descriptions
- other planning information
    - schedule dates
    - cost budgets
    - staff assignments

Topic 3: Work Breakdown Structures (cont'd)



The following is a fictional case study that illustrates how in major infrastructure projects distinct project phases and life cycles must be completed before a project proceeds.

Read the case study and then complete the exercise that follows it.

The Georgia Rail Project

Introduction

Traffic flow, congestion, and pollution are major issues for the state of Georgia. According to statistics gathered over the past ten years,

- the number of licensed drivers has increased by 44%
- on average, 21% extra people travel into the major cities between 8:00 am and 1:00 am each working day
- there has been a 47% increase in the use of automobiles during a working week
- automobile ownership was increased by 7% per year
- over 77% of Georgia drivers now travel alone to work, whereas just over 14% avail of the carpool facility, and 4% avail of public transport
- incidents of crashes are up 4%

Project History

Georgia's transport needs have been under consideration for some time. In 1994, the state initiated an investigation, which led to the publication of a transport strategy report in 1997.

The report found that the public did not consider the current public transportation system to be an adequate alternative to auto transport, resulting in a high reliance on the car.

Topic 3: Work Breakdown Structures (cont'd)

Based on this, the report suggested that the state incorporate a series of measures into its transportation policy:

- review the current public transportation system and invest in new and alternative modes of public transportation in urban commuter areas
- encourage and educate auto users so they see the benefits of alternative transportation with an emphasis on reducing "auto-reliance"

After a period of discussion among various government bodies and other stakeholders, a committee – Transport 2000 – was formed in 1999 to investigate the different alternatives. The committee evaluated alternatives based on expert opinion and historical information, as well as public opinion. The committee also identified the public as a key stakeholder in any transportation project and sought their opinion.

For historical data and expert opinion, the committee looked to developments in Arizona, where a state-of-the-art, $1.13 billion project proposes to link three cities (Phoenix, Tempe, and Mesa) by rail. Funded by the Arizona state government and the three cities, the Central Phoenix/East Valley Light Rail Transit system is scheduled for completion in August 2007. However, due to the success of the project, parts of the rail line will open to the commuter population in December 2006 and April 2007[1].

The Central Phoenix/East Valley Light Rail Transit system has the capacity to transport around 5000 passengers in each direction every hour. A private company will operate the system under a five-year franchise.

Project Proposal

In late 2000, the Transport 2000 committee proposed the establishment of a rail-based public transportation system between the major urban cities of the state. The objective was to provide a speedy, efficient, and cost-effective commuter system, allowing the state population to travel within and between urban districts.

The committee detailed their plans to the state by breaking down the project specification into three sections:

- urban rail system: link each urban "business" area with a reliable light-rail system
- inter-city connection: provide rail segments that will join each urban rail system
- vendor management: identified as a key aspect for the success of the project

The government accepted much of the committee's evidence and the findings, but the major stumbling block was the budget. The state did not accept that the committee could justify the level of investment required for the project with sufficient tangible benefits. It did not help that Phoenix's system was not up and running at the point of the committee reporting.

After lengthy discussion and analysis, the committee was disbanded in mid-2001 with its findings and proposals sitting in the governor's office.

Project Implementation Alternative

During 2002, the statistics continued to show an increase in auto use coupled with a slight increase in road fatalities. The state authorities accepted that the Transport 2000 proposal should be reexamined, although a thorough feasibility study would first be required. In late 2002, a feasibility team was established to present project implementation alternatives. The objective for the team was to highlight implementation objectives, alternatives, and critical success factors.

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[1] Information on Phoenix Rail System sourced from article in PM Network 2004 (Admed H. Chilmeran, PMP; Keep Costs under Control; PM NETWORK, FEB 2004)

Topic 3: Work Breakdown Structures (cont'd)

Matching business and project objectives

The feasibility team, in collaboration with government bodies, identified the business and strategic objectives:

No.	Business Objective	Strategic Objective
1	Reduce the amount of people using auto transport	1. Minimize traffic congestion 2. Minimize road fatalities 3. Increase public transportation options
2	Upgrade and "re-invent" the current public transportation system	1. Minimize traffic congestion 2. Increase appeal of state for new business location
3	Provide a reliable and efficient service to all individuals to accommodate both professional and private use	1. Increase commuter confidence in public transportation 2. Increase appeal of state for new business allocation
4	Establish a system that will generate revenue for the government	1. Profit orientated 2. Maximize sales potential

The feasibility team, like the previous committee, identified the public as a key factor in the success of any public-service project.

The public was broken into three categories:

- public users: potential customers with direct access to the rail system
- impacted users: people directly impacted by the construction of the railway system (i.e. land or property owners along the rail routes)
- operating users: rail operators that will work and maintain the system and provide a support function to the public users

Topic 3: Work Breakdown Structures (cont'd)

The project objectives can be summarized as follows: -

Project Objective No.	Business Objective No.	Project Objective Description
1	1,2,3	Provide light-rail system within major urban areas that will facilitate professional and private commuters
2	4	Provide a rail system between major urban areas that will facilitate professional and private commuters
3	1,2,3	Provide a transportation system that will reduce the number of auto users
4	1,2,3,4	Implement – in a seamless fashion – a new system that has minimal impact on current operations
5	3,4	Educate public on transportation alternatives to ensure each individual understands new system
6	1	Provide transportation system that is cost effective and geared toward profits

The feasibility team evaluated specialized contractors to recruit a team to establish detailed specification around the structural aspects of the project. The government also allocated a budget to invest in highly capable individuals who could provide a complete structural solution.

Project Implementation

Specialists recruited by the feasibility team subsequently presented a work breakdown structure (WBS) for the project, which subdivides the project work into the major elements and then their sub-elements. For example, a major element of work is the civil/track work, which is subdivided into five line sections. The system's work is split into light rail vehicles, the traction power/overhead contact system, fare collection machines, and light rail transit signals and communications. Other work elements, such as the station finishes, are treated as whole contract units.

The specialists developed the lower tiers of the WBS hierarchy in isolation. This practice provides flexibility and full control over respective responsibilities:

- WBS level 1 – program: local and federal programs identified
- WBS level 2 – project: the project's major work elements
- WBS level 3 – project units: the main units/packages associated with each project
- WBS level 4 – sections: the main sections of each unit
- WBS level 5 – contract: the main contracts that can be offered
- WBS level 6 – contract unit: level of work effort required, such as engineering and project management

The specialist team proposed that once the contracts and contract units were identified, the project could then be outsourced to different contractors, including, most likely, a consortium.

Topic 3: Work Breakdown Structures (cont'd)

Project Management

The feasibility team has proposed that a dedicated project management team be established within the government. The team would have total control over budgets and schedules and would report directly to the state legislature.

The control, planning, and management of the project present complex logistical issues. The scheme may entail numerous individual contract packages, which will require coordination.

At a very early stage, the feasibility team settled the key project management objectives as

- effective and efficient communication of information
- utilization of thorough project control techniques
- efficient and widely understood procurement and contractor processes

This standardization is necessary to ensure that all contractors are working in unison. To furnish timely and accurate cost reports, the project control team needs a comprehensive system that integrates cost and schedule, provides reporting capabilities consistent with the project requirements, and improves operating efficiency.

The system has to be capable of processing and analyzing a vast amount of incoming monthly cost data quickly and accurately. Also, the team could use integrated systems to perform risk and schedule simulation analysis where the relationship between the schedule and cost is not always clear.

Although technology has simplified data collection and scheduling, the feasibility team has identified that professionals must carefully study and analyze the system output to provide a logical, meaningful explanation of the causes of any cost and schedule variances. In this way, sound project control methodologies reduce cost overruns, control cost growth, help meet project schedule objectives, and ultimately satisfy the client's expectations.

Feasibility Report

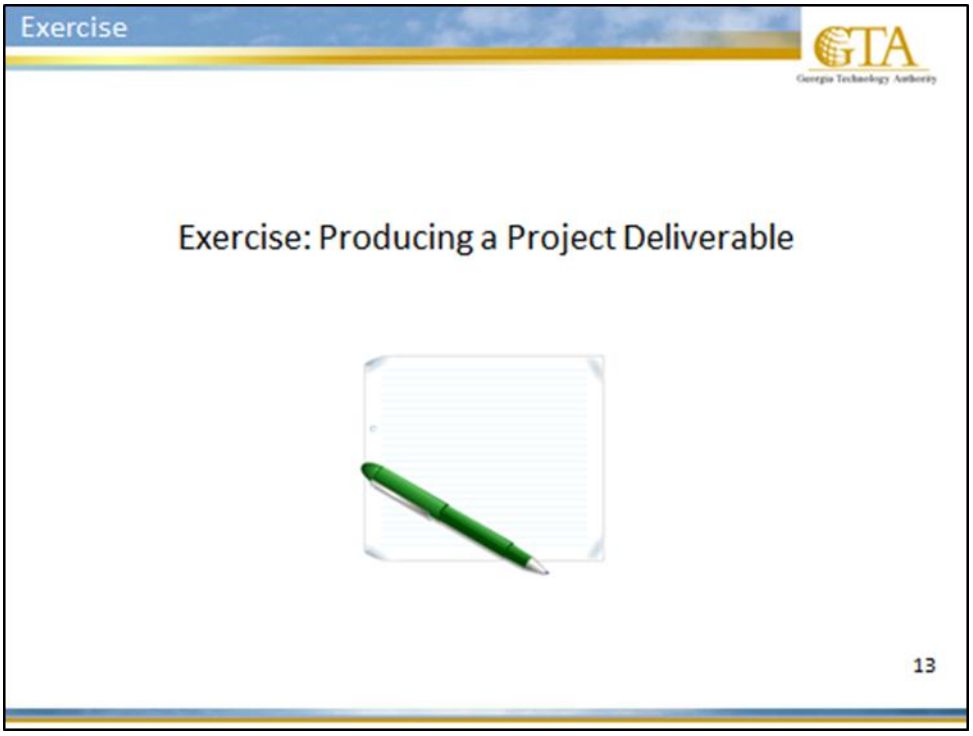
The feasibility team completed their study on schedule with an outline of strategy, detailed recommendations, and a list of preferred suppliers.

The main outcomes from the team are the following:

- The light-rail system should be piloted in one city. Based on the relative success of the pilot and after a period of "customization", the transportation initiative can be deployed in other areas.
- Contractor participation is a key aspect to the success of the project, and the government should establish and work with a set of preferred suppliers.
- The government should establish a detailed project management office that has the authority to manage and control the project and report to senior government officials.

The feasibility team gave the green light for the project, based on these recommendations.

Topic 4: Exercise - Producing and Using a Project Deliverable

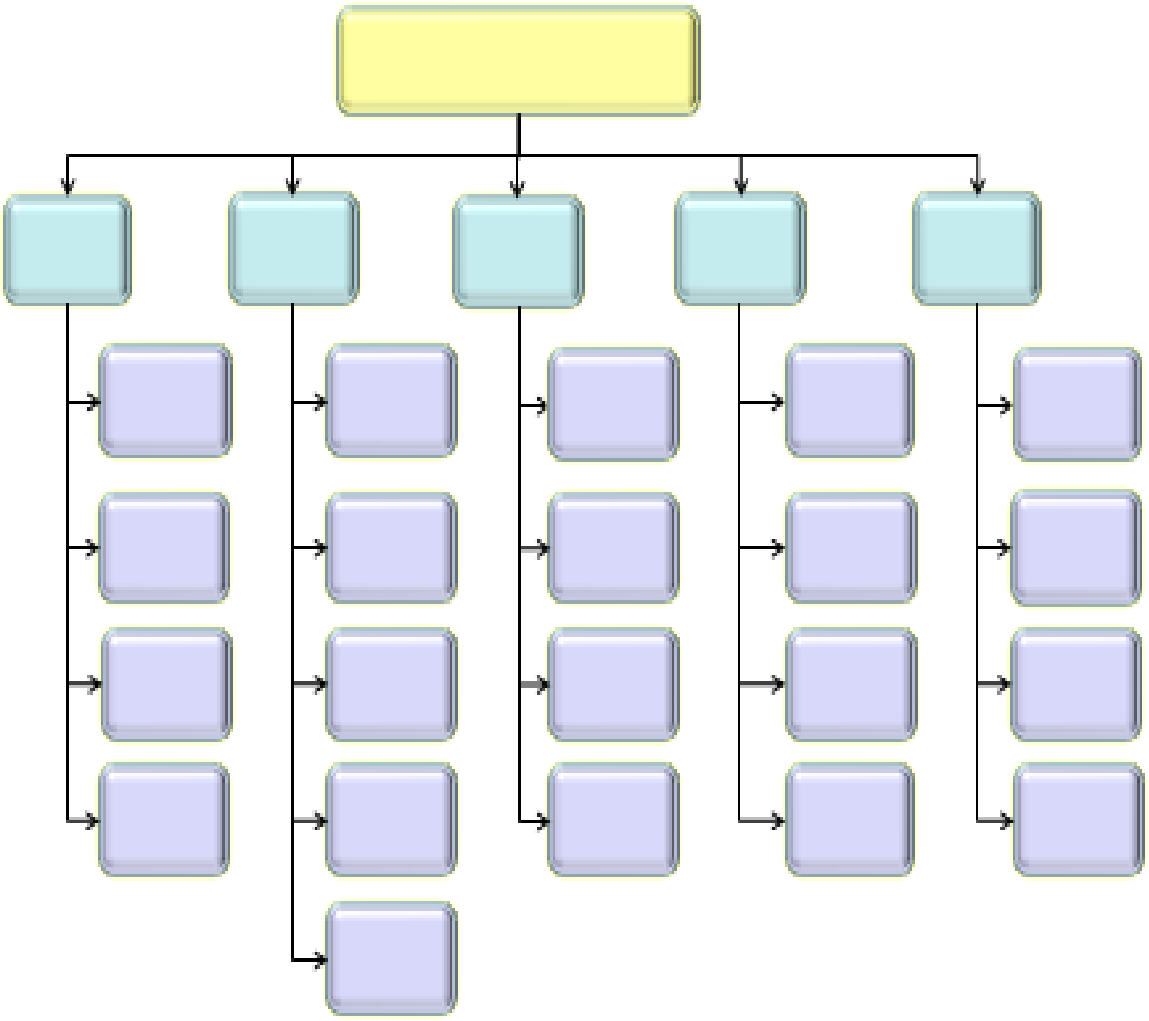


You are about to commence the planning phase for the light rail system project. Because it is such a large project, the team has decided to break up the planning according to various functions. You have been requested to identify the work involved in surveying and reviewing the site of the light rail system, including the delivery of preliminary designs that can be used to award a fixed-price contract to a civil-design vendor.

Your first task is to define the scope of work through a work breakdown structure.

Exercise Worksheet

Figure based on the Project Management Institute, *A Guide to the Project Management Body of Knowledge, (PMBOK® Guide) – Fourth Edition, Project Management Institute, Inc., 2008.*



Lesson 1: Summary

The lesson is now completed and the following topics have been covered:

Topic 1: Introduction to Project Time and Cost Management

- Project **scope management** is made up of a number of processes that define and control the work that is included in the project. These processes include **collect requirements**, **define scope, create WBS, verify scope,** and **control scope**.

- Planning is a project manager's major responsibility. If project planning is performed correctly, then it is conceivable that the project can run itself. Project **time management** processes include **define activities, sequence activities, estimate activity resources, estimate activity duration, develop schedule, control schedule.**

- Project **cost management** includes the processes involved in planning, controlling, and managing costs so that a project can be completed within the approved budget: These are **estimate costs, determine budget, and control costs.**

The accumulation of the outputs from scope, time and cost are the core plans of the project management plan.

From this topic you should **take away** the following points:

- different processes are required to deliver schedules and budgets
- scope, time, and cost are the significant components of the project management plan
- there are specific processes associated with scope management, time management, and cost management

Topic 2: Defining a Project Deliverable

- The **work breakdown structure (WBS)** is a deliverable-oriented hierarchy of decomposed project components that organizes and defines the total scope of the project.

- The WBS presents a **work package** which is a deliverable at the lowest level of the WBS, and can be used to help evaluate accomplishments.

- **Decomposition** involves subdividing the major project deliverables or sub deliverables into smaller, more manageable components until the deliverables are defined in sufficient detail to support development of project activities

- A WBS is used, through decomposition, to define the project scope and hence the project deliverable

From this topic you should **take away** the following points:

- the work breakdown structure is the basis of scheduling and budgeting
- a deliverable is a piece of work that can be given a cost, scheduled, and controlled
- a deliverable (or work package) is the basis of a schedule and budget. These are the activities that are sequenced and estimated.

Lesson 1: Summary (cont'd)

Topic 3: Work Breakdown Structures

- A WBS is a deliverable-oriented grouping of project components that organizes and defines the total scope of the project.

- Any work not in the WBS is outside the scope of the project.

From this topic you should **take away** the following points:

- the WBS is a tool that delivers work packages, using the 80-hour rule to define a work package
- the WBS is a structure / template that will allow you to decompose projects into work packages (for a sample WBS, see Tools and Templates handout)

Topic 4: Producing and Using a Project Deliverable

- An exercise is presented to demonstrate the delivery of a WBS

- The exercise objective is to link project scope with work deliverables. The result of the exercise is a work breakdown structure

From this topic you should **take away** the following:

- a work breakdown structure for a sub-section of the 'Georgia Light Rail' project

Lesson 2: Sequencing Project Work

Topic 1: Logic Diagrams

Topic 2: Activity Sequencing Templates (Activity on Node)

Topic 3: Activity Relationships for Precedence Diagramming Methods

Topic 4: Precedence Diagramming Method

Topic 5: Producing an Activity Sequence

Topic 6: Guidelines to Estimation

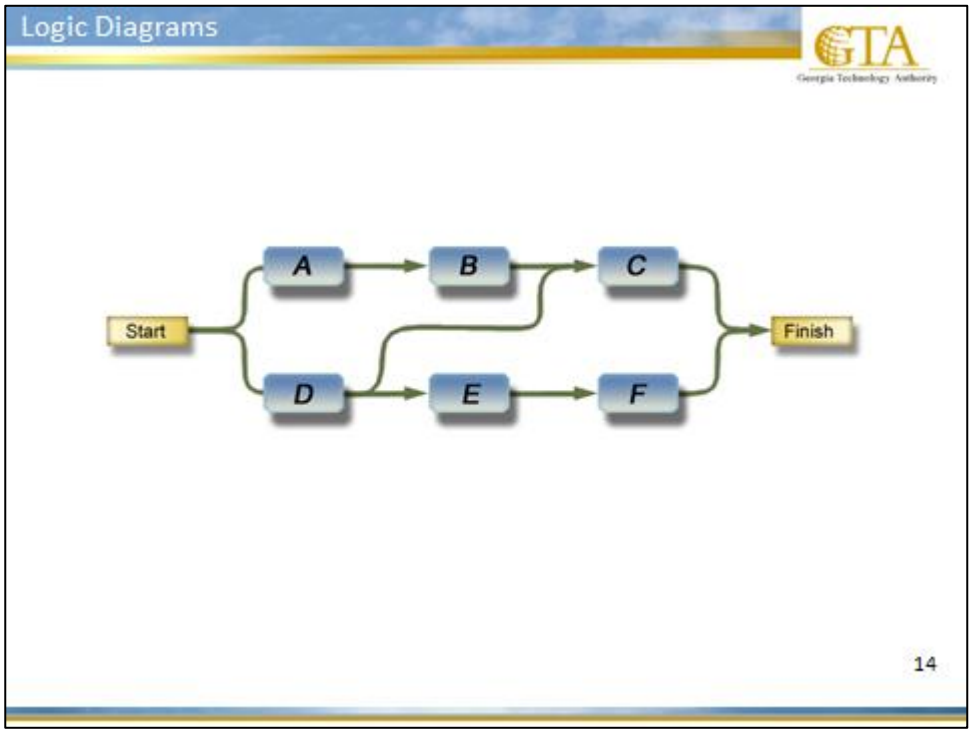
Topic 7: Activity Resource Requirements

Student learning objectives

After completing this lesson, you should be able to

- describe the basis of a project schedule and the link between a work breakdown structure and a project schedule
- outline the different sequencing tools that are available
- describe the different types of activity relationships that exist
- explain what precedence diagramming methods are and how they can be used to understand project duration and flexibility
- use a precedence diagramming method to deliver a project schedule with durations and flexibility
- define the principles behind time and cost estimation
- describe how to establish a resource requirement profile before scheduling activities

Topic 1: Logic Diagrams



Logic Diagrams

The first step in the planning process is to determine the logical flow of all project activities from the beginning to the end of the project. This is done using a logic diagram.

A **logic diagram,** also known as a **project network diagram,** is a schematic display of the logical relationships of project activities. Project activities are presented as boxes connected by arrowed lines that point from left to right. In this way, a procedure or sequence for undertaking projects activities is presented.

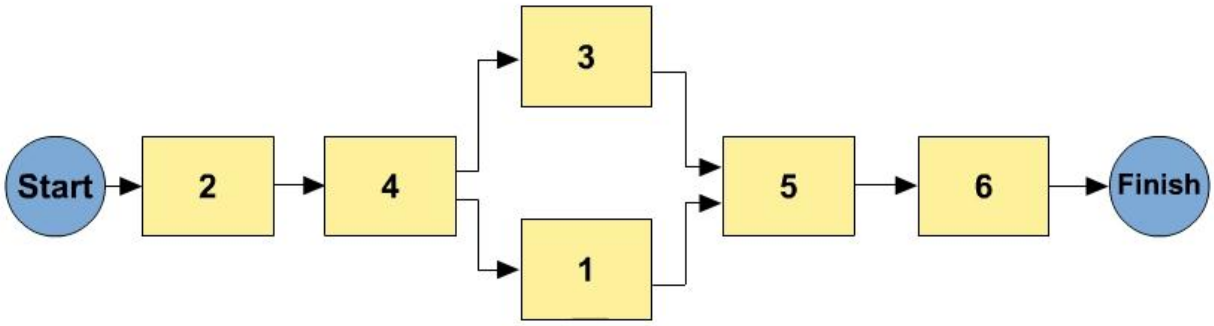
Here is an example of a basic activity list for selecting a vendor for a generic government project; along with a corresponding logic diagram that shows the sequence of work and the relationships between activities:

Activity List:

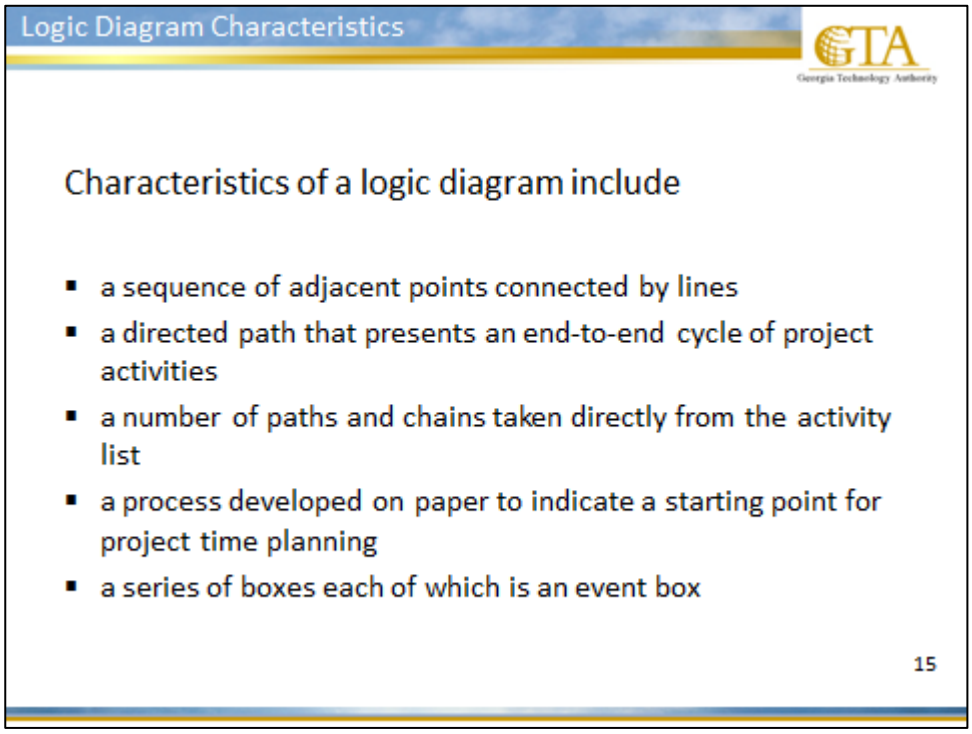
Activity Number	Activity	Activity Predecessor
1	Identify Vendors	4
2	Identify Contract Requirements	-
3	Interview Vendors	4
4	Advertise Proposal	2
5	Select Vendors	1,3
6	Sign Contract	5

Topic 1: Logic Diagrams (cont'd)

Network Diagram:



Topic 1: Logic Diagrams (cont'd)

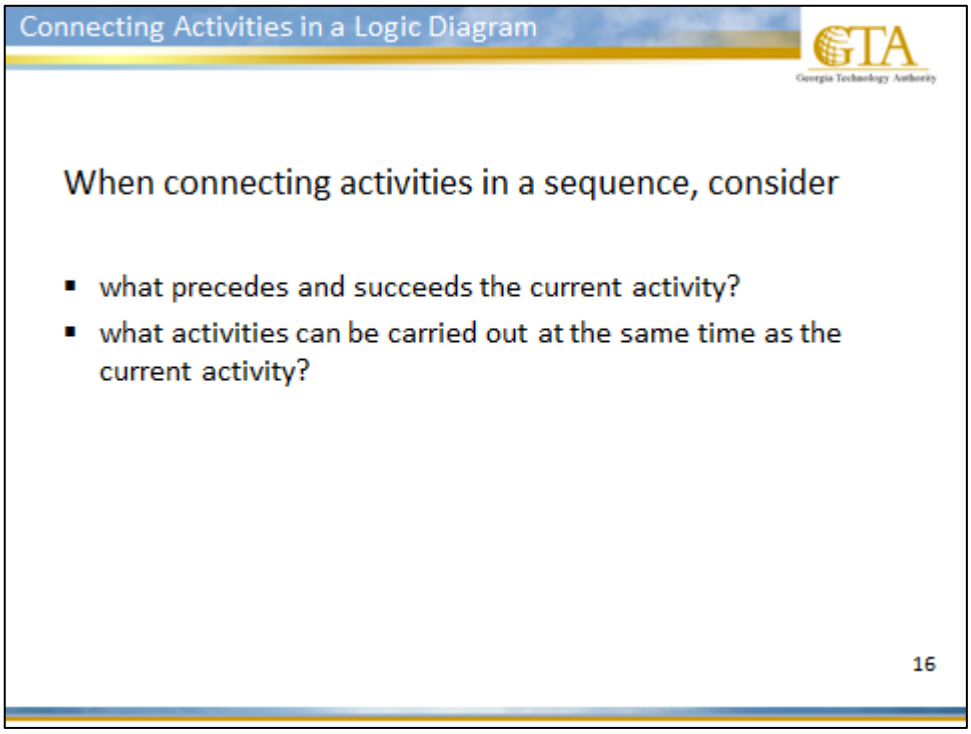


Logic diagrams are probably the most difficult figures to construct. They are developed to illustrate the inductive and deductive reasoning necessary to achieve some objective within a given timeframe. The major difficulty in developing logic diagrams is the inability to answer such key questions as: What happens if something goes wrong? Can I quantify any part of the diagram's major elements?

Logic diagrams are constructed similarly to bar charts on the supposition that nothing will go wrong and are usually accompanied by detailed questions, possibly in a checklist format, that require answering. The following questions would be representative of those that might be asked on a government R&D project based around the introduction of web-based payroll system:

- What documentation must be released to start the described activity and possibly the elements within each activity?
- What information is required before this documentation can be released? (What prior activities must be completed, work designed, studies finalized, etc.?)
- What are the completion, or success, criteria for the activity?
- What are the alternatives for each phase of the program, if success is not achieved?
- What other activities are directly dependent on the result of this activity?
- What other activities or inputs are required to perform this activity?
- What are the key decision points, if any, during the activity?
- What documentation signifies completion of the activity (i.e. report, drawing, etc.)?
- What management approval is required for final documentation?

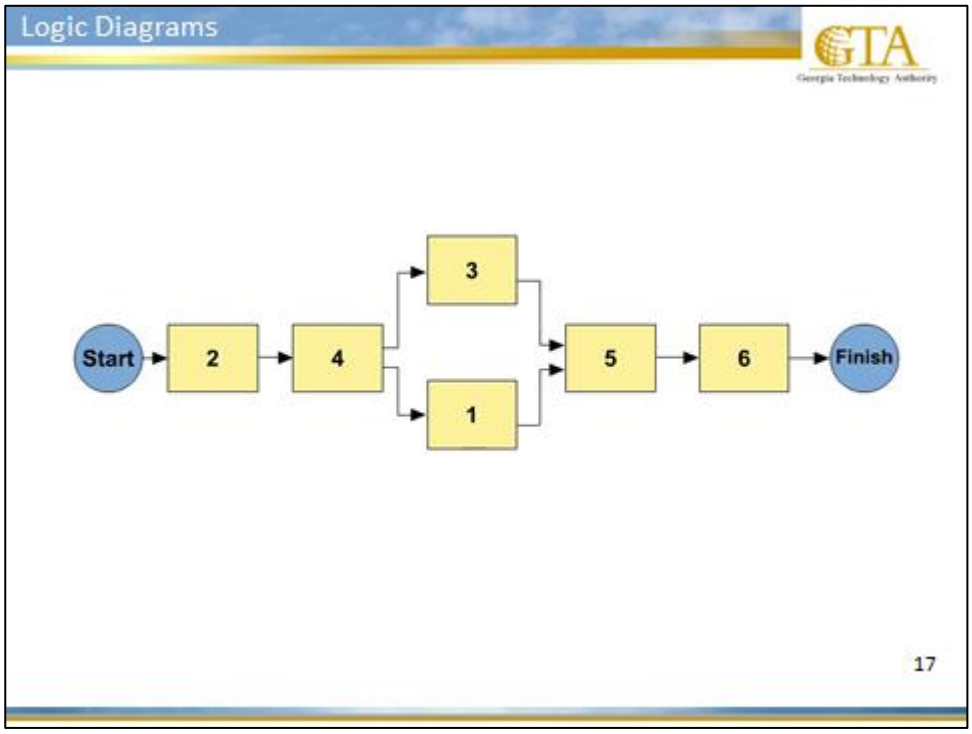
Topic 1: Logic Diagrams (cont'd)



Logic diagrams display the relationships between project activities in a logical sequence. When connecting these activities in a sequence, it is necessary for the planner to continually ask the following questions:

- what activities must be done before the activity I am currently considering? In other words, what precedes this activity?
- what activity can be started after the activity that I am considering? What succeeds this activity?
- what activities can be carried out at the same time as the activity I am considering?

Topic 1: Logic Diagrams (cont'd)



Each activity has a *successor* and a *predecessor*, collectively known as dependencies. When activities occur at the same time as the activity being considered, they are said to be *concurrent*.

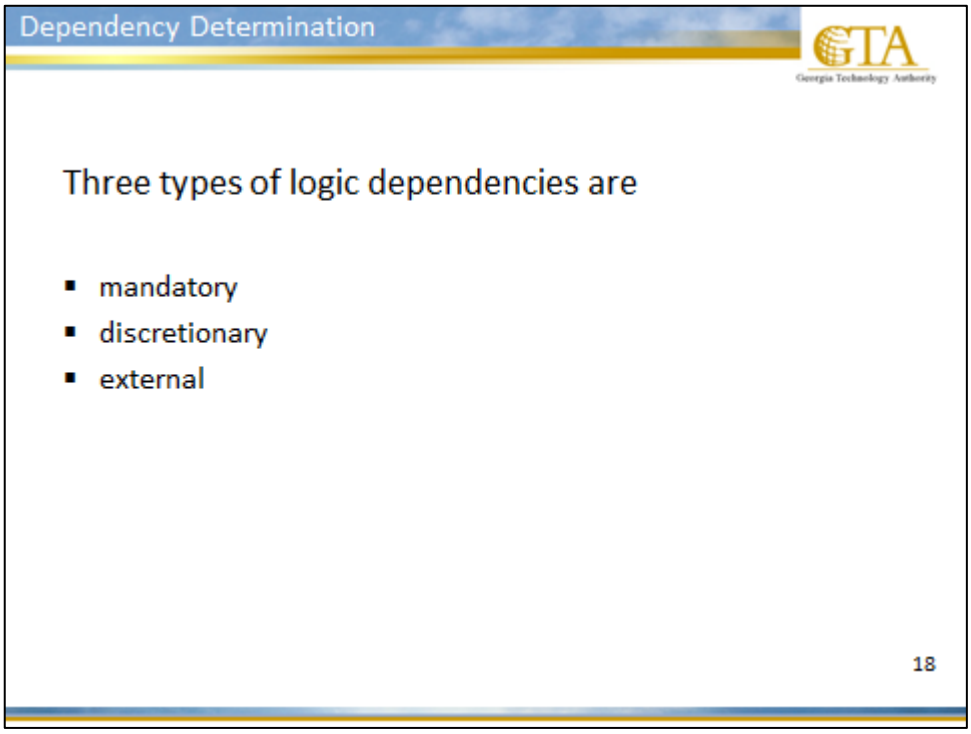
For example, the above slide displays the logic diagram for selecting a vendor for a generic piece of work. Several pieces of information can be interpreted from the diagram.

For example, activity 2 is a predecessor of activity 4 because you have to identify contract requirements before you advertise. Also, activity 1 is concurrent with activity 3 because you identify and interview vendors at the same time. Activity 6 is a successor to activity 5 because you have to select vendors before you sign contracts with them.

The logic diagram shown here also displays a start node and a finish node as circular.

Logic diagrams are useful purely as starting points for visualizing the sequence of activities from the presented activity list.

Topic 1: Logic Diagrams (cont'd)



Dependency Determination
Logical dependencies can be mandatory, discretionary, or external.

- **Mandatory dependencies**

  Also known as hard logic, these are inherent in the nature of the work being done. Mandatory dependencies often involve physical limitations – for example, it would be impossible to test a product before it has been assembled.

- **Discretionary dependencies**

  Also known as preferred or soft logic, these are generally defined by the project management team during the process of establishing the sequence of activities. They are based on knowledge of

  - best practice – activities are sequenced with knowledge of what is considered best practice
  - some unusual aspect of the project – where a specific sequence is desired, even though there are other acceptable sequences
  - preferred activity sequences – based on previous experience of a successful project performing the same type of work
  - obligations – which are particularly useful for projects with large procurements. On many government projects, the main product of the project is purchased from the private sector. Some governments can obligate the funds for these contracts if the contract is signed before the end of the fiscal year. This obligation places the contract funds into a separate account that can be used only for the specific contract. The planning of such obligations can be considered based on the discretion of the project team.

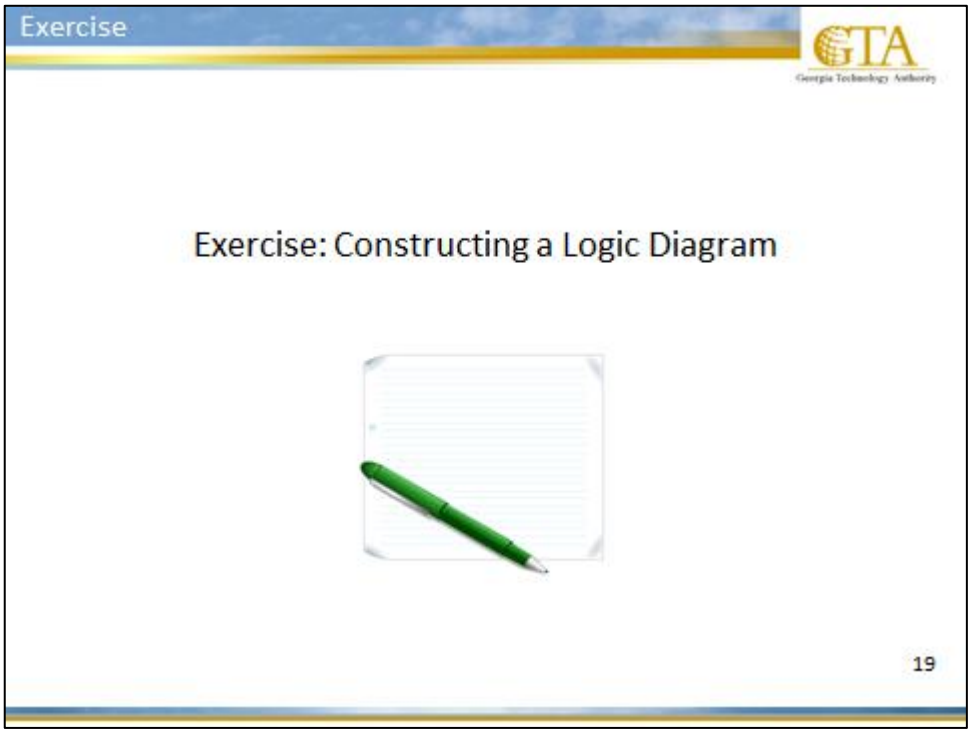
Topic 1: Logic Diagrams (cont'd)

- **External dependencies**

  These are dependencies that have interfaces with other projects or with non-project activities. An example is the beginning of a project in an unknown territory, where you may need to account for the political situation.

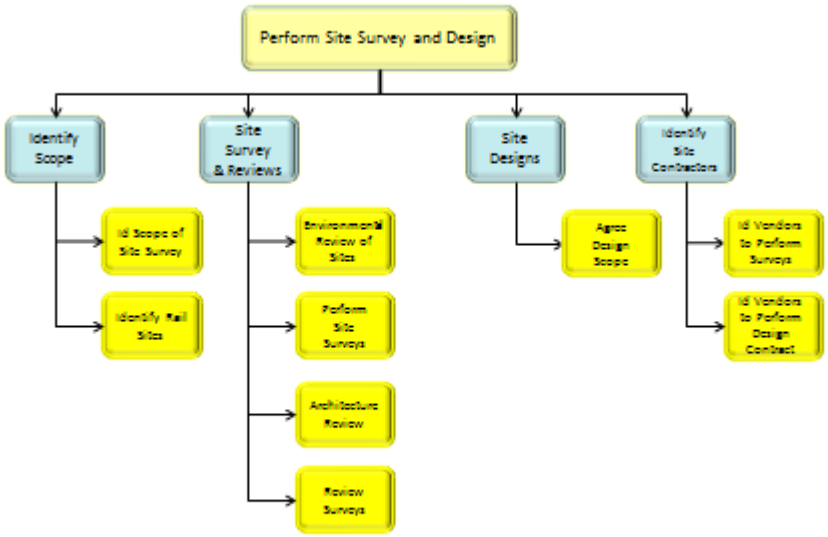
Determining project dependencies is an important part of constructing a logic diagram. Only when you understand the dependencies, and therefore the successor and predecessor to each activity, will you be able to arrange all project activities in a logical sequence.

Topic 1: Exercise – Constructing a Logic Diagram



You are about to commence the planning phase for the light rail system project. Due to the large nature of the project, the project team has decided to break up the planning according to the various functions. You are requested to identify the work that would be involved in surveying and reviewing the site of the light rail system and to deliver preliminary designs that can then be used to award a fixed-price contract to a civil design vendor.

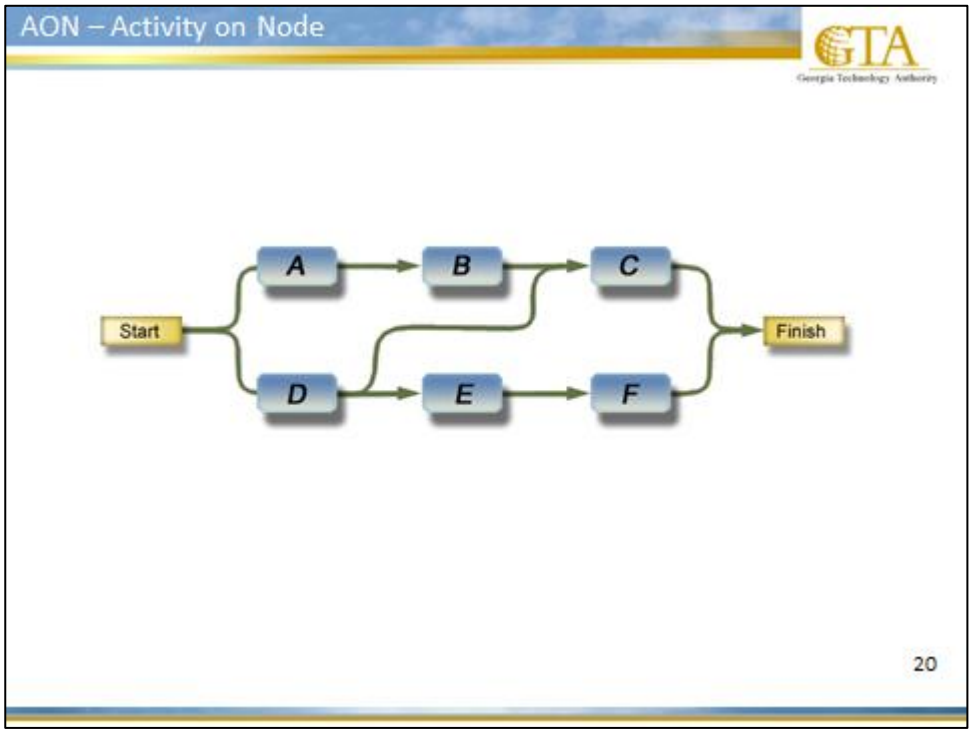
Your first task was to define the scope of work through a work breakdown structure. This is completed, and you are now requested to **extract the activities** and **construct a logic diagram** with these activities.



Exercise Worksheet

Exercise Worksheet

Topic 2: Activity Sequencing Templates (AON)



A logic or network diagram shows a sequence of work, including whether activities can be done at the same time or have to be done in a particular order. In addition, network diagrams have the following characteristics:

- they include durations in the form of start and finish dates for each activity
- they can show whether the timing of a particular activity is crucial to finishing the project by a given completion date (i.e. critical path)
- they can demonstrate milestones and in turn can be used to control project progress

There is one type of network diagram that is commonly used – activity-on-node (AON).

Activity On Node

Activity on Node (AON) is a diagramming method that uses boxes or rectangles (nodes) to represent activities and connects them with arrows that show dependencies. AON - which was introduced by two major corporations (DuPont and Sperry Road) - is the more popular type of diagram that defines the paths and activities that are critical to the project, and is associated with the critical path method (CPM).

AON includes four types of dependencies or precedence relationships:

- **finish-to-start** – the start of the work of the successor depends on the completion of the work of the predecessor (this is the most commonly used type of logical relationship)
- **finish-to-finish** – the completion of the work of the successor depends on the completion of the work of the predecessor

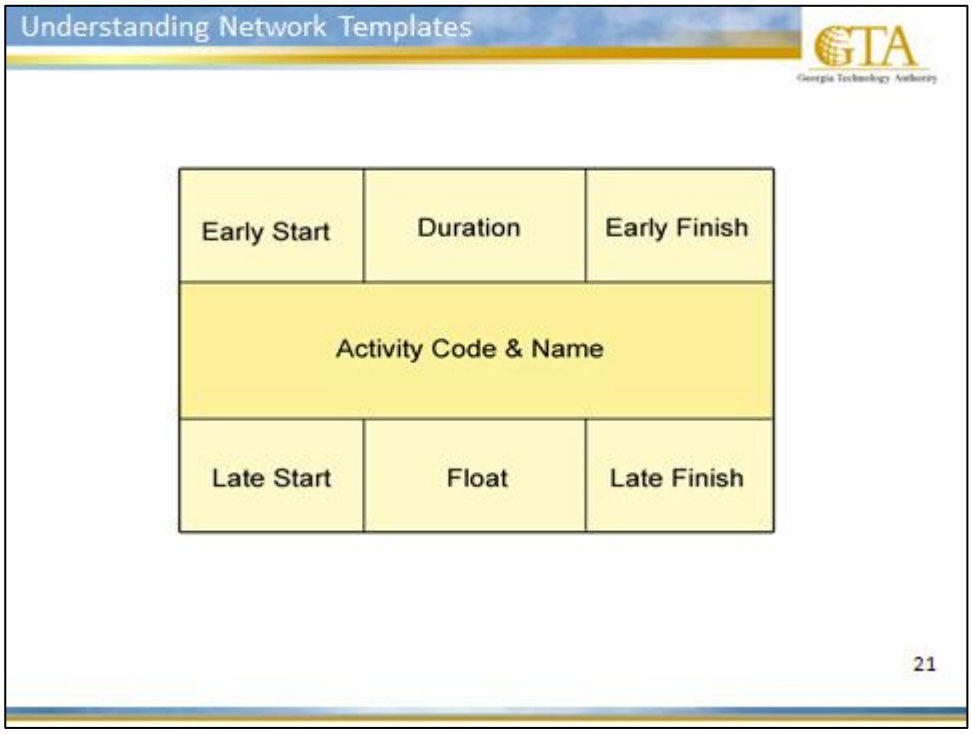
Topic 2: Activity Sequencing Templates (AON) (cont'd)

- **start-to-start** – the start of the work of the successor depends on the start of the work of the predecessor (these relationships are rarely used and only by professional scheduling engineers)

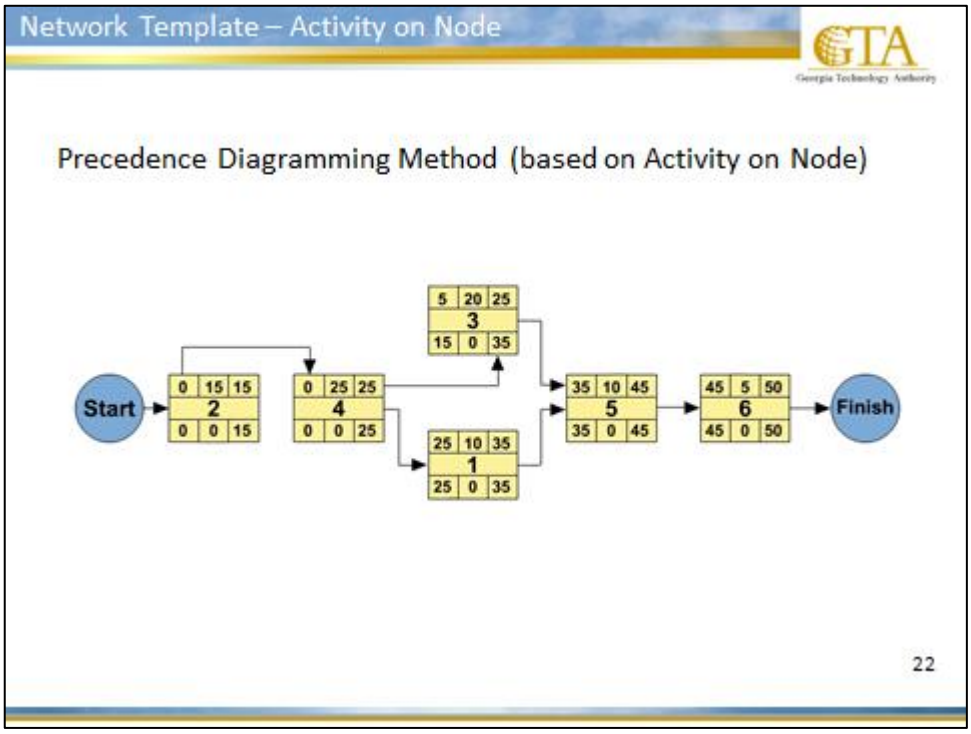
- **start-to-finish** – the completion of the successor depends on the start of the predecessor

Start-to-start, finish-to-finish, or start-to-finish relationships can produce unexpected results because these types of relationships have not been consistently implemented.

Topic 2: Activity Sequencing Templates (AON/AOA) (cont'd)



Topic 2: Activity Sequencing Templates (AON) (cont'd)

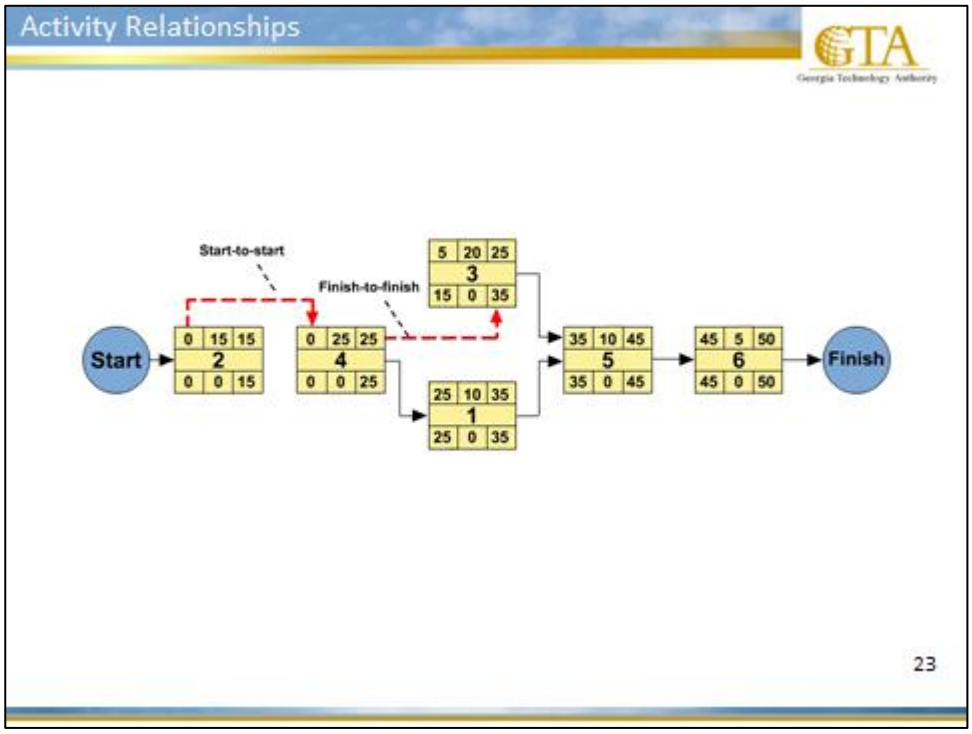


Network templates

Standardized networks can be used in preparing project network diagrams. They can include an entire project or only a portion – subnet or fragment – of it. Subnets are particularly useful when a project includes several identical or nearly identical features, such as floors on a high-rise office building.

The slide illustrates a network template, commonly known as a precedence diagramming method.

Topic 3: Activity Relationships for Precedence Diagramming Methods



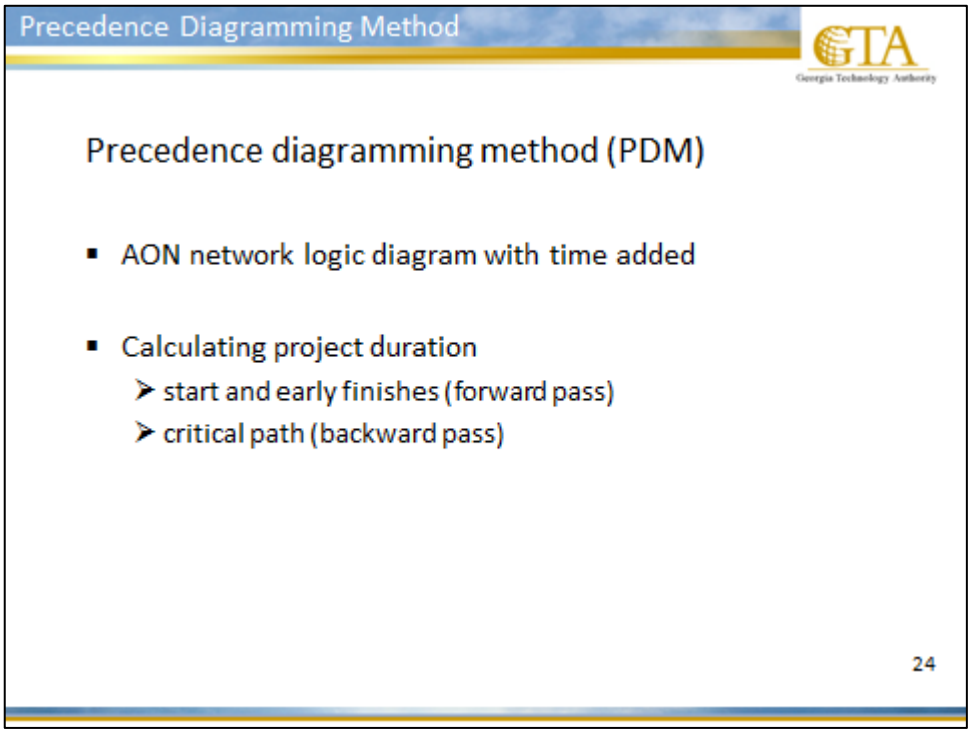
When examining any network, the relationships should be analyzed and categorized. In the example of selecting a vendor, it can be assumed that as soon as the contract requirements are formulated, the vendor may be identified. Hence this is a start-to-start relationship.

In addition, as soon as the vendor is identified, the interviews can be finished, giving a finish-to-finish relationship.

The network diagram shown on the slide does not change the logic of the preceding example, but rather presents the logic using different types of relationships:

- **finish-to-start:** this is often the default / inherent relationship that exists in logic diagrams and are presented as non-highlighted connections in the graphics
- **start-to-start**
- **finish-to-finish**

Topic 4: Precedence Diagramming Method

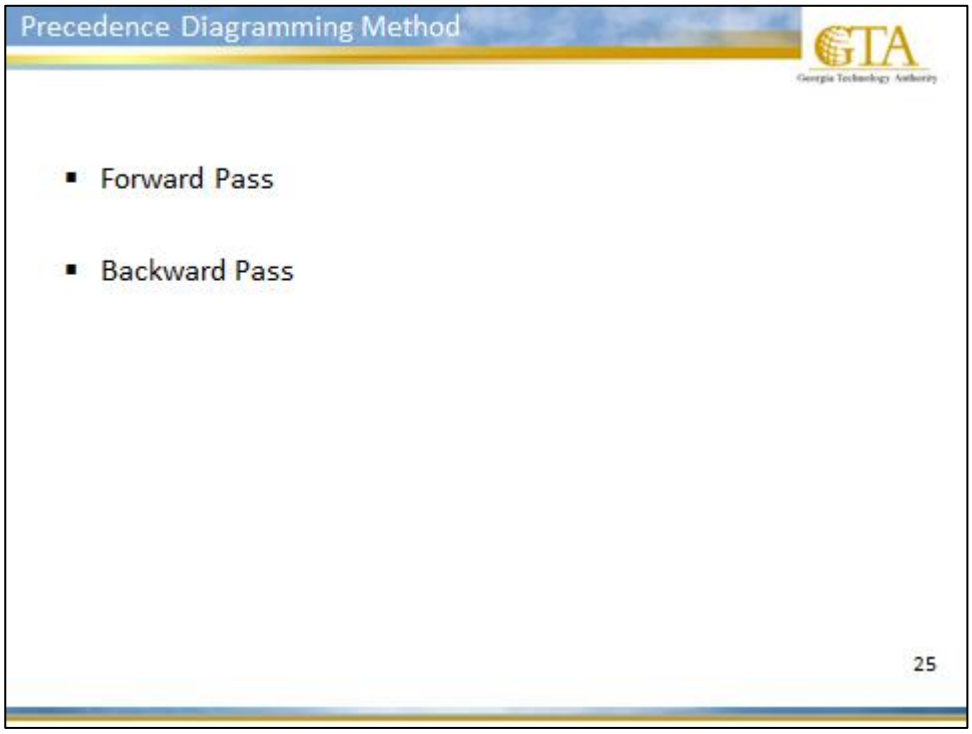


Precedence Diagramming Method

The **precedence diagramming method (PDM)** is a way of constructing a project network diagram that employs boxes or rectangles (nodes) to represent the activities and connects them with arrows that show the dependencies. Essentially, it is an AON network logic diagram with time added.

To calculate project duration using a PDM, you identify the early start and early finishes using a calculation known as forward pass. A similar calculation, known as backward pass, is used to calculate the critical path for the project with the float of each activity.

Topic 4: Precedence Diagramming Method (cont'd)



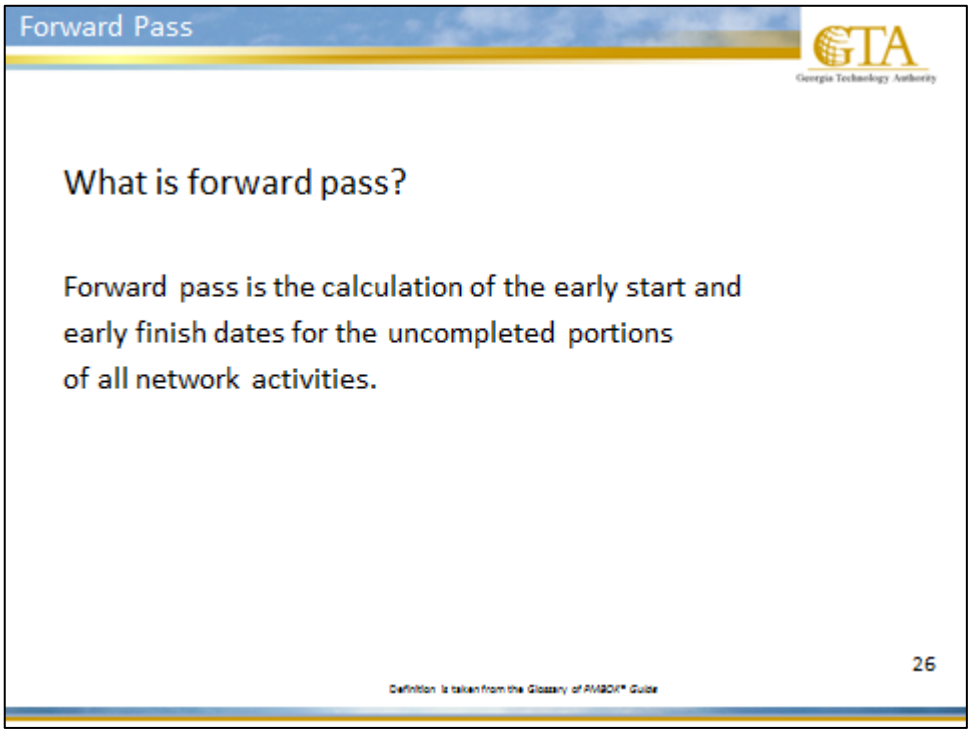
Forward Pass

Forward pass is the calculation of the early start and early finish dates for the uncompleted portions of all network activities.

Backward Pass

Backward pass is the calculation of late finish dates and late start dates for the uncompleted portions of all network activities. It is determined by working backwards through the network logic from the project's end date. The end date may be calculated in a forward pass or set by the customer or sponsor.

Topic 4: Precedence Diagramming Method (cont'd)

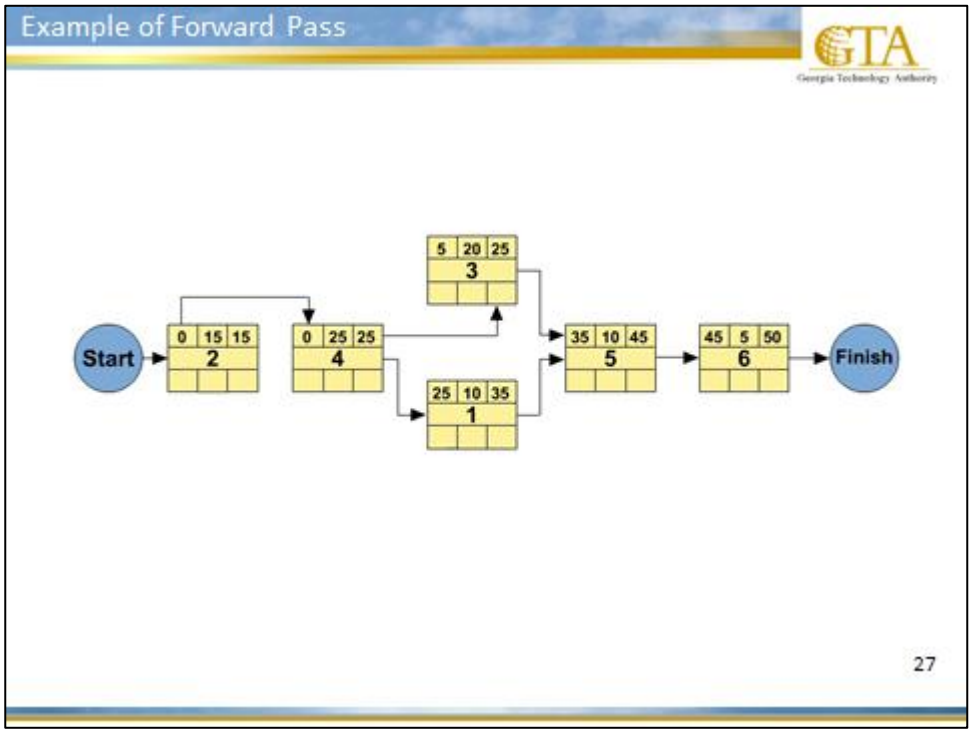


Forward Pass

- **Early Start Date:** In the critical path method, the early start date is the earliest possible point in time at which the uncompleted portions of an activity (or a project) can start, based on the network logic and any schedule constraints. Early start dates can change as the project progresses and changes are made to the project plan.

- **Early Finish Date:** In the critical path method, the early finish date is the earliest possible point in time at which the uncompleted portions of an activity (or a project) can finish, based on the network logic and any schedule constraints. Early finish dates can change as the project progresses and changes are made to the project plan.

Topic 4: Precedence Diagramming Method (cont'd)



Let's take a look at three examples of forward pass.

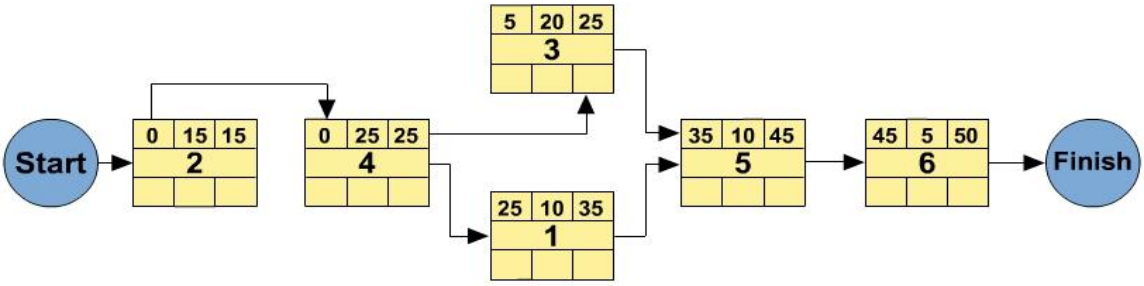
- Forward pass with a finish-to-start date: The early finish of the preceding activity becomes the early start of the succeeding activity. An example is activity 6, which has an early start that is the same as the early finish of activity 5 (i.e. 45 days).

- Forward pass with a start-to-start date: The early start of the preceding activity becomes the early start of the succeeding activity. An example is activity 4, which has an early start that is the same as the early start of activity 2 (i.e. 0 days).

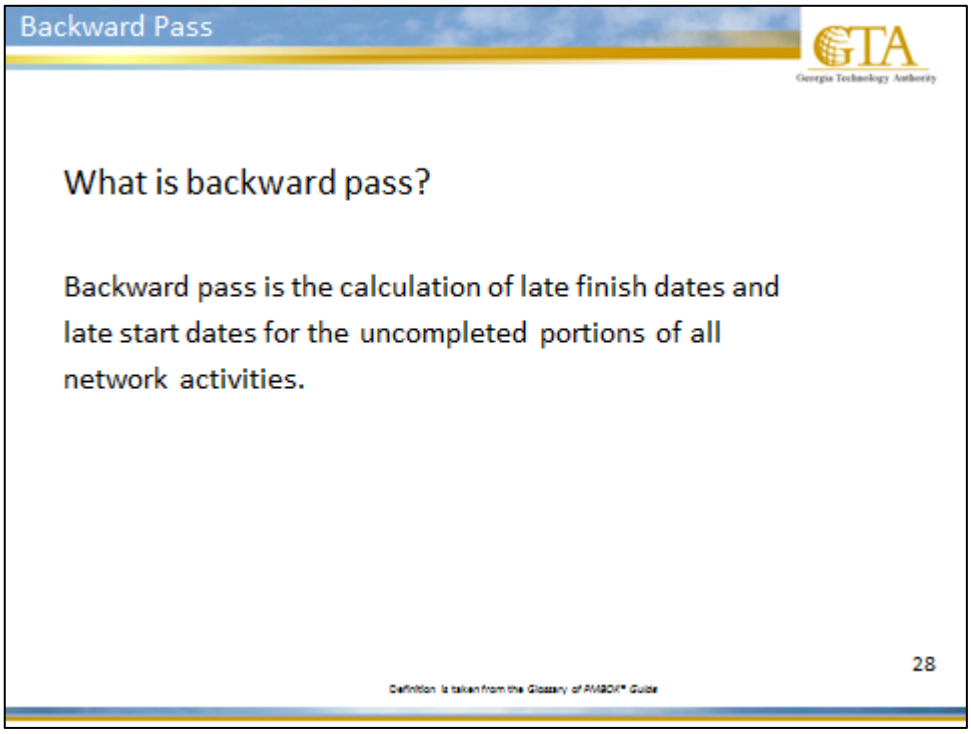
- Forward pass with a finish-to-finish date: The early finish of the preceding activity becomes the early finish of the succeeding activity. An example is activity 3, which has an early finish that is the same as the early finish of activity 4 (i.e. 25 days). In this case, the early start of activity 3 is 5 days (i.e. early finish of 25 days – duration of 20 days)

The rule for the forward pass is to always take the highest preceding constraint.

The duration for this schedule is 50 days, as illustrated on the slide, and below:



Topic 4: Precedence Diagramming Method (cont'd)

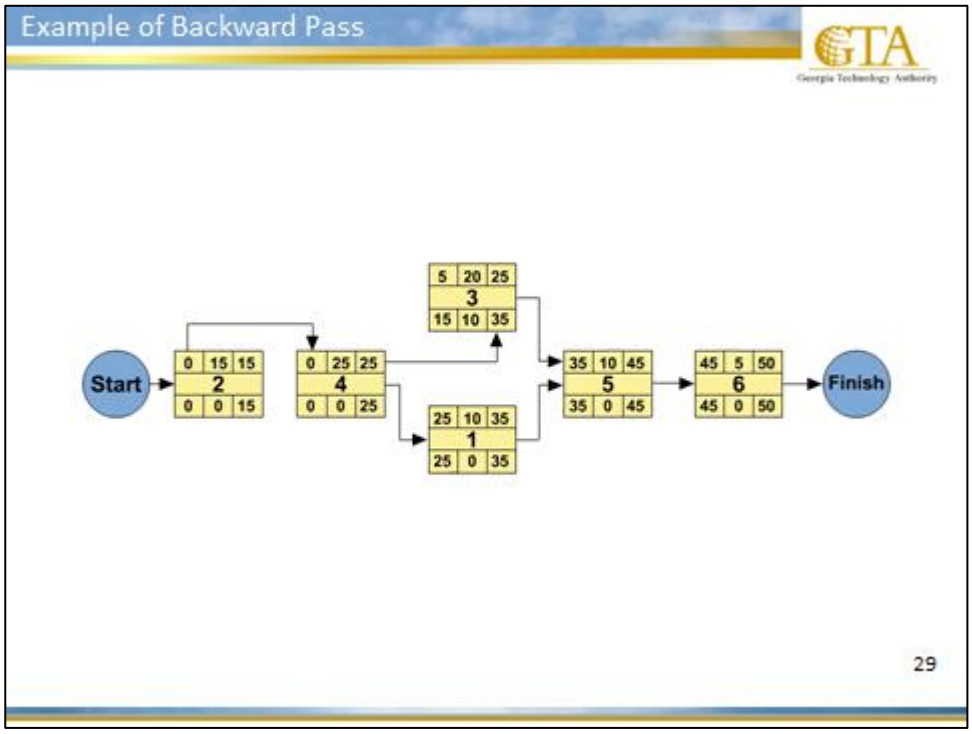


Definition is taken from the Glossary of *PMBOK® Guide*

Backward Pass

- **Late Start Date**: In the critical path method, the late start date is the latest possible point in time that an activity may begin without delaying a specified milestone (usually the project finish date).
- **Late Finish Date**: In the critical path method, the late finish date is the latest possible point in time that an activity may be completed without delaying a specified milestone (usually the project finish date).
- **Float**: Float is the amount of time that an activity may be delayed from its early start without delaying the project finish date. Float is a mathematical calculation and can change as the project progresses and changes are made to the project plan. Float is also called slack, total float, and path float.

Topic 4: Precedence Diagramming Method (cont'd)

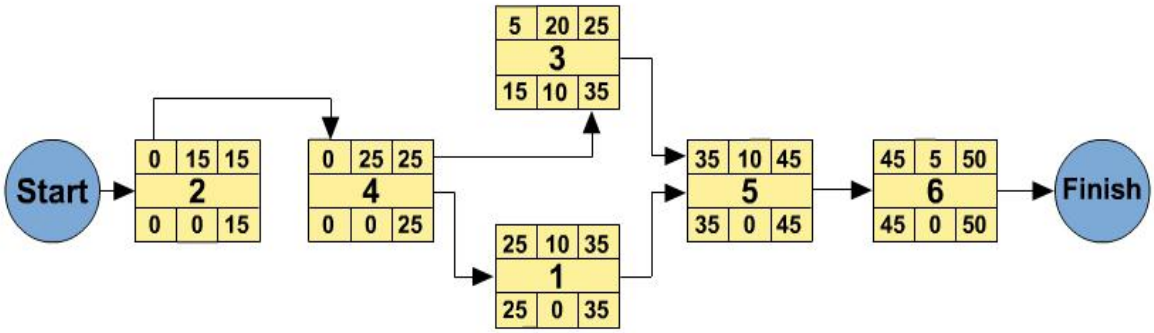


Let's take a look at three examples of backward pass.

- Backward pass with a finish-to-start date: The late start of the succeeding activity becomes the late finish of the preceding activity. An example is activity 5, which has a late finish that is the same as the late start of activity 6 (i.e. 45 days).

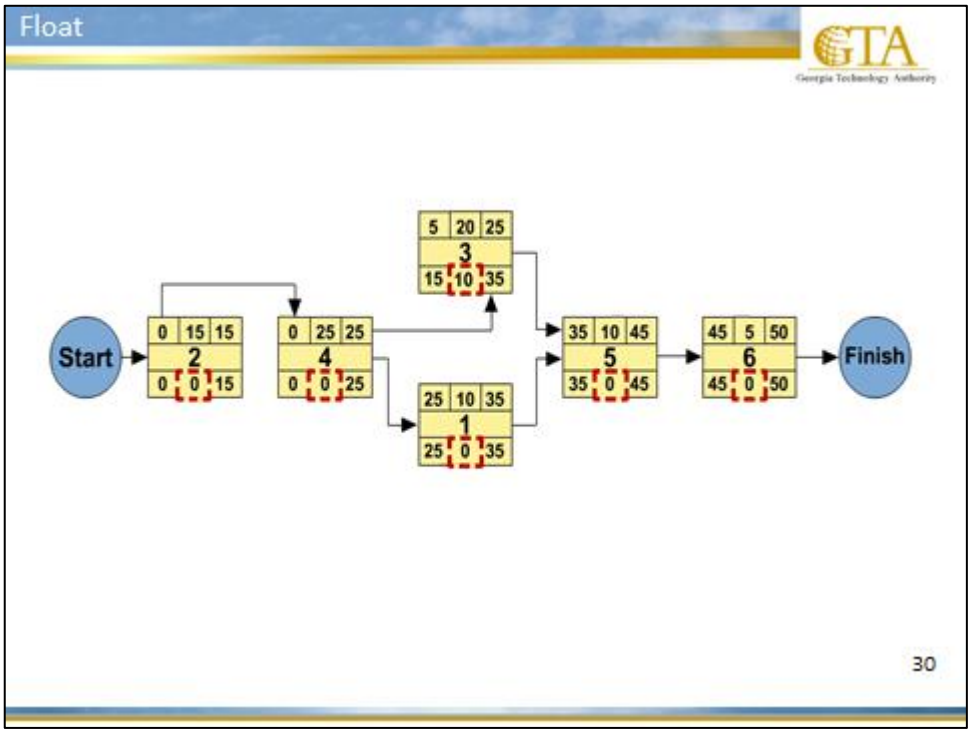
- Backward pass with a start-to-start date: The late start of the succeeding activity becomes the late start of the preceding activity. An example is activity 2, which has a late start that is the same as the late start of activity 4 (i.e. 0 days). In this case, the late finish of activity 2 is 15 days (i.e. late start of 0 days + duration of 15 days).

- Backward pass with a finish-to-finish date: The late finish of the succeeding activity becomes the late finish of the preceding activity. An example is activity 4, which has a late finish that is the same as the late start of activity 3 if the constraint with activity 1 was not present (i.e. 35 days).



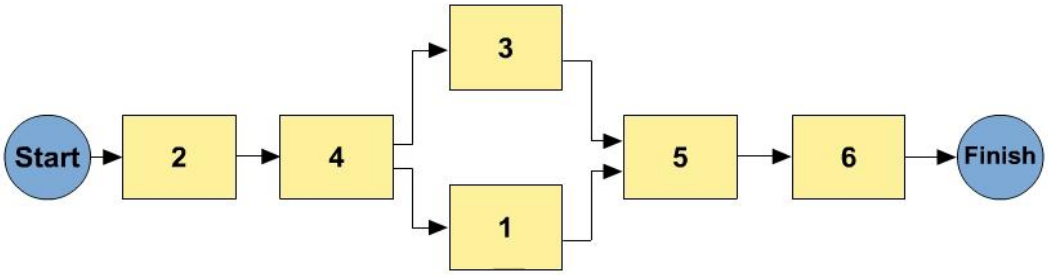
The rule for the backward pass is to always take the lowest succeeding constraint.

Topic 4: Precedence Diagramming Method (cont'd)



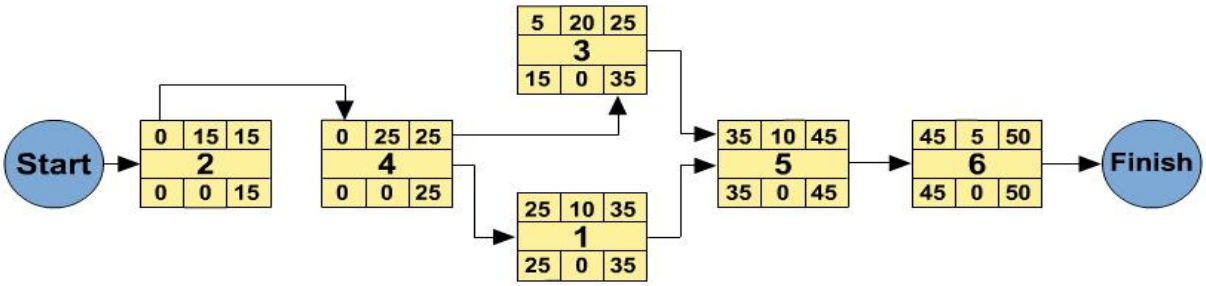
Float is calculated for each activity by identifying the difference between late starts and late finishes. If these are the same, the float is zero, which indicates a critical activity. Remember that float is the amount of time that an activity may be delayed from its early start without delaying the project finish date. For example activity 3 can be delayed 10 days without affecting the overall project duration. This float is calculated by subtracting the late start time from the early start time for activity 3.

In summary, the precedence diagramming method (PDM) combines a network logic diagram with estimated durations for each activity:



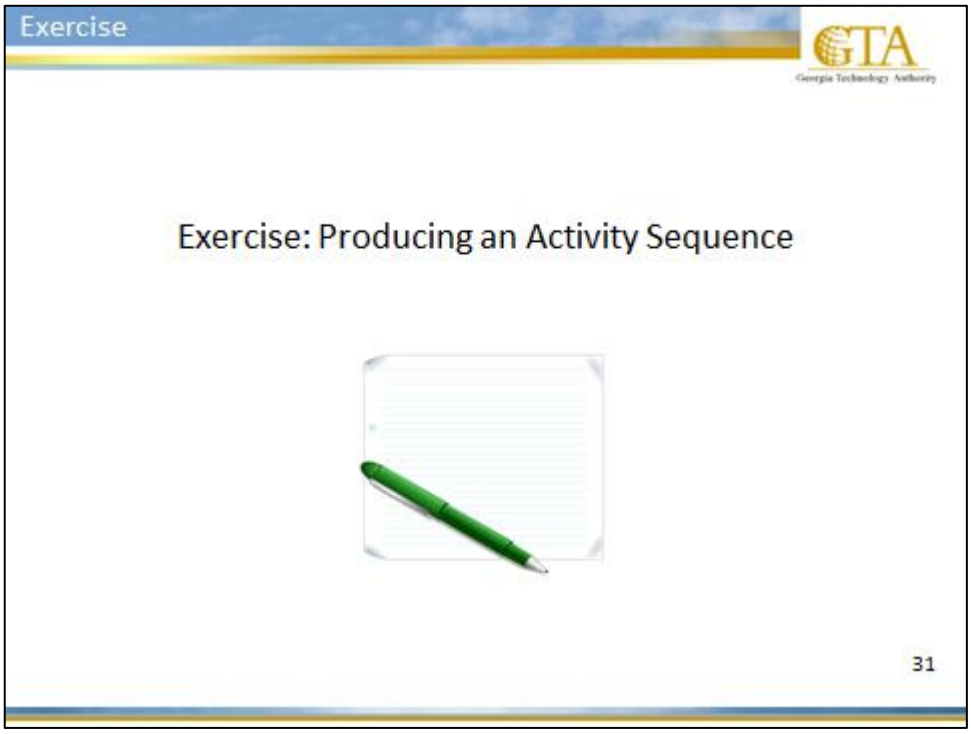
Topic 4: Precedence Diagramming Method (cont'd)

Activity Number	Activity	Activity Predecessor	Duration
1	Identify Vendors	4	10
2	Identify Contract Requirements	-	15
3	Interview Vendors	4	20
4	Advertise Proposal	2	25
5	Select Vendors	1,3	10
6	Sign Contract	5	5



The network diagram can in turn be used as the basis for a project schedule, which is part of the project management plan. As we have seen, this network template illustrates project duration of 50 days.

Topic 5: Exercise – Producing an Activity Sequence



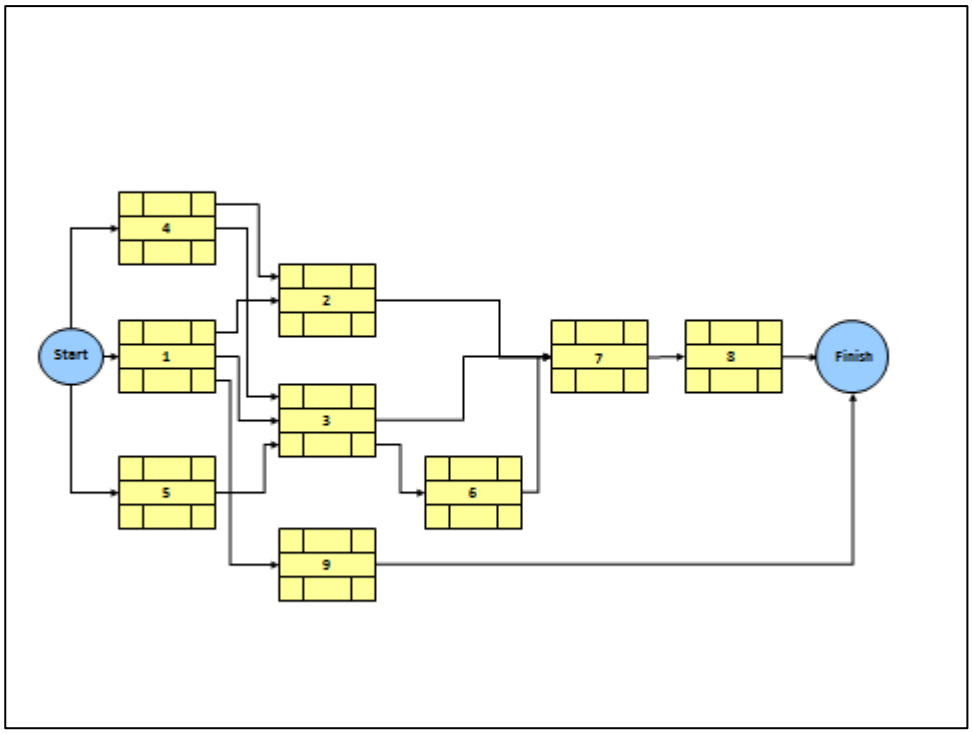
You are about to commence the planning phase for the light rail system project. Due to the large nature of the project, the project team has decided to break up the planning according to the various functions. You are requested to identify the work that would be involved in surveying and reviewing the site of the light rail system and to deliver preliminary designs that can then be used to award a fixed-price contract to a civil design vendor.

A logic diagram, sequencing the identified activities, is in place. You have been requested **to identify the project duration and the critical path given the following activity durations.**

Activity List:

Activity	Activity Predecessor	Duration (in weeks)
Identify Scope of Site Reviews	-	1
Environmental Review of Sites	1,4	3
Perform Site Surveys	1,4,5	3
Identify Vendors to Perform Surveys	-	3
Identify Rail Sites	-	2
Architecture Review	3	2
Review Surveys	2,3,6	1
Agree on Design Scope	7	6
Identify Vendors to Perform Design Contract	1	2

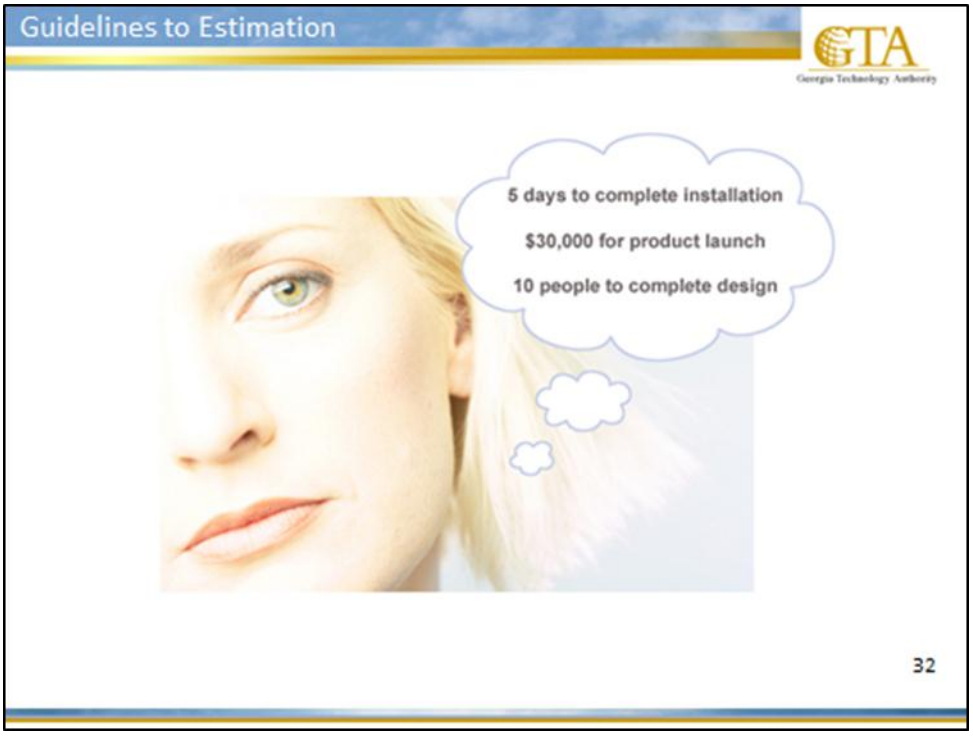
Network Diagram:



Exercise Worksheet: Forward Pass

Exercise Worksheet: Backward Pass

Topic 6: Guidelines to Estimation



Reliable estimates are a key element of a good schedule and cost baseline plan. Because there is no exact science for making estimates, it is important to have a thorough understanding of the definitions and guidelines that are available.

Estimate
An **estimate** is an assessment of the likely quantitative result of a project. It is usually applied to project costs and durations and should always include some indication of accuracy (e.g., ±x percent). An estimate is generally used with a modifier (e.g., preliminary, conceptual, feasibility), and some application areas have specific modifiers that imply particular accuracy ranges (e.g., order-of-magnitude estimate, budget estimate, and definitive estimate in engineering and construction projects).

Time Estimating
Time estimating is the process of developing project activity durations for input to schedules based on project scope and resource information. An estimate is frequently progressively elaborated and can be assumed to be progressively more accurate. Team members most familiar with the nature of a specific activity should make, or at least approve, an estimate.

Elapsed time may need to be factored into estimates for the number of work periods required to complete an activity. For example, if concrete curing for a construction project requires four days of elapsed time, it may require from two to four work periods, based on a) which day of the week it begins, and b) whether weekend days are treated as work periods.

This issue can be handled using computerized scheduling software that employs alternative work-period calendars.

Topic 6: Guidelines to Estimation (cont'd)

Cost Estimating

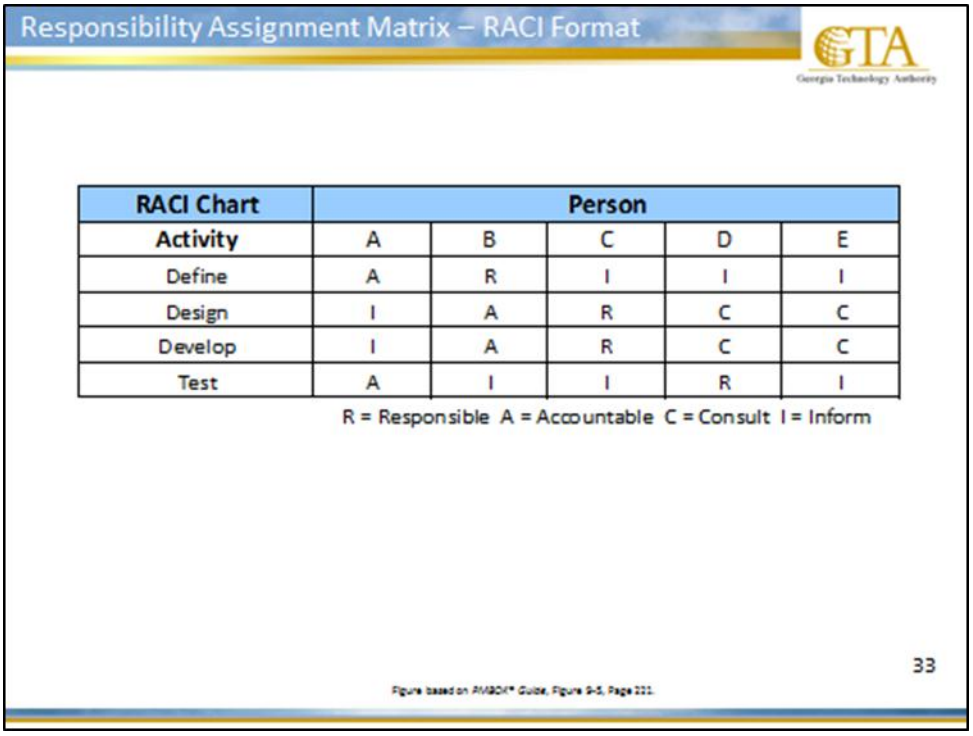
Cost estimating is the process of developing an approximation (estimate) of the costs of the resources required to complete project activities. This process includes identifying and considering various costing alternatives. For example, the cost-estimating process must consider whether additional work during a project's design phase will be offset by the expected savings in the production phase of the project.

A distinction should be drawn between cost and price estimating:

- cost estimating involves developing an assessment of the likely quantitative result of a project – the cost of providing a product or service

- price estimating is a business decision that uses the cost estimate as one of many factors to decide how much to charge for the product or service

Topic 7: Activity Resource Requirements



RACI Chart	Person				
Activity	A	B	C	D	E
Define	A	R	I	I	I
Design	I	A	R	C	C
Develop	I	A	R	C	C
Test	A	I	I	R	I

R = Responsible A = Accountable C = Consult I = Inform

Figure based on PMBOK® Guide, Figure 9-5, Page 221.

Activity Resource Estimating

Activity resource estimating is the process of determining what physical resources (people, equipment, and materials) are required for a project, what quantities of each resource should be used, and when the resource will be available to perform project activities. This process must be closely coordinated with cost estimating.

Role and Responsibility Assignments

At the outset of any project, project roles (who does what) and responsibilities (who decides what) need to be assigned to the appropriate project stakeholders. Project roles and responsibilities, which may vary over time, should be closely linked to the project scope definition. A **responsibility assignment matrix (RAM)**, as illustrated on the slide, is frequently used to make this link. RAMs are developed at various levels for projects. For example, a high-level RAM defines which group or unit is responsible for each component of the work breakdown structure, whereas lower-level RAMs are used within the group to assign roles and responsibilities for specific activities to individual members of the group.

Resource Availability

Up-to-date and accurate knowledge about resource availability is necessary for activity resource estimating. Assumptions made about the availability of each resource – such as the amount and type of resource, its location, and the time periods of availability – should be documented. Resource descriptions can vary over the course of a project. For example, in the early phases of an engineering design project, available people resources may include large numbers of junior and senior engineers, with the pool limited in later stages of the project to individuals who have gained specific experience in the earlier phases.

Activity Resource Requirements

The output of the activity resource estimating process is a description of **activity resource requirements** – the types and quantities of resources needed for each activity in a work package. The estimated resources for each work package are determined by aggregating these requirements. Resources requirements for higher-level components of the work breakdown structure can then be worked out based on the lower-level values, with the schedule development process determining when the resources are needed (see lesson 3 for a discussion of the schedule development process).

Topic 7: Activity Resource Requirements (cont'd)

Government HR Systems
The civil service distinguishes **government human capital management** from that in the private sector (*Government Extension to A Guide to the PMBOK® Guide Third Edition*; Chapter 9). In an elected government, policies are likely to change from one election to another. Equally, the availability of project resources may be affected by the tenure of **elected officials** or **appointed civil servants**.

Civil servants hold office from one administration to another, and remain politically neutral. As a guarantee of this neutrality, they have tenure in their positions. Consequently, project managers in the civil service do not usually choose their staff - the project manager must create a viable performing team from what he or she is given. Thus project managers need to master teambuilding skills, understand the different personality types, and motivate these individuals to produce a functioning team.

Lesson 2: Summary

The lesson is now completed and the following topics have been covered:

Topic 1: Logic Diagrams

- The first step in the planning process is to determine the logical flow of all project activities from the beginning to the end of the project.

- This is done using a **logic diagram** where each activity has a **successor** and a **predecessor**, collectively known as dependencies.

- The logical dependencies can be mandatory, discretionary, or external and is the starting point in developing a project schedule

From this topic you should **take away** the following points:

- a logic diagram represents the connection between a WBS (i.e. work packages) and a schedule. It is the sequence of work packages (also referred to as activities) that is the backbone of any schedule.
- to construct a logic diagram, a project manager must determine the flow of all project activities, taking logical dependencies into consideration

Topic 2: Activity Sequencing Templates (Activity on Node)

- Activity-on-node (AON) is the most common activity sequencing method used.
    - **AON** is a diagramming method that uses **nodes to represent activities** and connects them with arrows that show dependencies.
    - It defines the paths and activities that are critical to the project, and is associated with the critical path method (CPM).
    - AON includes four types of dependencies or precedence relationships**: finish-to-start, finish-to-finish, start-to-start, start-to-finish.**
    - An AON is the basis for the precedence diagramming method

- The precedence diagramming method is an intuitive and popular means of sequencing and scheduling activities

From this topic you should **take away** the following points:

- the **AON** diagramming method can be represented using a **network template** and is known as the **precedence diagramming method**

Topic 3: Activity Relationships for Precedence Diagramming Methods

- The **finish-to-start** relationship is usually the default / inherent relationship that exist in logic diagrams.
- The other typical relationships are **start-to-start** and **finish-to-finish** and are used to shorten project durations by allowing activities to occur in parallel. The other method is **start-to-finish** which is not frequently used.

From this topic you should **take away** the following point:

- several different types of relationships are used in sequencing activities including finish-to-start, start-to-start, finish-to-finish, and start-to-finish

Lesson 2: Summary (cont'd)

Topic 4: Precedence Diagramming Method

- The **precedence diagramming method (PDM)** combines a network logic diagram with estimated durations for each activity. Two algorithms are used to calculation the project duration:
    - **Forward pass** is the calculation of the early start and early finish dates for the uncompleted portions of all network activities.
    - **Backward Pass** is the calculation of late finish dates and late start dates for the uncompleted portions of all network activities.

  The **float** is the amount of time that an activity may be delayed from its early start without delaying the project finish date.

From this topic you should **take away** the following points:

- forward pass and backward pass are algorithms used to calculate early starts, early finishes, late starts and late finishes for each activity in a network diagram
- once the various durations for an activity are calculated, a project manager can then construct a project sequence using the precedence diagramming template and identify activity floats

Topic 5: Producing an Activity Sequence

- An exercise is presented to demonstrate the production of an activity sequence. It uses an activity sequence from the Georgia Light Rail project

From this topic you should **take away** the following points:

- to construct a project sequence, a project manager uses the precedence diagramming template (for an example of the template, see Tools & Templates handout)

Topic 6: Guidelines to Estimation

- An **estimate** is an assessment of the likely cost or time result of a project.
    - **Time estimating** is the process of developing project activity durations for input to schedules based on project scope and resource information
    - **Cost estimating** is the process of developing an approximation (estimate) of the costs of the resources required to complete project activities. This process includes identifying and considering various costing alternatives.

From this topic you should **take away** the following point:

- estimation is a significant element of effective planning, scheduling and control, and is applicable to time and cost management

Lesson 2: Summary (cont'd)

Topic 7: Activity Resource Requirements

- **Activity resource estimating** is the process of determining what physical resources are required for a project, what quantities of each resource should be used, and when the resource will be available to perform project activities.

- The output of the activity resource estimating process is a description of **activity resource requirements** – the types and quantities of resources needed for each activity in a work package.

- Up-to-date and accurate knowledge about **resource availability** is necessary for activity resource estimating. Assumptions made about the availability of each resource should be documented and resource descriptions can vary over the course of a project.

From this topic you should **take away** the following points:

- a responsibility assignment matrix is a means of identifying roles and assigning responsibilities for resources (for a sample responsibility assignment matrix, see Tools & Templates handout)
- effective identification of resources is a key element in establishing budgets and schedules

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Lesson 3: Schedule Development

Topic 1: Developing a Project Schedule

Topic 2: Critical Path Method (CPM)

Topic 3: Leads and Lags

Topic 4: Schedule Compression

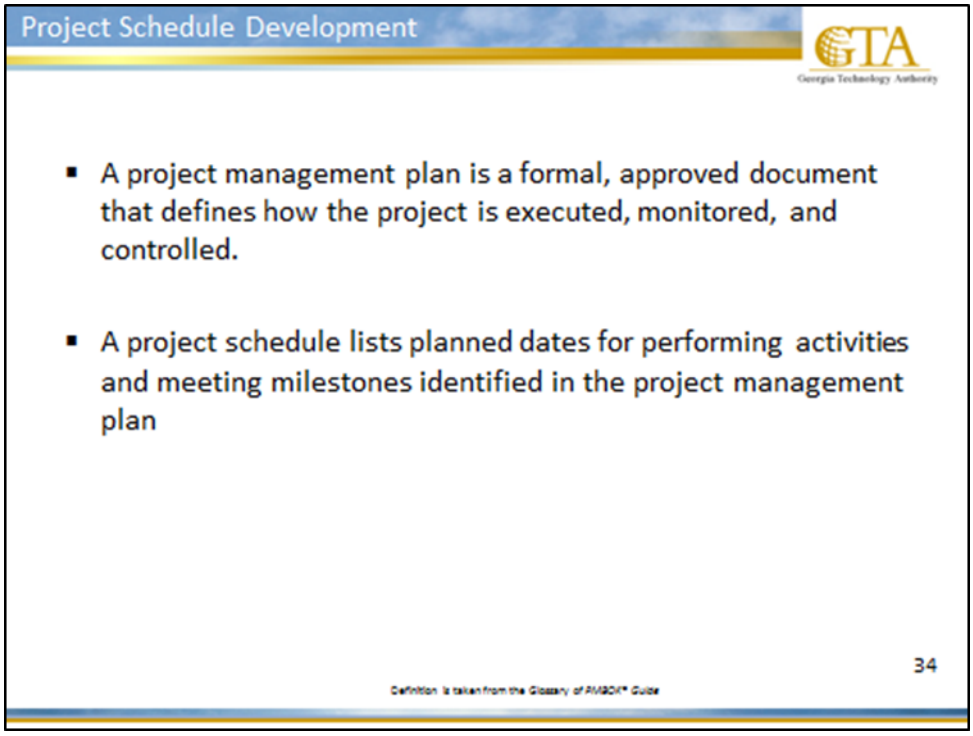
Topic 5: Resource Leveling

Student learning objectives

After completing this lesson, you should be able to

- explain how critical path methodology is used to develop project schedules
- describe the difference between a lead and a lag
- describe the different components of a project schedule and the application of calendar time
- explain schedule compression and describe how it is used in project management planning
- define resource leveling algorithms and how they are used in project management planning
- use different schedule development tools and techniques to deliver a project schedule

Topic 1: Developing a Project Schedule



Definition is taken from the Glossary of *PMBOK® Guide*

Project Management Plan versus Project Schedule

A **project management plan** is a formal, approved document used to manage project execution and control. The primary use of the project management plan is to document all plans and facilitate communication among stakeholders with approved scope, cost and schedule baselines. The components of a project management plan include:

- project charter
- project scope statement
- work breakdown structure
- scope management plan
- master project schedule
- schedule management plan
- project cost baseline
- cost management plan
- project risk management plan
- project quality management plan
- procurement management plan
- project communication management plan
- project change management plan
- project staffing management plan

A **project schedule** lists planned dates for performing activities and meeting milestones identified in the project management plan.

Project Schedule Development

Developing a project schedule involves analyzing project activity sequences, durations, and resource requirements to determine start and finish dates for project activities. Start and finish dates must be realistic if the project is to finish as scheduled.

Topic 1: Developing a Project Schedule (cont'd)

The main inputs in the schedule development process are calendars and constraints (including constraints specific to government projects).

- **Calendars**

  Project and resource calendars identify periods when work can take place.

  Project calendars affect all resources – for example, some projects take place only during normal business hours, whereas other projects include day and night shifts.

  Resource calendars affect a specific resource or category of resources – for example, a project team member may be on vacation or certain categories of workers may only be available on certain days of the week.

  Application of calendars to project schedules is accomplished through the use of software applications, where the project is allocating resources and activities. With the Georgia Light Rail project, it may be that project resources will not work weekends or public holidays. This is reflected in the project schedule using a calendar of available and non-available times.

- **Constraints**

  Constraints limit a project management team's options. The two main categories of time constraints considered during schedule development are imposed dates and key events or major milestones.

  - Imposed dates

    These dates are used to restrict project start or finish dates so that they occur either no earlier than a specified date or no later than a specified date. The "start no earlier than" and the "finish no later than" constraints are the most commonly used imposed dates. Situations where imposed dates impact project schedules are weather restrictions on outdoor activities or restricted delivery dates for materials from third parties.

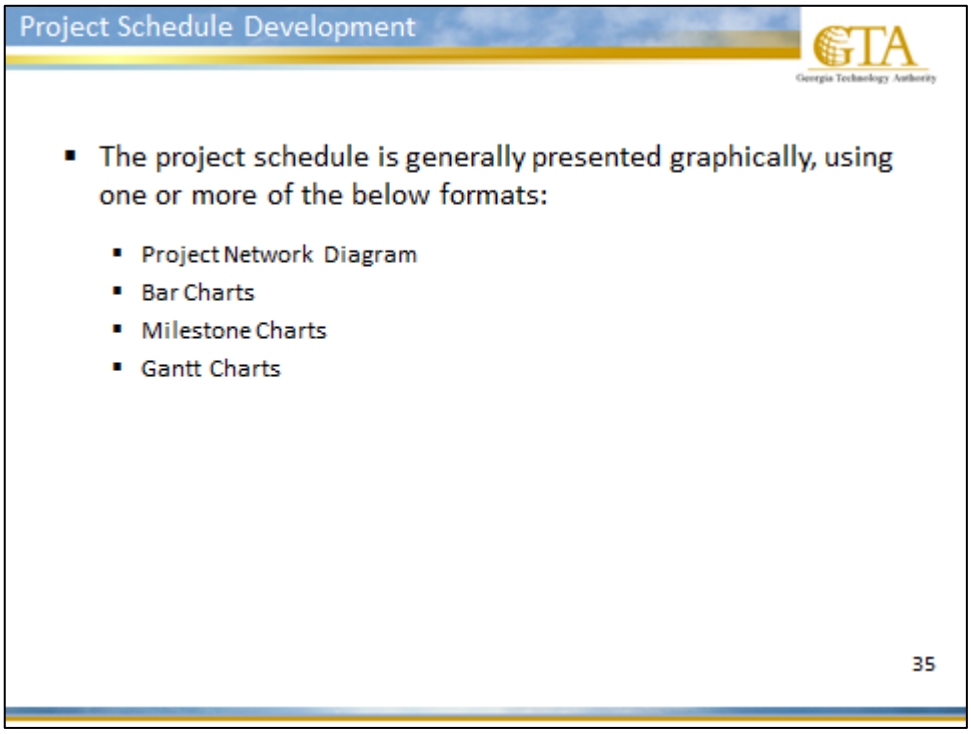
  - Key events or major milestones

    These are significant project events that mark the completion of certain deliverables by a specified date. Project stakeholders often request that such dates be included in the schedule. Once scheduled, these dates become expected and may only be changed with great difficulty.

    Milestones are often used to indicate interfaces with work that is outside – but linked to – the scope of the project.

    Government projects face another constraint in the form of the annual budget cycle (*Government Extension to the PMBOK® Guide Third Edition*; p40). Elected officials typically approve budgets that last for one fiscal year at a time. If there are "use it or lose it" provisions that require funds to be spent by the end of a fiscal year, any project delays can cause the loss of funding if work moves from one fiscal year into the next.

Topic 1: Developing a Project Schedule (cont'd)



Project Schedule

The **project schedule** is the main output from schedule development and includes at least the planned start and expected finish dates for each project activity. The project schedule, which is a preliminary schedule until resource assignments have been confirmed, is presented in summary form (the master schedule) or in detail.

The project schedule is generally presented graphically, using one or more of the following formats:

- project network diagrams
- bar charts
- milestone charts
- Gantt charts

Topic 1: Developing a Project Schedule (cont'd)

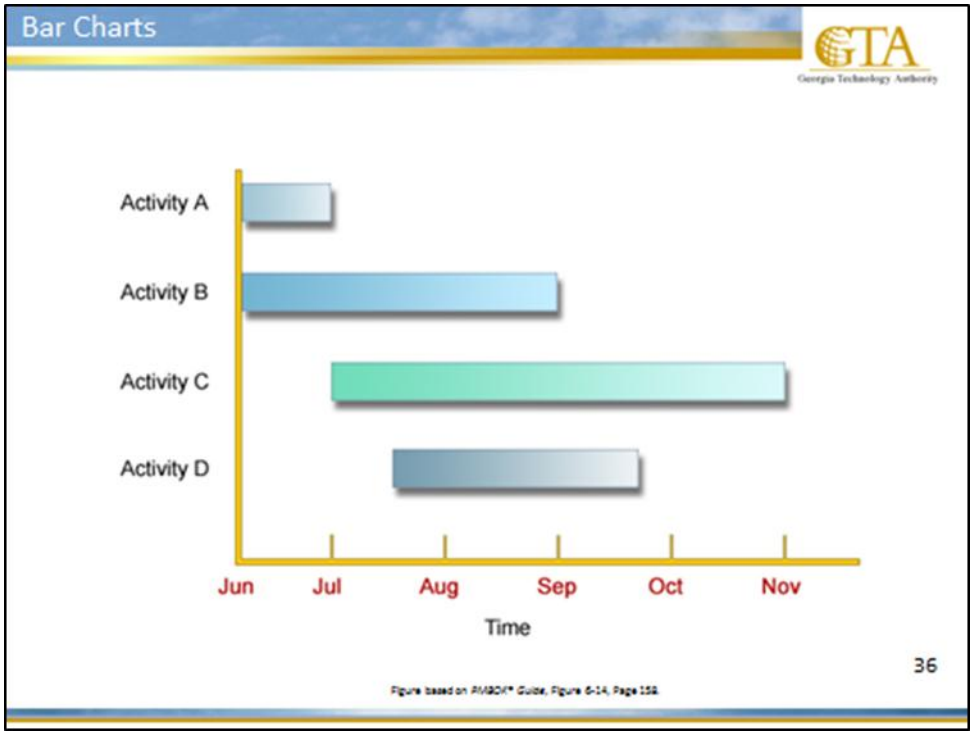


Figure based on PMBOK® Guide, Figure 6-14, Page 158.

Bar charts indicate activity start and end dates, as well as expected durations. Bar charts are easy to read and are often used in management presentations.

Topic 1: Developing a Project Schedule (cont'd)

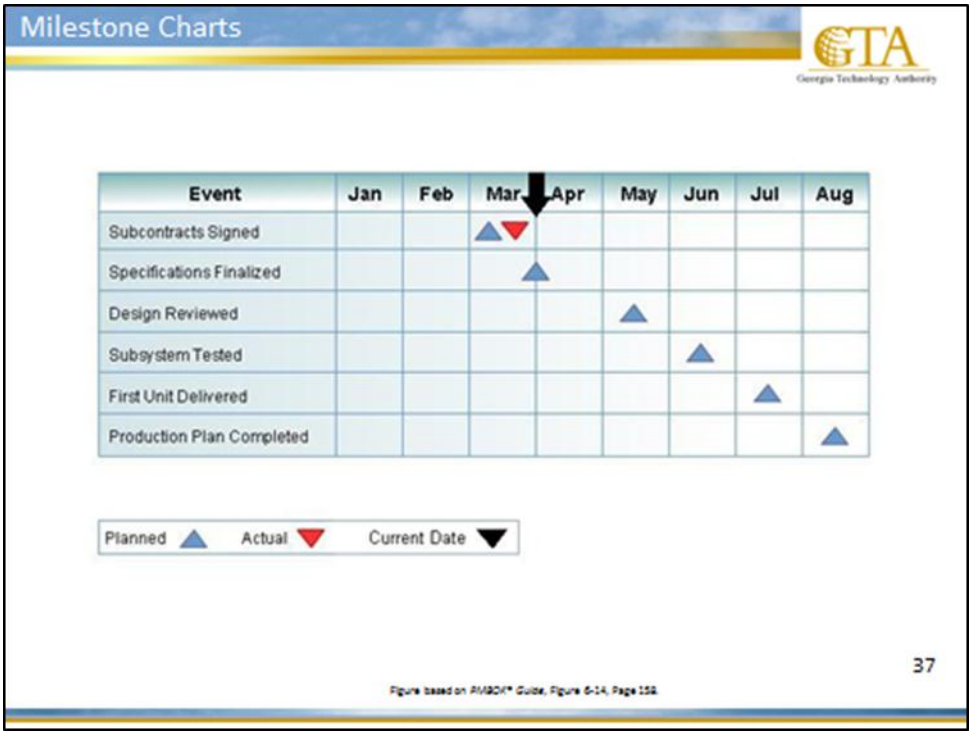


Figure based on PMBOK® Guide, Figure 6-14, Page 158.

Milestone charts are similar to bar charts, but they only show the scheduled start or completion of major deliverables and key external interfaces.

A milestone is an activity with zero duration. Milestones are generally associated with significant events, such as

- project start
- project finish
- deliverables or reports
- availability of product items, etc.

A milestone should be associated with significant deliverables or events in a project.

Topic 1: Developing a Project Schedule (cont'd)

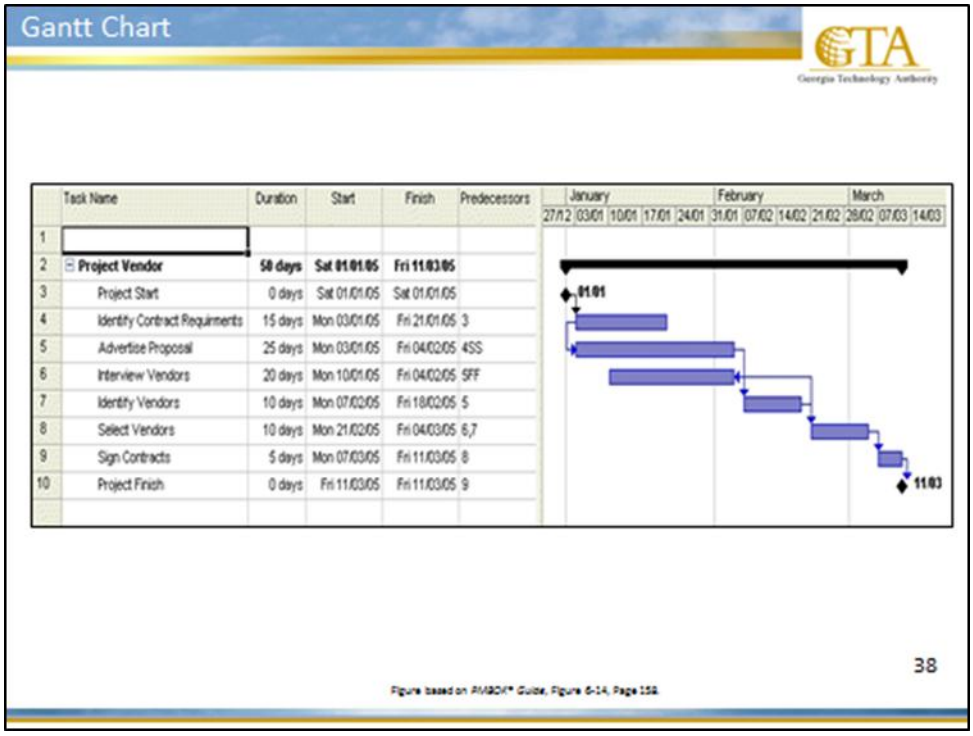


Figure based on PMBOK® Guide, Figure 6-14, Page 158.

Bar charts and milestone charts are subsets of the Gantt chart.

The **Gantt chart** is connected to the WBS as both reflect project activities. The WBS presents work packages, which can be decomposed further into specific project activities. A Gantt chart presents these project activities in a sequenced and logical fashion, with associated time and resource estimates.

A Gantt chart is an ideal way of presenting a network schedule. The slide illustrates a project network diagram with date information added.

Project network diagrams generally show both the activity dependencies and the project's critical path activities.

Topic 2: Critical Path Method (CPM)

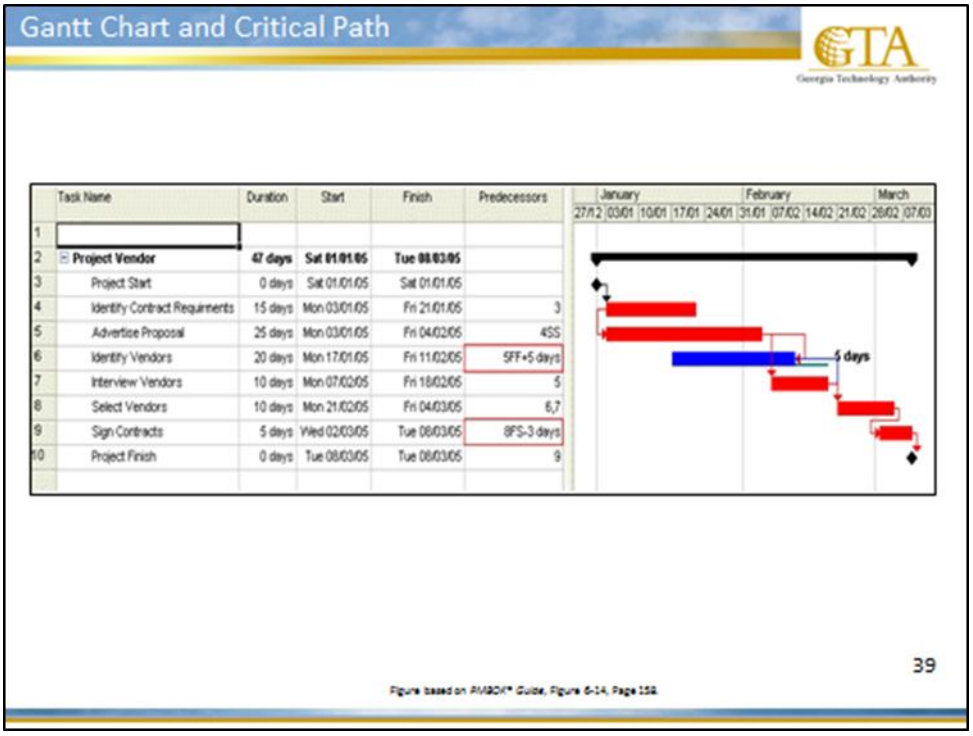


Figure based on PMBOK® Guide, Figure 6-14, Page 158.

The Critical Path Method (CPM)

The **critical path** is the series of activities that determines the duration of a project. In a deterministic model, the critical path is defined as those activities with float less than or equal to a specified value, often zero. It is the longest path through the project.

Critical path method (CPM) is a network analysis technique used to predict project duration by analyzing which sequence of activities (which path) has the least amount of scheduling flexibility (the least amount of float). Early dates are calculated by means of a forward pass, using a specified start date. Late dates are calculated by means of a backward pass, starting from a specified completion date (usually the forward pass-calculated project early finish date).

CPM calculates the theoretical early and late start and finish times for all project activities without taking into account resource limitations. The resulting times indicate the time periods within which the activity could be scheduled given resource limits and other known constraints. Calculated early and late times are the same on the critical path because float is zero. On non-critical paths, the schedule flexibility is called total float and is calculated using the difference between early and late times.

Topic 2: Critical Path Method (CPM) (cont'd)

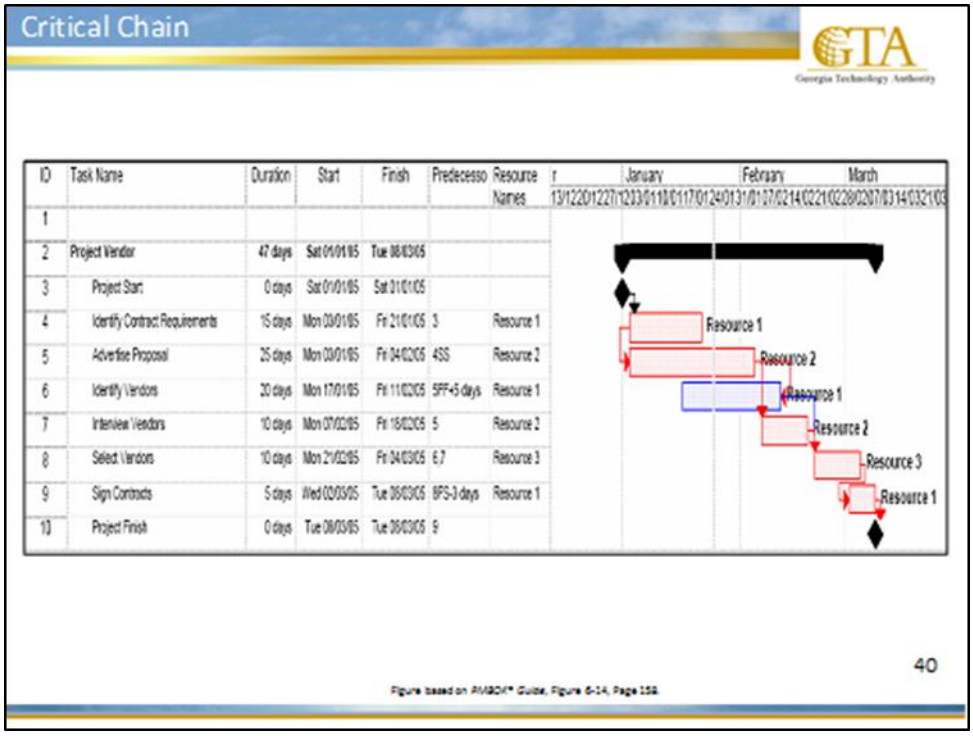


Figure based on PMBOK® Guide, Figure 6-14, Page 158.

Critical Chain

The **schedule network** is initially built using activity logic, required dependencies, and defined constraints. Then the critical path is calculated and identified. Resource availability is assigned, and the resource-driven result is then determined. This result often alters the critical path, and this change must be managed.

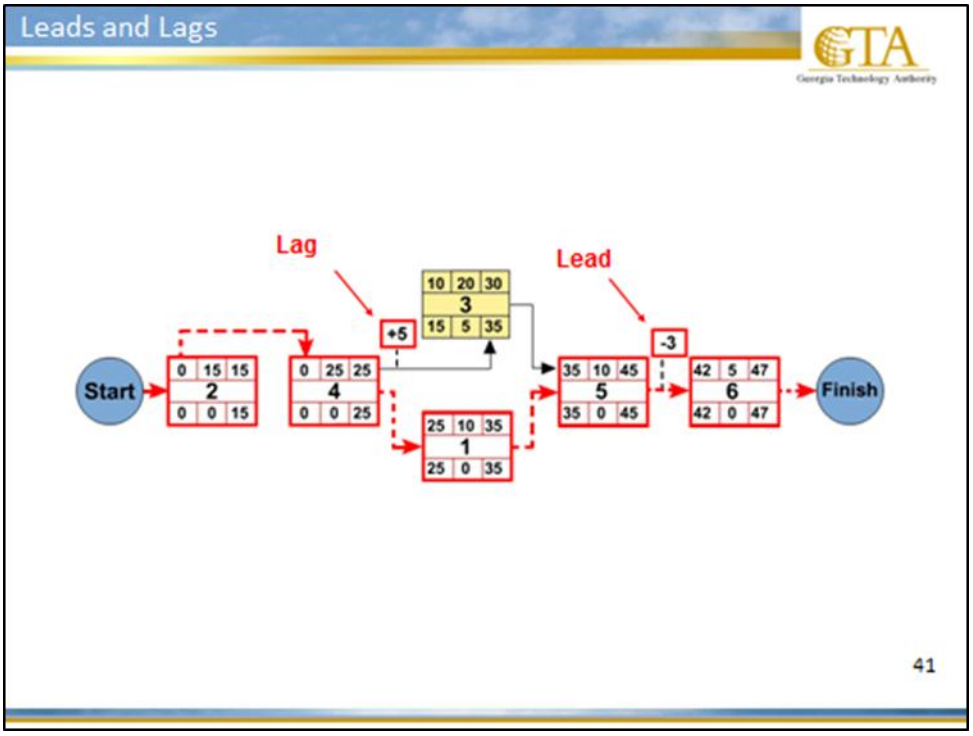
The **critical chain** is defined as the longest chain of dependent events where the dependency is either task or resource related. This is the longest chain that is most likely to impact the overall duration of the project. Critical chain is about understanding how resources and tasks can impact on project durations, and evaluating potential time reductions given these interactions.

If resource availability is not a constraint, then a project's critical chain becomes the same as its critical path. It aggregates the largest amount of contingency added to any project in buffers, to protect due-date performance.

To avoid wasting this contingency through bad multitasking or poorly synchronized integration, critical chain has evolved into a management style where project planners attempt to understand the behavioral aspects of the schedule and attempt to implement new behaviors to make significant time reductions. It uses buffer management instead of earned value management to assess the performance of a project.

Earned value management technique does not distinguish progress on the critical path. Whereas the critical chain methodology is all about understand the optimal fit of time, contingency and resourcing for the project schedule.

Topic 3: Leads and Lags



Leads and Lags

A **lead** is a modification of a logical relationship that allows an acceleration of the successor task. For example, in a finish-to-start dependency with a ten-day lead, the successor activity can start ten days before the predecessor has finished.

A **lag** is a modification of a logical relationship that directs a delay in the successor task. For example, in a finish-to-start dependency with a ten-day lag, the successor activity cannot start until ten days after the predecessor has finished. Such a lag might be required between ordering a piece of equipment and installing or using it.

In the example shown on the slide, the project team decides on the following after analyzing the project network:

- a five-day lag is required between “interviewing vendors” and “advertising the proposal”. This allows for any late applications to arrive.
- a three-day lead is identified between “signing the contract” and “selecting vendors” as the project team believes that preparatory work can be started on the contract during the time of selecting the vendors.

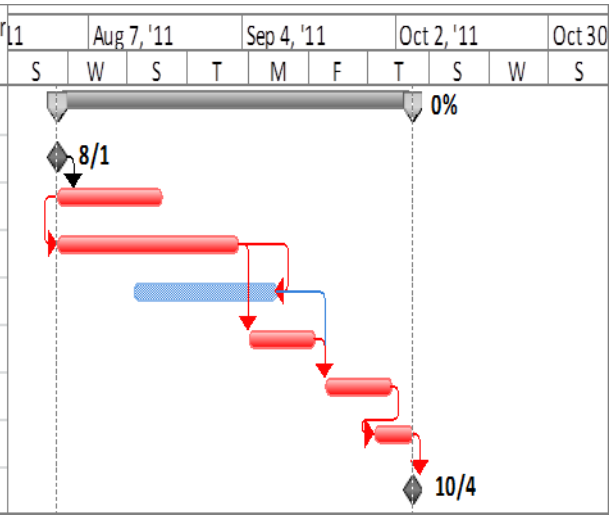
Topic 3: Leads and Lags (cont'd)

Activity Number	Activity	Duration	Leads / Lags
1	Identify Vendors	10	-
2	Identify Contract Requirements	15	-
3	Interview Vendors	20	5
4	Advertise Proposal	25	-
5	Select Vendors	10	-
6	Sign Contract	5	-3

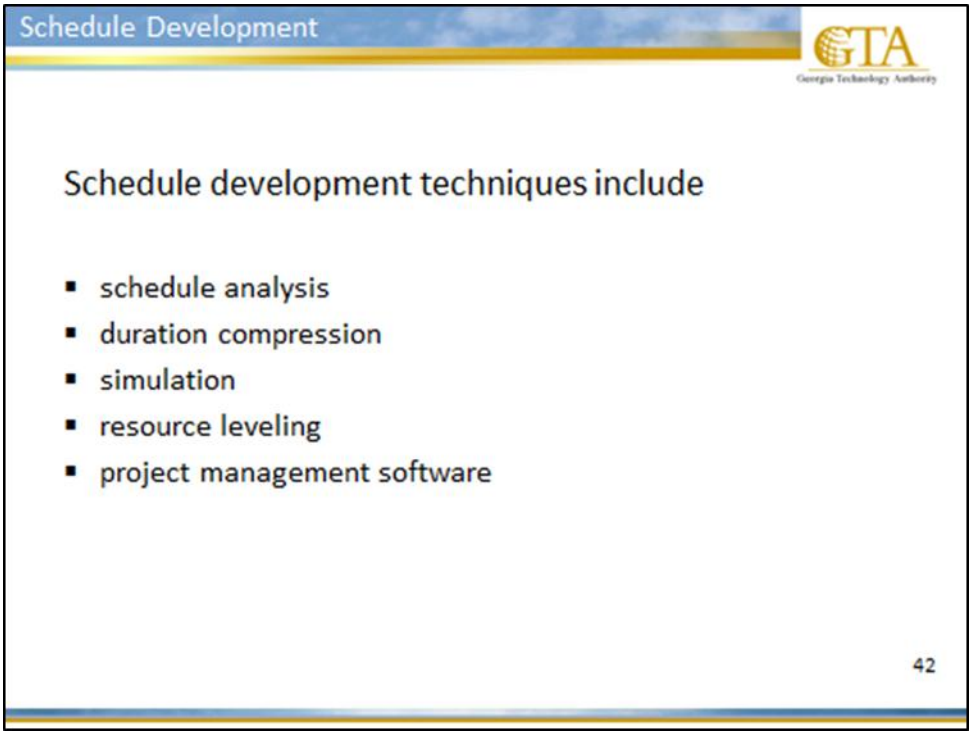
The activity list (showing leads and lags) can be transferred into a network diagram with project duration of 47 days (see slide).

The **Gantt chart** displayed below is the equivalent of the network diagram with the leads and lags.

ID	Task Name	Duration	Start	Finish	Predecessor
0	**Project Vendor**	**47 days**	**8/1/11**	**10/4/11**	
1	Project Start	0 days	8/1/11	8/1/11	
2	Identify Contract Requiremen	15 days	8/1/11	8/19/11	1
3	Advertise Proposal	25 days	8/1/11	9/2/11	2SS
4	Identify Vendors	20 days	8/15/11	9/9/11	3FF+5 days
5	Interview Vendors	10 days	9/5/11	9/16/11	3
6	Select Vendors	10 days	9/19/11	9/30/11	4,5
7	Sign Contracts	5 days	9/28/11	10/4/11	6FS-3 days
8	Project Finish	0 days	10/4/11	10/4/11	7



Topic 4: Schedule Development



Schedule development entails determining the start and finish dates for project activities. It involves analyzing activity sequences, activity durations, and resource requirements to create an accurate project schedule.

It makes use of the following techniques:

- **schedule analysis** – used to calculate the theoretical time period of the project, which is the early start and finish dates of all project activities given resource limitations and other known constraints

- **duration compression** – a special form of mathematical analysis that tries to shorten the project schedule without changing the project scope. There are two major duration compression techniques, crashing and fast tracking:

    - **crashing** involves analyzing cost and schedule tradeoffs to determine how, if at all, the greatest amount of compression can be obtained for the least incremental cost

    - **fast tracking** involves conducting activities in parallel that would normally be done in sequence (e.g., starting to write code on a software project before the design is complete)

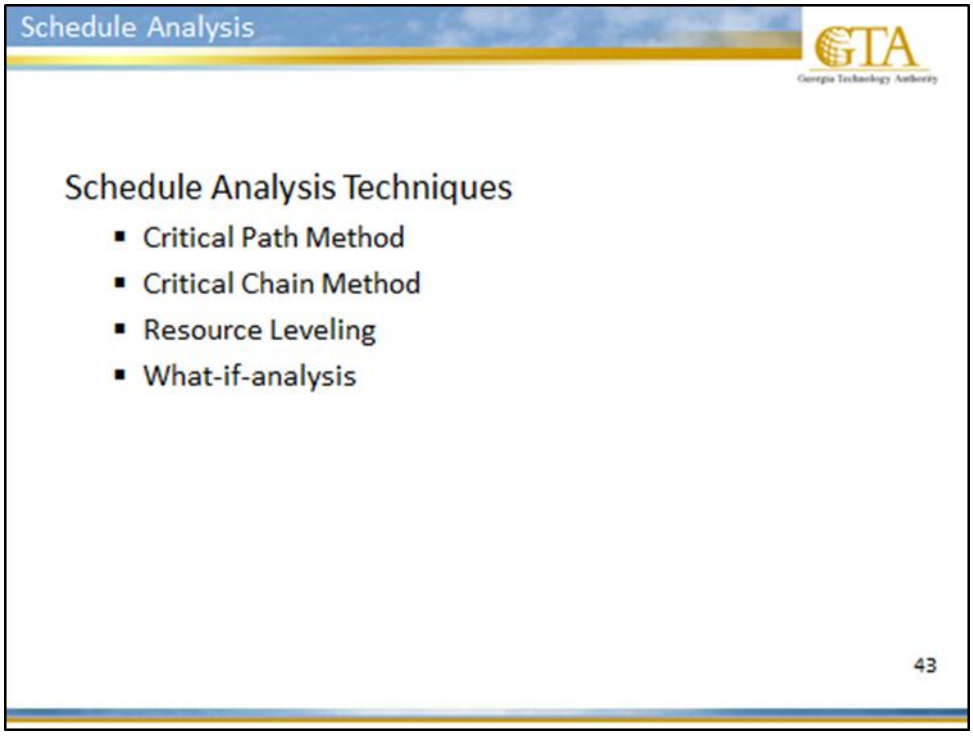
- **simulation** – used to calculate multiple project durations with different sets of activity assumptions

- **resource leveling** – used to balance resource allocation (e.g. allocating additional resources to a project to ensure that its duration is in line with the original estimate)

- **project management software** – used to help automate certain tasks, for example the calculation of mathematical analysis, and to help create alternative schedules quickly

Schedule compression uses many of these techniques.

Topic 4: Schedule Development (cont'd)

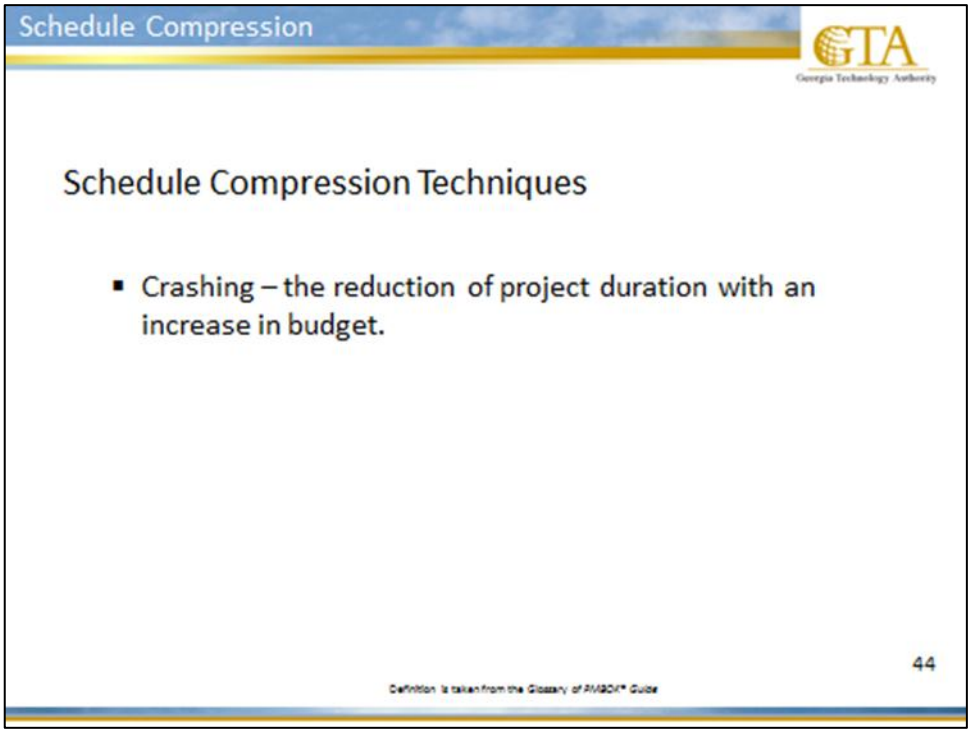


The most widely known schedule analysis techniques are

- **critical path method (CPM)**
  CPM calculates a single, deterministic early and late start and finish date for each activity. This is based on specified, sequential network logic and a single duration estimate. The aim of CPM is in calculating float to determine which activities have the least scheduling flexibility.

- **critical chain method**
  Critical Chain Method modifies the schedule to level over-allocated resources along the critical path. This often results in a different critical path than before adding resources to the activities. Another feature of the critical chain method is the use of buffers. The project buffer is added at the end of the project as a contingency for schedule slippage. Additional buffers called feeding buffers are inserted to those activities that feed the critical path to protect against schedule slippage that feeds the critical path.

Topic 4: Schedule Development (cont'd)



Definition is taken from the Glossary of *PMBOK® Guide*

Duration Compression - Crashing

Crashing involves analyzing cost and schedule tradeoffs to determine how, if at all, the greatest amount of compression can be obtained for the least incremental cost. Crashing does not always result in a viable alternative and it may in fact increase cost.

The **activities on the critical path** are examined to understand where time savings can be made. While this results in project time saving, the budget is impacted as very often time savings result in increased resources, materials or equipment.

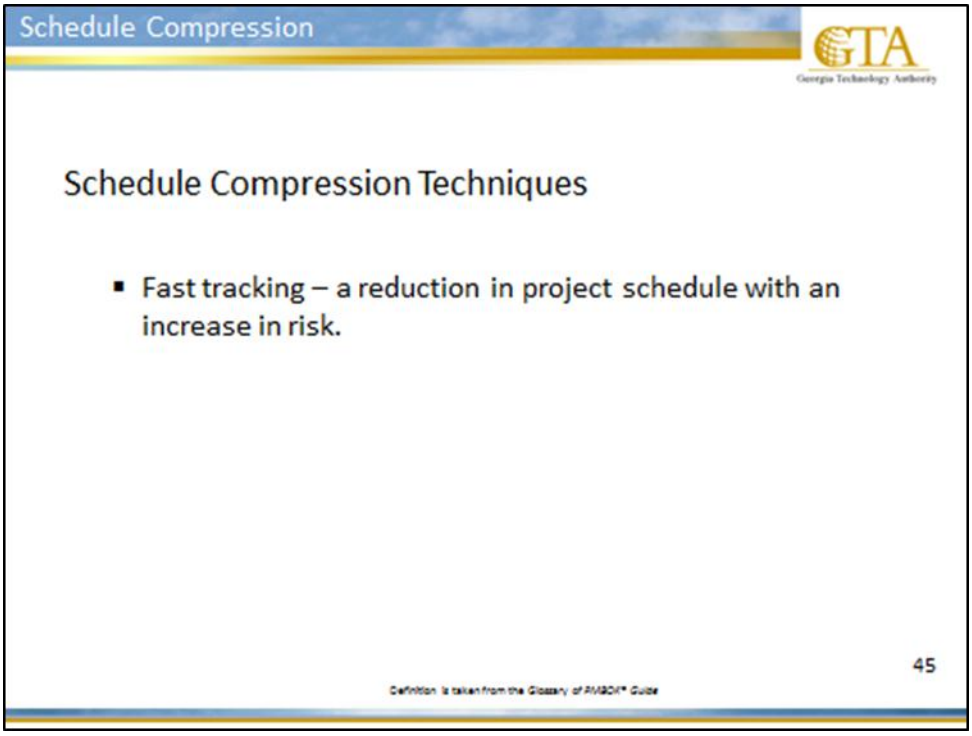
Using the CPM approach, project managers can determine the cost of speeding up or crashing certain phases of a project. To do this, it is necessary to calculate the normal expected time for each activity and the crashing cost per unit time. CPM charts, which are closely related to PERT charts, show the visual representation of the effects of crashing.

Only those activities on the critical path are considered, starting with the activities for which the crashing cost per unit time is lowest.

If the critical path consists of four activities, the first activity to be crashed is the one with the lowest crashing cost. The activity with the next lowest crashing cost is crashed next and so on.

When an activity is crashed, there is a strong possibility that a new critical path will be developed, which may include those elements that were bypassed because they were not on the original critical path.

Topic 4: Schedule Development (cont'd)



Definition is taken from the Glossary of *PMBOK® Guide*

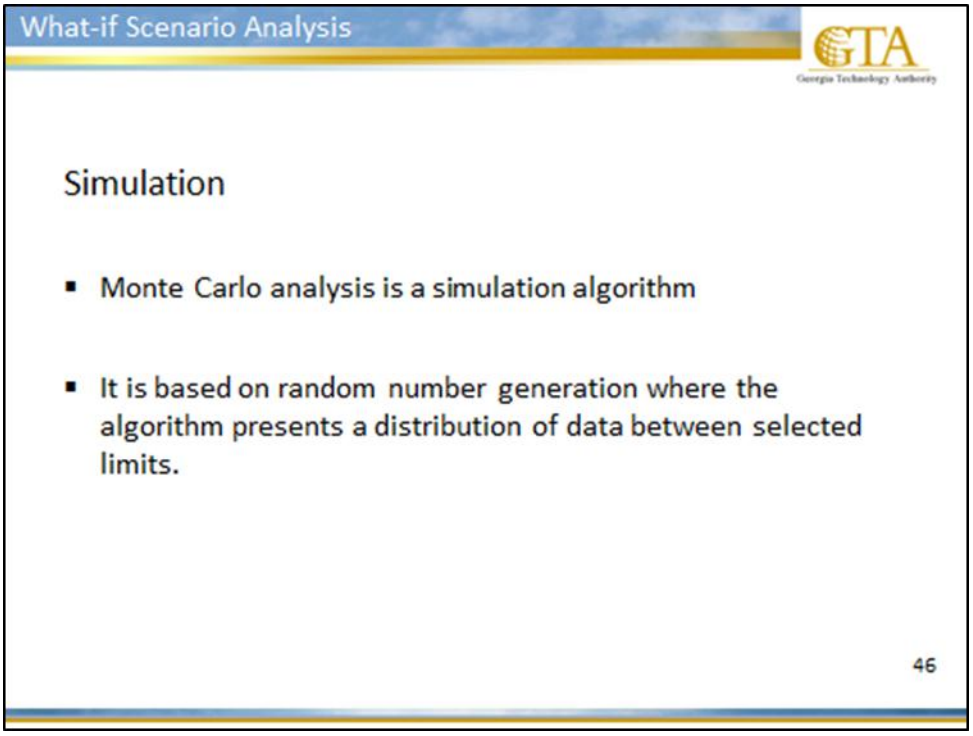
Duration Compression – Fast Tracking

Let's assume management wishes to keep the end date of a project fixed, but the start date is delayed because of a lack of adequate funding. How can this be accomplished without sacrificing quality? The answer is to **fast track the project**.

Fast tracking involves conducting activities in parallel that would normally be done in sequence (e.g., starting to write code on a software project before the design is complete).

Fast-tracking a job can accelerate the schedule but requires that additional risks be taken. If the risks materialize, then either the end date will slip or expensive rework will be needed. Almost all project-driven companies fast-track projects, but there is danger when fast-tracking becomes a way of life.

Topic 4: Schedule Development (cont'd)



Simulation

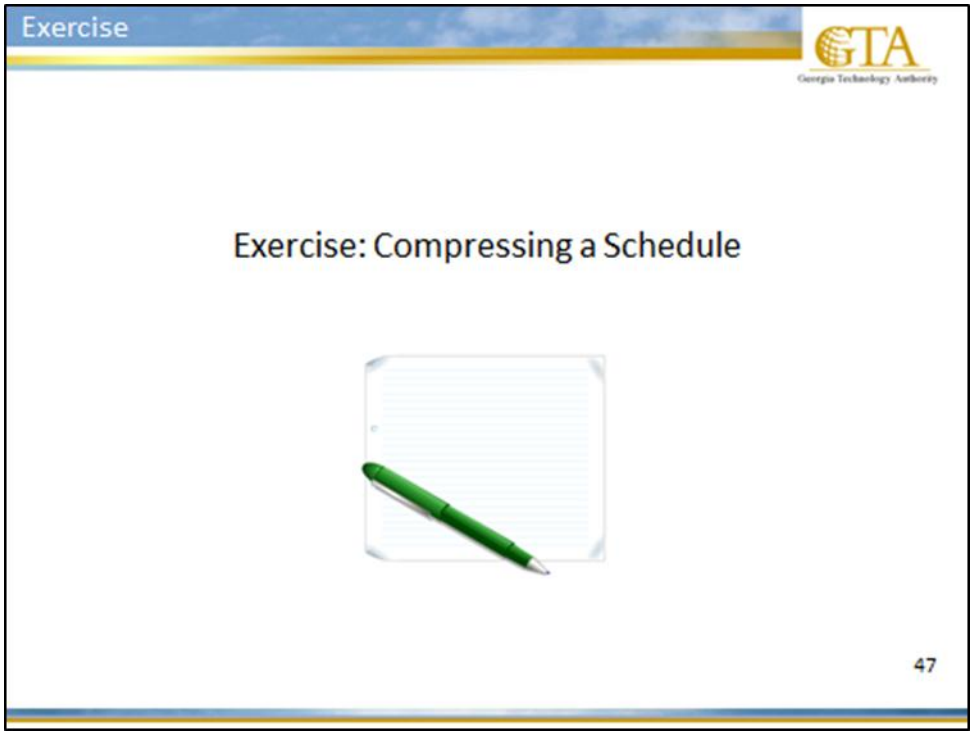
Project management uses simulation to calculate multiple project durations with different sets of activity assumptions. Monte Carlo analysis, a common simulation technique, involves defining a distribution of probable results for each project activity and using the results to calculate a distribution of probable results for the total project.

Monte Carlo analysis is based on random number generation where the algorithm presents a distribution of data between selected limits.

Here is a sample strategy for combining critical chain and simulation methods in a way that can be very beneficial to project management:

- develop the **work breakdown structure** and activity network diagram in the usual way
- obtain **quality judgments** about activity completion times and resource requirements. This is usually achieved by interviewing the best available experts. These judgments should be expressed as probability distributions. Breaking apart important contingencies is a good way to obtain a better representation and a more realistic estimate.
- understand that **learning** is essential to improving future judgments. A graphic of actual outcomes versus estimates is an excellent feedback tool.
- develop a **project model**. As available resources permit, shorten the project management schedule to conduct more activities in parallel (being careful to recognize resource conflicts and multi-tasking inefficiencies).
- provide **activity leaders** with convenient access to the project model. The project manager should be especially involved in monitoring ongoing activities and alerting workgroups to be prepared as work on critical activities approaches.

Topic 4: Schedule Compression (cont'd)



You are in the middle of the planning phase for the light rail system project. Due to the large nature of the project, the team has decided to break up the planning according to various functions. You have been asked to identify the work that would be involved in surveying and reviewing the site of the light rail system and delivering preliminary designs that can then be used to award a fixed-price contract to a civil-design vendor.

The following are the list of identified activities and the corresponding network diagram critical path:

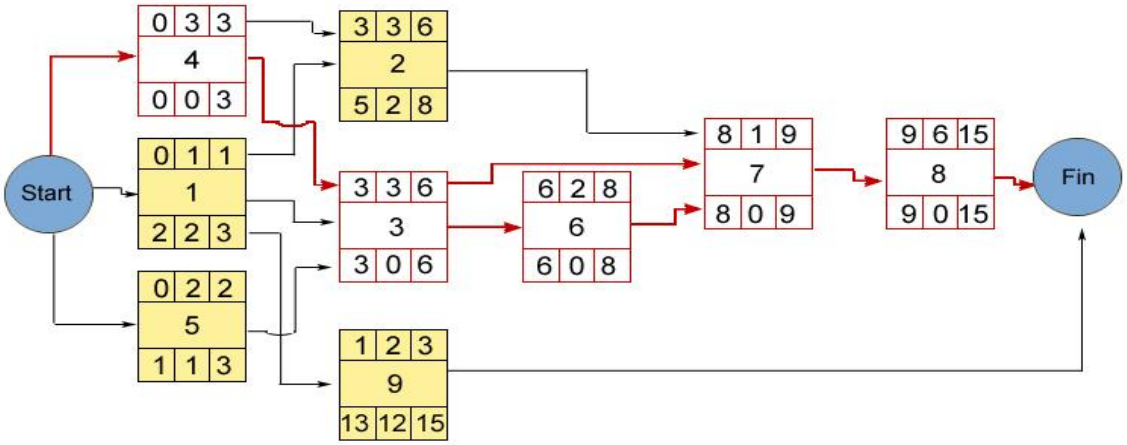
- step 1: examine the list of identified activities and corresponding network diagram critical path
- step 2: reduce the duration of this project to 7 weeks
- step 3: ending point of the exercise is when the activities that can be compressed in the logic diagram

Activity List:

Activity Number	Activity	Duration (weeks)
1	Identify Scope of Site Reviews	1
2	Environmental Review of Sites	3
3	Perform Site Surveys	3
4	Identify Vendors to Perform Surveys	3
5	Identify Rail Sites	2
6	Architecture Review	2
7	Review Surveys	1
8	Agree on Design Scope	6
9	Identify Vendors to Perform Design Contract	2

Topic 4: Schedule Compression (cont'd)

Network diagram:



Exercise Worksheet

Exercise Worksheet

Topic 5: Resource Leveling

Resource Leveling

Resource leveling (also known as the resource-based method) is any form of network analysis in which scheduling decisions (start and finish dates) are determined by **resource management concerns** (e.g., limited resource availability or difficult-to-manage changes in resource levels). Resource leveling frequently results in a project duration that is longer than the preliminary schedule

Reallocating resources from non-critical to critical activities is a common way to bring the schedule back, or as close as possible, to the originally intended overall duration. In addition, using extended working hours or different technologies can help shorten durations that have extended the preliminary schedule. Fast tracking can also be used to reduce the overall project duration.

Some projects have finite and **critical project resources** that must be scheduled in reverse from the project ending date. This is known as reverse resource allocation scheduling. As we've learned, the critical chain modifies the project schedule to account for limited resources.

Successful project management is both an art and a science that attempts to control corporate resources within the constraints of time, cost, and performance. Most projects are unique activities for which there may not be reasonable standards for forward planning. As a result, the project manager may find it extremely difficult to stay within the time-cost-performance triangle shown in the slide.

Resource Requirements

The duration of most activities is significantly influenced by the resources assigned to them. For example, two people working together may be able to complete a design activity in half the time it takes either of them individually. A person working half time on an activity will generally take at least twice as much time as the same person working full time.

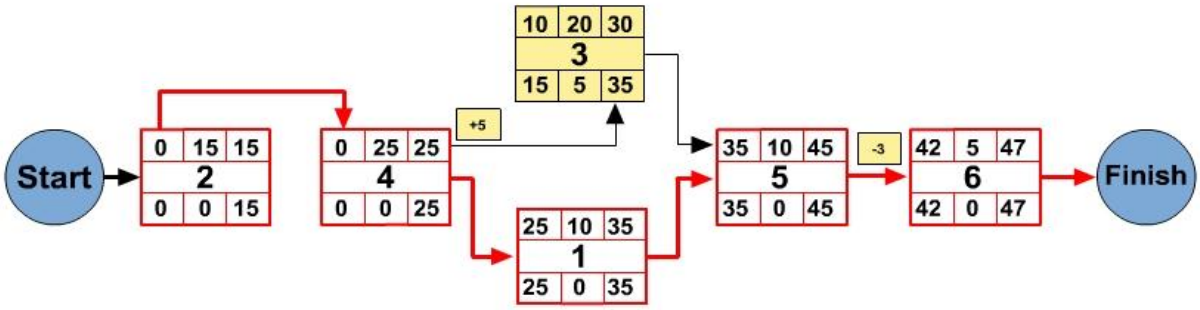
Topic 5: Resource Leveling (cont'd)

As additional resources are added, projects can experience communication overload, which reduces productivity. Production tends to improve proportionally less than the increase in resource.

In this example, the following resources are available for the project:

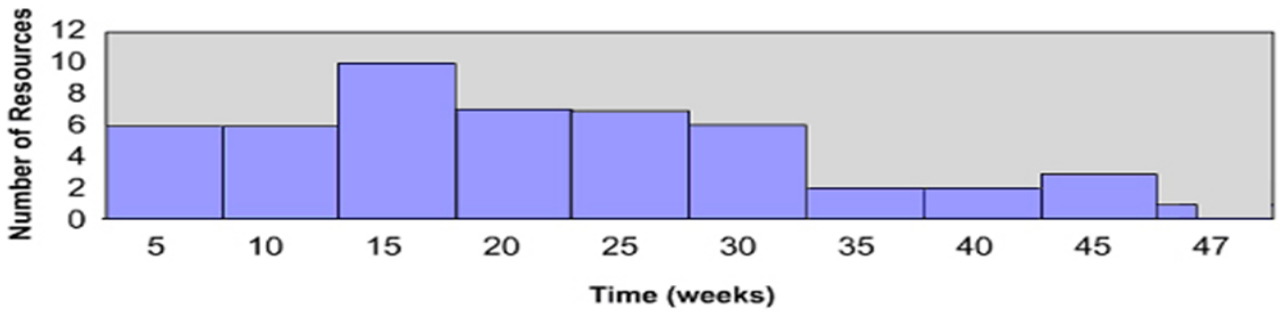
Activity Number	Activity	Duration	Resources
1	Identify Vendors	10	2
2	Identify Contract Requirements	15	3
3	Interview Vendors	20	4
4	Advertise Proposal	25	3
5	Select Vendors	10	2
6	Sign Contract	5	1

And when applied to the following project network, the resulting resource profile is



The cart below depicts the number of resources needed per week based on the network diagram.

	Resources per Week									
Activities	5	10	15	20	25	30	35	40	45	47
1						2	2			
2	3	3	3							
3			4	4	4	4				
4	3	3	3	3	3					
5								2	2	
6									1	1
Total	6	6	10	7	7	6	2	2	3	1



Lesson 3: Summary

The lesson is now completed and the following topics have been covered:

Topic 1: Developing a Project Schedule

- A **project management plan** is a formal, approved document used to manage project execution and control. This contain a list of project plans ranging from project charters, scope statement to cost and schedule management plans

- A **project schedule**, which is part of the project management plan, lists planned dates for performing activities and meeting milestones identified in the project management plan.

- The project schedule is generally presented graphically, using one or more of the following formats: **project network diagrams, bar charts, milestone charts, Gantt charts**.

From this topic you should **take away** the following points:
- several different tools and techniques (bar-charts, milestone charts, and Gantt charts) are associated with a project schedule
- the Work Breakdown Structure is the origin of the work that makes up each of these tools and techniques

Topic 2: Critical Path Method (CPM)

- **Critical path method (CPM)** is a network analysis technique used to predict project duration by analyzing which sequence of activities (which path) has the least amount of scheduling flexibility (the least amount of float).

- The **critical chain** is defined as the longest chain of dependant events where the dependency is either task or resource related.

From this topic you should **take away** the following points:
- a project manager identifies the critical path using the precedence diagramming method template
- critical chain is about understanding how resources and tasks can impact on project durations, and evaluating potential time reductions given these interactions

Topic 3: Leads and Lags

- A **lead** is a modification of a logical relationship that allows an acceleration of the successor task. A **lag** is a modification of a logical relationship that directs a delay in the successor task.

From this topic you should **take away** the following point:
- leads and lags apply to the precedence diagramming method and are used to modify logical relationships between activities

Lesson 3: Summary (cont'd)

Topic 4: Schedule Compression

- The schedule development process uses the following compression / analysis techniques:
  - **schedule analysis** – used to calculate the theoretical time period of the project, which is the early start and finish dates of all project activities given resource limitations and other known constraints
  - **duration compression** – a special form of mathematical analysis that tries to shorten the project schedule without changing the project scope. There are two major duration compression techniques, crashing and fast tracking.
  - **simulation** – used to calculate multiple project durations with different sets of activity assumptions
  - **resource leveling** – used to balance resource allocation (e.g. allocating additional resources to a project to ensure that its duration is in line with the original estimate)
  - **project management software** – used to help automate certain tasks, for example the calculation of mathematical analysis, and to help create alternative schedules quickly

From this topic you should **take away** the following points:

- there are a number of schedule compression techniques available to project managers, including crashing (reducing project duration with an increase in cost) and fast-tracking (reducing project duration with an increase in risk)
- the exercise asked to reduce the project duration without increasing cost, so risk was increased. This resulted in fast-tracking the project by changing activity relationships (i.e. from finish-to-start to start-to-start)

Topic 5: Resource Leveling

- **Resource leveling** (also known as the resource-based method) is any form of network analysis in which scheduling decisions (start and finish dates) are determined by resource management concerns (e.g., limited resource availability or difficult-to-manage changes in resource levels).

A combination of the various techniques can be used to find the optimal project duration with the correct balance of resources and appropriate budget

From this topic you should **take away** the following point:

- there are various types of resource-leveling, each of which can be applied to find the optimal fit between resources and project durations

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Lesson 4: Time and Cost Estimation

Topic 1: Parametric Modeling Estimation

Topic 2: Analogous Estimation

Topic 3: Bottom-up Estimation

Topic 4: Program Evaluation Review Technique

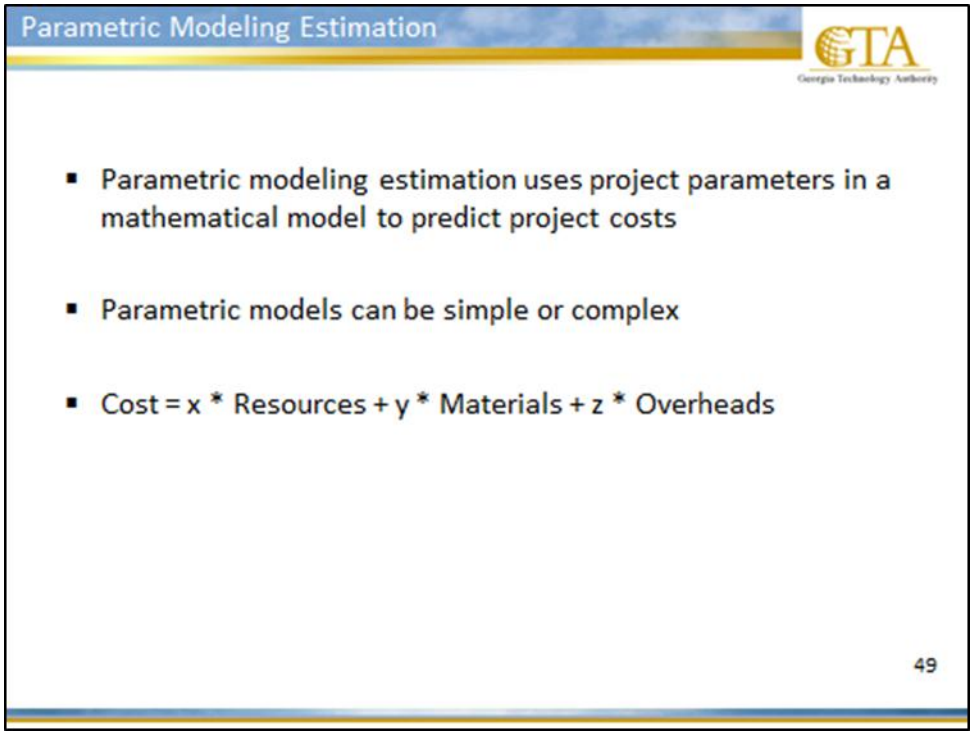
Topic 5: Delivering a Project Estimate

Student learning objectives

After completing this lesson, you should be able to

- define parametric modeling and explain how it can be used in project planning
- define analogous estimation and explain how it can be used in project planning
- define bottom-up estimation and explain how it can be used in project planning
- define three-point estimation and explain how to use it to statistically evaluate schedules or budgets
- use estimation tools and techniques to present expected project costs and durations

Topic 1: Parametric Modeling Estimation



Parametric modeling uses the characteristics (parameters) of a project in a mathematical model to predict project costs. Models may be simple or complex, depending on the nature of the project. For example, a residential construction project could use a simple model to determine the cost of the project per square foot of living space. A more complex model would be appropriate for a software development project (i.e. introduction of web-based systems for payroll systems) that involves many different adjustment factors that need to be accounted for in the model.

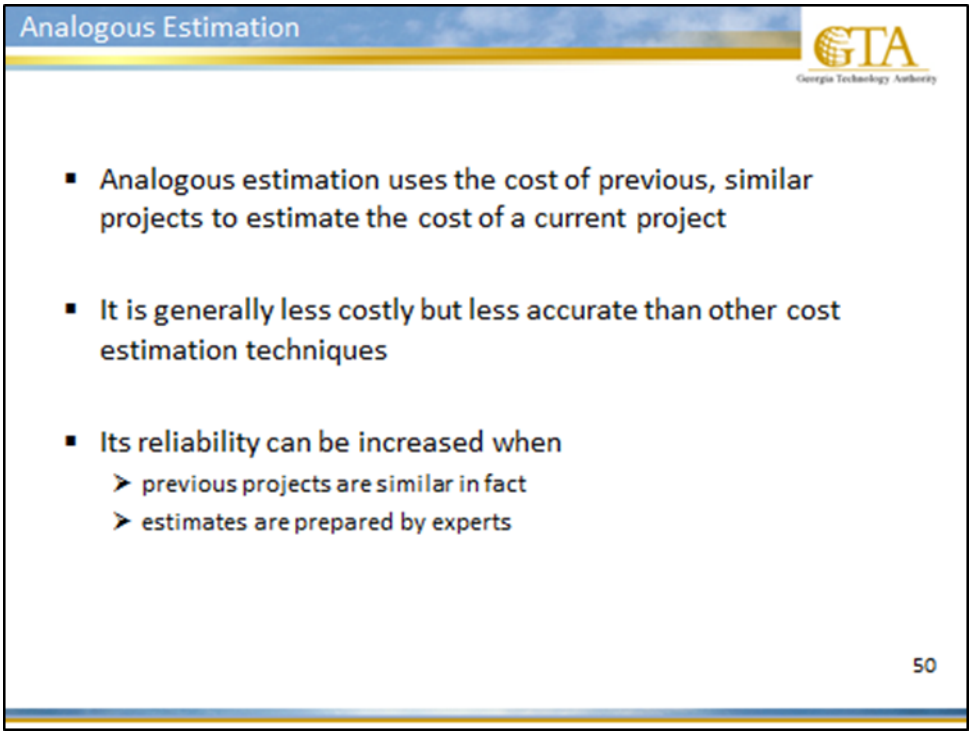
An example of a simple parametric model is **Cost = 40 * Resources + 40 * Materials + 20 * Overheads**. This model shows that the key drivers are resources and materials when establishing a cost estimate. The factors associated with the variables are weightings that demonstrate their relative impact.

Parametric models are most likely to be reliable when

- historical information used to develop the model is accurate.
- parameters used in the model are readily quantifiable.
- the model is scalable (i.e., it works for large as well as small projects).

Parametric modeling is particularly applicable to environments where the nature of the project work is repetitive (i.e. manufacturing of systems)

Topic 2: Analogous Estimation

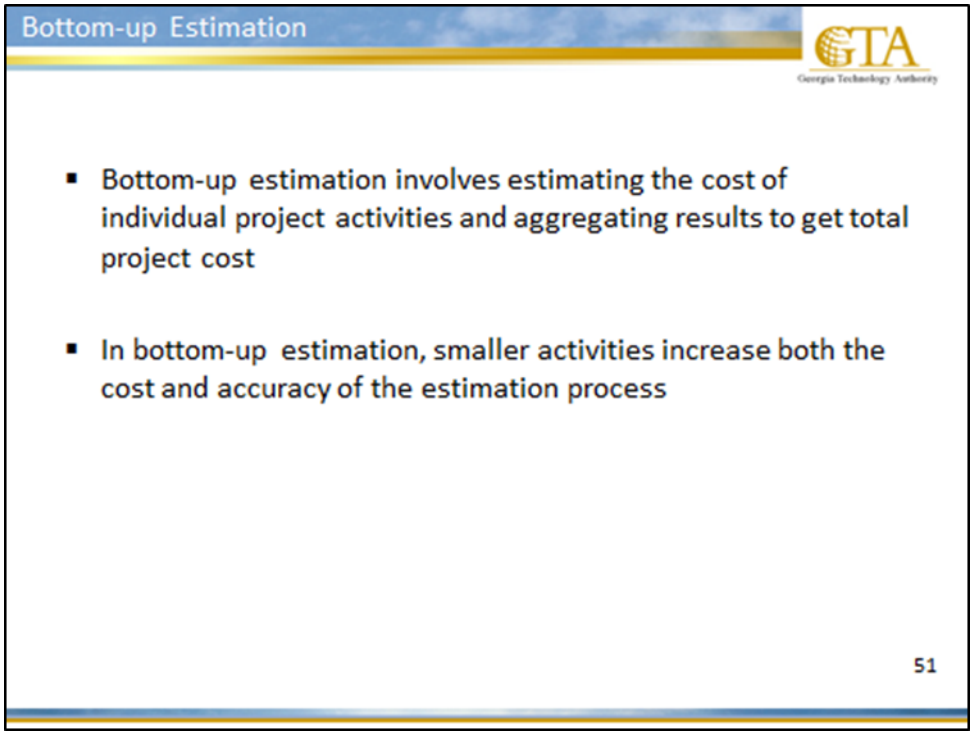


Analogous estimation, also called **top-down estimating**, involves using the actual cost of a previous, similar project as the basis for estimating the cost of the current project. It is often used in the early phases of a project when there is a limited amount of detailed information available.

Analogous estimation is a form of expert judgment about potential resource requirements that can be made available from such sources as other units within the performing organization, consultants, professional and technical associations, or industry groups. It is less costly than other techniques because it is based on existing information. However, it is also generally less accurate because similarities between projects cannot be guaranteed. The process is most likely to be reliable when

- previous projects are similar in fact and not just in appearance.
- individuals or groups preparing estimates have the required expertise.

Topic 3: Bottom-up Estimation



Bottom-up estimation involves estimating the cost of individual project activities or work packages and then summarizing individual estimates to get a project total.

Bottom-up estimation is dependent on a well-structured work breakdown structure (WBS). The low level of the WBS presents activities/work packages that can be associated with a time and cost estimate.

Topic 3: Bottom-up Estimation (cont'd)

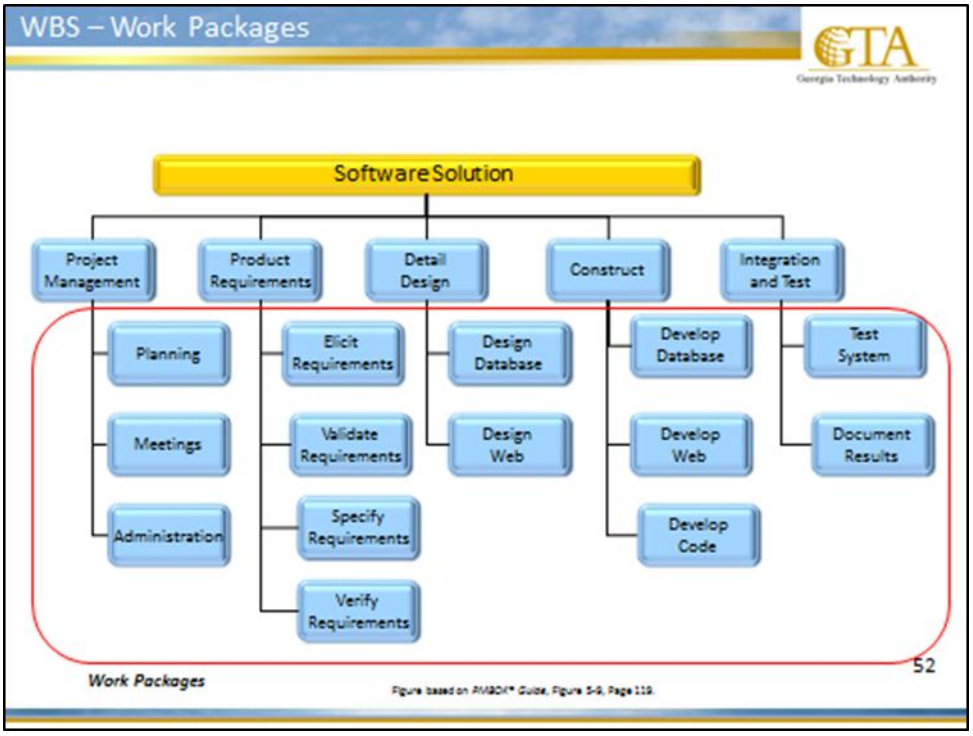


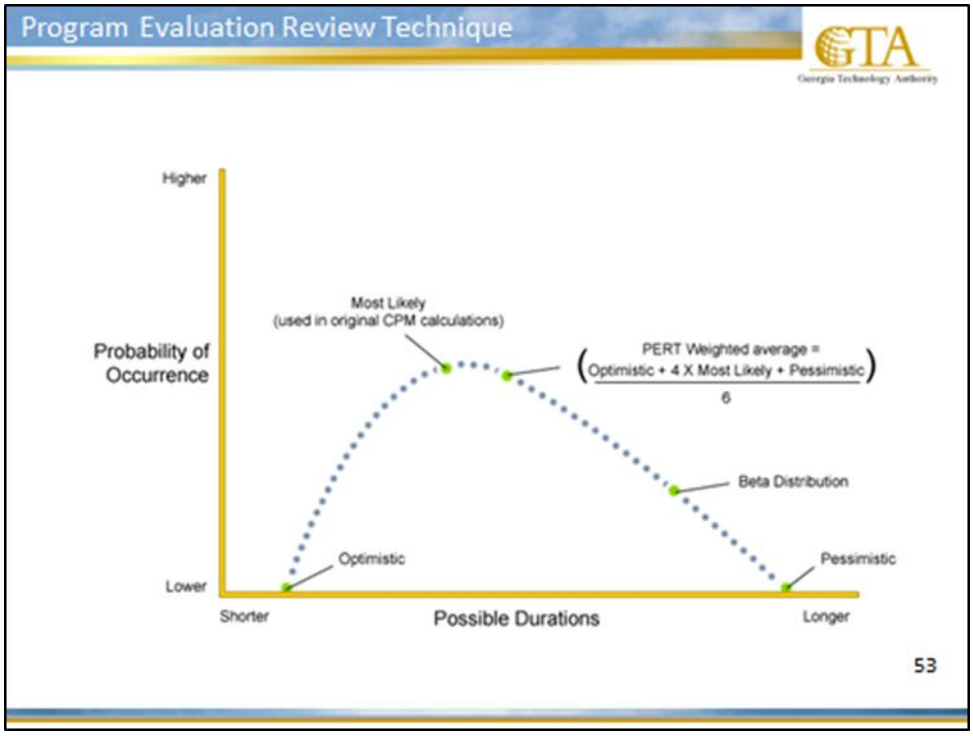
Figure based on *PMBOK® Guide*, Figure 5-9, Page 119.

As the low-level components of the WBS are estimated, they can be accumulated to present estimates at various levels. The WBS with estimates can also be referred to as a **cost breakdown structure (CBS)**.

When it is not possible to estimate the cost of a complex activity with a reasonable degree of confidence, the work within the activity is deconstructed into more detail. Each piece of work's **resource requirements are estimated**, and these estimates are then aggregated into a total quantity for each of the activity's resources. If there are dependencies between activities, the pattern of resource usage needs to be reflected in the estimated requirements of the activity and these estimates need to be documented.

The size and complexity of an individual activity or work package determines the size and accuracy of bottom-up estimation: smaller activities increase both the cost and accuracy of the estimation process.

Topic 4: Program Evaluation Review Technique

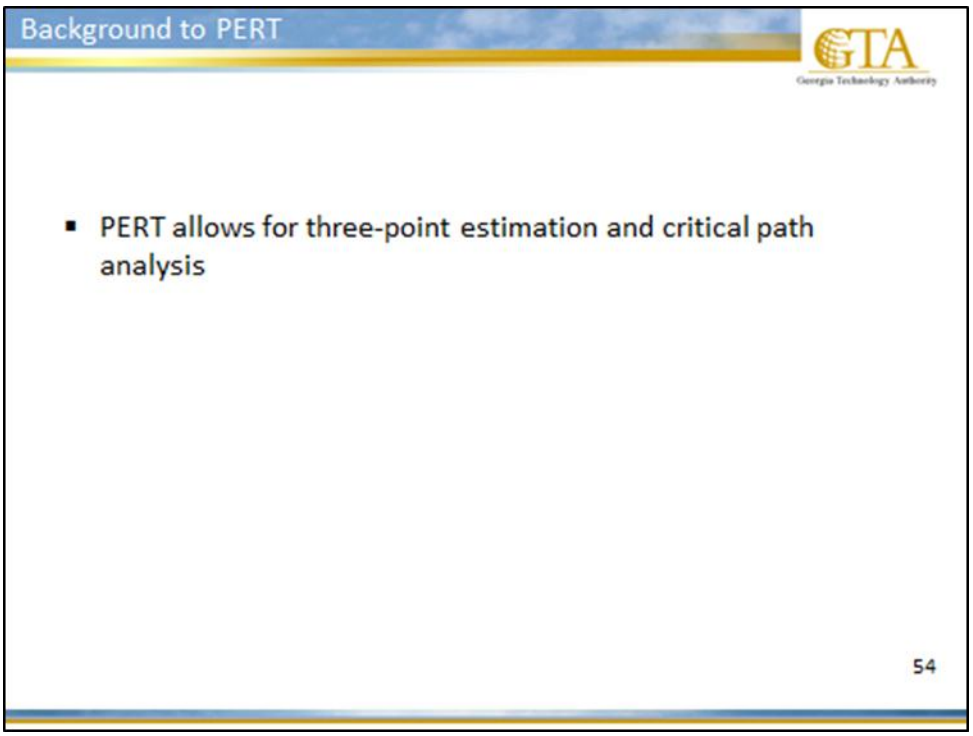


Program Evaluation and Review Technique (PERT) is a calculation method that uses a weighted average duration estimate to determine activity durations. It uses the distribution's mean (expected value) instead of the most likely estimate originally used in critical path method (CPM). In PERT, estimates of completion time are obtained for each activity in the form of three points:

- **most likely** – the calculated activity duration given the likely available resources and their productivity, realistic expectations regarding the availability of these resources, dependencies on other participants, and interruptions on the type of activities
- **optimistic** – the calculated activity duration based on a best-case scenario of what is described in the most likely estimate
- **pessimistic** – the calculated activity duration based on a worst-case scenario of what is described in the most likely estimate

An activity duration estimate constructed using some average of the three estimated durations can provide a more accurate estimate than the single point most likely estimate.

Topic 4: Program Evaluation Review Technique (cont'd)



PERT Requirements

When PERT was first developed, it consisted of a number of basic requirements. For example, the individual tasks undertaken to complete a project must be clear so that they can be sequenced as part of a schedule.

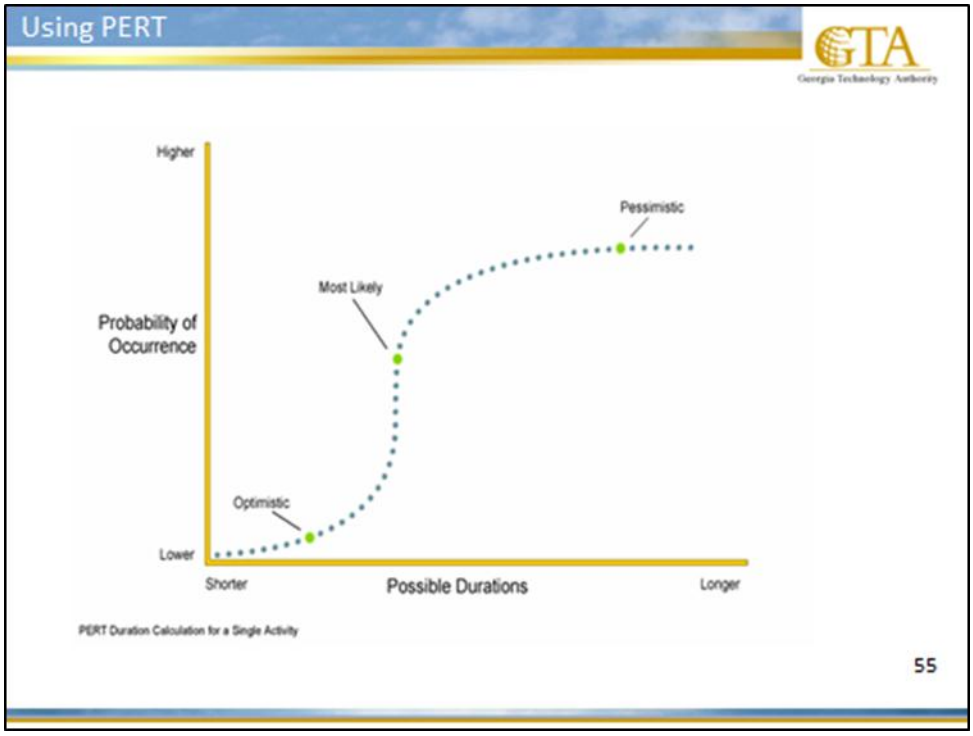
These events and activities are sequenced on the network using a highly logical set of ground rules that allow the determination of critical paths.

Time estimates are calculated for each activity on a three-way basis – optimistic, most likely, and pessimistic. These figures should be estimated by the person(s) most familiar with the activity.

PERT's extensive planning (i.e. three-way basis) helps identify critical path analysis independencies that can be used to indicate where the greatest effort is required to keep a project on schedule. The probability of meeting deadlines by developing alternate plans is another application. For example, the probability of achieving the desired result can be compared against the pessimistic and optimistic estimates.

The **three-way basis for estimation** (optimistic, most likely, and pessimistic) is used to derive an expected time. PERT is used for R&D projects where the risks in calculating time durations have a high variability, and is the basis for variance simulation.

Topic 4: Program Evaluation Review Technique (cont'd)



Functional managers are required to evaluate situations and submit their best estimates when calculating the elapsed time between events. These estimates are more reliable if the manager has a large volume of historical data to work from. In the case of non-repetitive activities, functional managers must base their estimates on three possible assumptions related to the completion time:

- the **most optimistic completion time** – assumes that everything will go according to plan and that difficulties will be kept to a minimum
- the **most pessimistic completion time** – assumes that everything will not go according to plan and the maximum number of difficulties will develop
- the **most likely completion time** – this is the time that most often occurs when this event occurs many times

To combine these three times into a single expression for expected time, two more assumptions must be made:

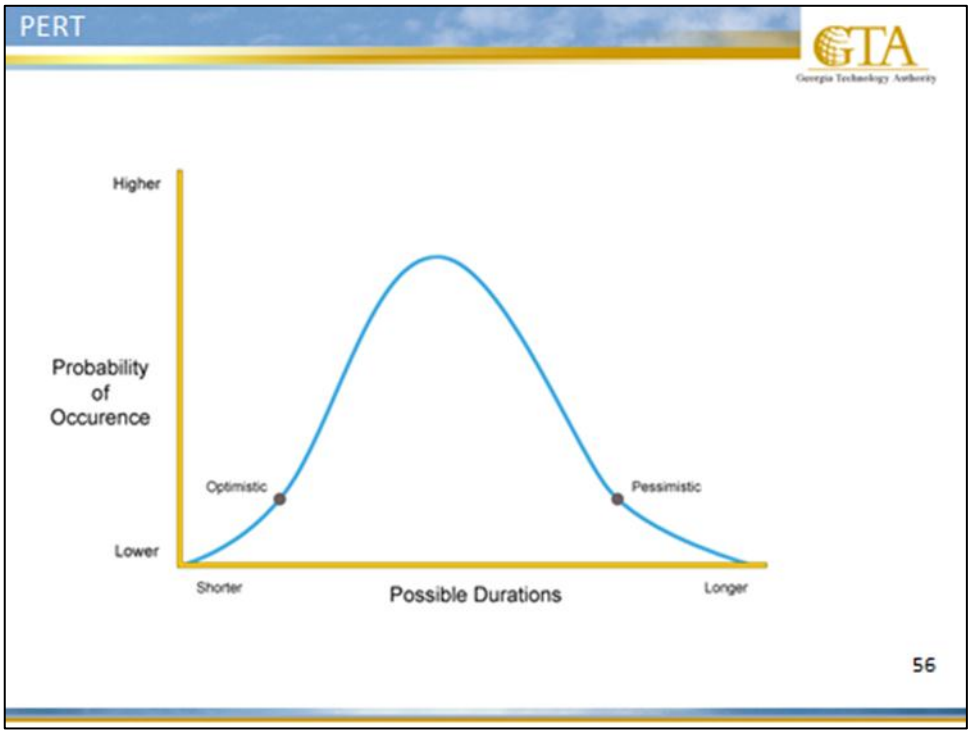
- standard deviation is one-sixth of the time requirement range

  This assumption is based on the probability theory, where the end points of a curve are three standard deviations from the mean.

  The standard deviation is a measure of uncertainty. It can also be defined as the difference between the forecast and the actual. The higher the standard deviation is, the greater the risk or variance associated with the project.

- the probability of distribution of the time required to perform an activity must be expressible as a beta distribution

Topic 4: Program Evaluation Review Technique (cont'd)



PERT uses the following expressions to find the expected time between events:

$$t_e = \frac{to + 4tm + tp}{6}$$

t_e = expected time
to = most optimistic time
tp = most pessimistic time
tm = most likely time

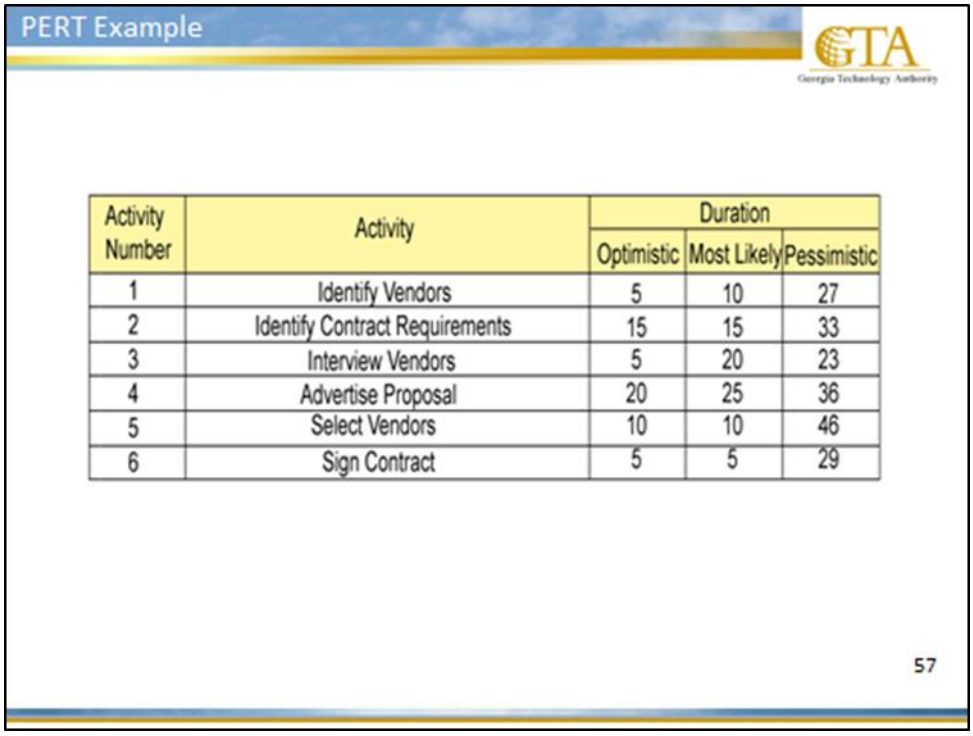
In order to calculate the probability of completing the project on time, the standard deviation of each activity can be obtained from this expression:

$$\sigma t_e = \frac{tp - to}{6}$$

σ = standard deviation of expected time te

Another expression that can be used is variance (v), which is the square of the standard deviation. This expression is useful when comparing expected values.

Topic 4: Program Evaluation Review Technique (cont'd)

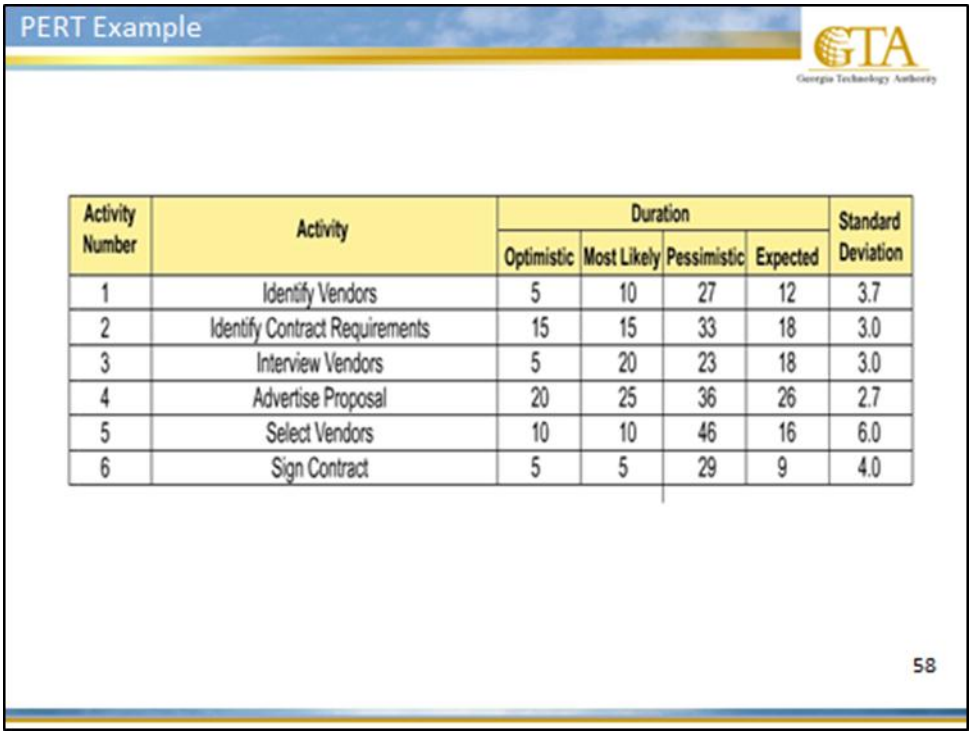


Activity Number	Activity	Duration		
		Optimistic	Most Likely	Pessimistic
1	Identify Vendors	5	10	27
2	Identify Contract Requirements	15	15	33
3	Interview Vendors	5	20	23
4	Advertise Proposal	20	25	36
5	Select Vendors	10	10	46
6	Sign Contract	5	5	29

The following are the optimistic, most likely, and pessimistic estimates available for a project to sign a contract:

Activity Number	Activity	Duration		
		Optimistic	Most Likely	Pessimistic
1	Identify Vendors	5	10	27
2	Identify Contract Requirements	15	15	33
3	Interview Vendors	5	20	23
4	Advertise Proposal	20	25	36
5	Select Vendors	10	10	46
6	Sign Contract	5	5	29

Topic 4: Program Evaluation Review Technique (cont'd)



PERT Example

Activity Number	Activity	Duration				Standard Deviation
		Optimistic	Most Likely	Pessimistic	Expected	
1	Identify Vendors	5	10	27	12	3.7
2	Identify Contract Requirements	15	15	33	18	3.0
3	Interview Vendors	5	20	23	18	3.0
4	Advertise Proposal	20	25	36	26	2.7
5	Select Vendors	10	10	46	16	6.0
6	Sign Contract	5	5	29	9	4.0

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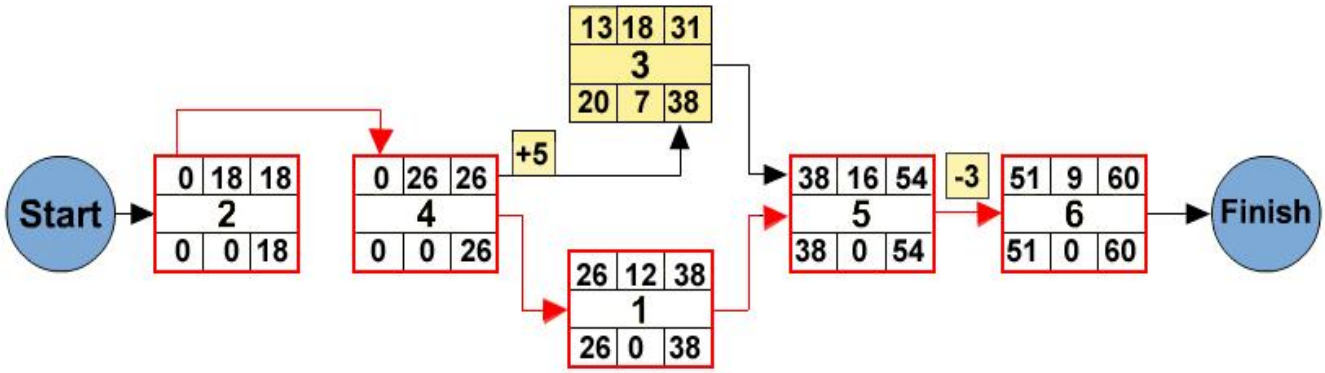
Given this data, and the application of PERT, the expected durations can be calculated using **to + 4 tm + tp / 6** and the standard deviation using **tp – to / 6**:

Activity Number	Activity	Duration				Standard Deviation
		Optimistic	Most Likely	Pessimistic	Expected	
1	Identify Vendors	5	10	27	12	3.7
2	Identify Contract Requirements	15	15	33	18	3.0
3	Interview Vendors	5	20	23	18	3.0
4	Advertise Proposal	20	25	36	26	2.7
5	Select Vendors	10	10	46	16	6.0
6	Sign Contract	5	5	29	9	4.0

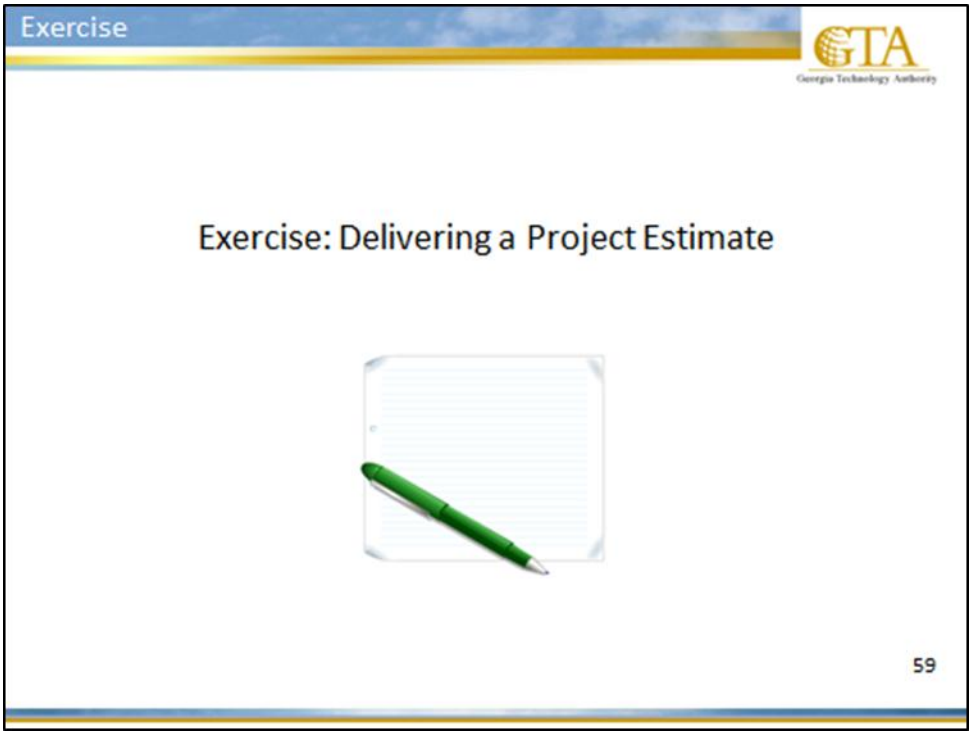
Topic 4: Program Evaluation Review Technique (cont'd)

When the project expected duration is applied, the project network is as follows, with extended project duration of 60 days.



This indicates that there is a time risk associated with this network. For example, the duration for selecting vendors is between 10 days (optimistically) and 46 days (pessimistically). The expected duration is 16 days. However, this may be an activity that requires contingency. Contingency is discussed in detail in lesson 5 topic 1.

Topic 5: Exercise – Delivering a Project Estimate



You are in the middle of the planning phase for the light rail system project. You have been requested to identify the work that would be involved in surveying and reviewing the site of the light rail system and delivering preliminary designs that can then be used to award a fixed-price contract to a civil-design vendor.

The list of identified activities and the corresponding network diagram with critical path are displayed on the next page.

You need to update the estimate for the time duration of the project. The current time estimates are one point (i.e. most likely), but your project stakeholders would like to see the expected duration, using the following formulae:

- to find the expected time (t*e*) between events

$$t_e = \frac{to + 4tm + tp}{6}$$

t_e = expected time
to = most optimistic time
tp = most pessimistic time
tm = most likely time

- the standard deviation of each activity

$$\sigma t_e = \frac{tp - to}{6}$$

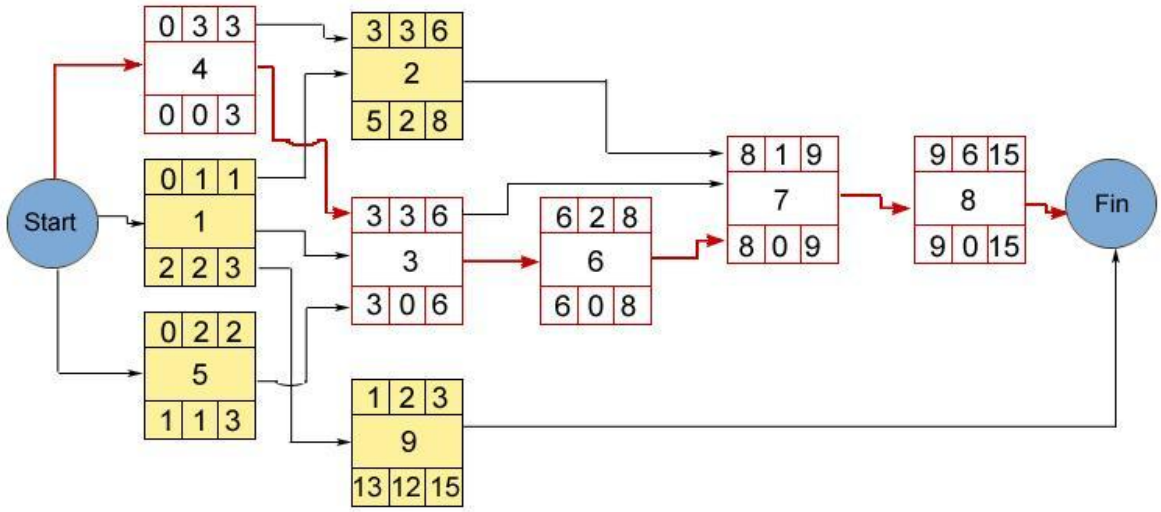
σ = standard deviation of expected time te

Topic 5: Exercise – Delivering a Project Estimate (cont'd)

Activity List:

Activity Number	Activity	Duration			
		Optimistic	Most Likely	Pessimistic	Expected
1	Identify Scope of Site Reviews	1	1	7	
2	Environmental Review of Sites	3	3	3	
3	Perform Site Surveys	3	3	9	
4	Identify Vendors to Perform Surveys	1	3	5	
5	Identify Rail Sites	1	2	3	
6	Architecture Review	1	2	9	
7	Review Surveys	1	1	1	
8	Agree on Design Scope	4	6	8	
9	Identify Vendors to Perform Design Contract	2	2	8	

Network Diagram:



Lesson 4: Summary

The lesson is now completed and the following topics have been covered:

Topic 1: Parametric Modeling Estimation

- **Parametric modeling** uses the characteristics (parameters) of a project in a mathematical model to predict project costs.

From this topic you should **take away** the following point:
- parametric models are used to estimate durations and costs

Topic 2: Analogous Estimation

- **Analogous estimation**, also called **top-down estimating**, involves using the actual cost of a previous, similar project as the basis for estimating the cost of the current project.

- It is often used in the early phases of a project when there is a limited amount of detailed **information available**.

From this topic you should **take away** the following point:
- previous project experience is a legitimate basis from which to estimate durations and costs

Topic 3: Bottom-up Estimation

- **Bottom-up estimation** involves estimating the cost of individual project activities or work packages and then summarizing individual estimates to get a project total.

- It is dependent on a well-structured **work breakdown structure (WBS)**.

From this topic you should **take away** the following point:
- a work breakdown structure template can be used to estimate durations and costs

Topic 4: Program Evaluation Review Technique

- **Program Evaluation and Review Technique (PERT)** is a calculation method that uses a weighted average duration estimate to determine activity durations. The estimates of completion time are obtained for each activity in the form of three points:
    - **most likely**
    - **optimistic**
    - **pessimistic**

- To combine these three times into a single expression for **expected time**, it is assumed that **standard deviation** is one-sixth of the time requirement range, and the probability of distribution of the time required to perform an activity must be expressible as a beta distribution.

Lesson 4: Summary (cont'd)

From this topic you should **take away** the following points:

- the Program Evaluation and Review Technique uses the following formulae:
  - to find the **expected time** between events:

$$t_e = \frac{to + 4tm + tp}{6}$$

t_e = expected time
to = most optimistic time
tp = most pessimistic time
tm = most likely time

  - the **standard deviation** of each activity can be obtained from this expression:

$$\sigma t_e = \frac{tp - to}{6}$$

σ = standard deviation of expected time te

Topic 5: Delivering a Project Estimate

- An exercise is presented to demonstrate the calculation and delivery of a project estimate.

From this topic you should **take away** the following point:

- the PERT formulae can be used to deliver an expected project duration using the precedence diagramming method template

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Lesson 5: The Project Budget

Topic 1: Allocating Contingency

Topic 2: Cost Budgeting and Baseline

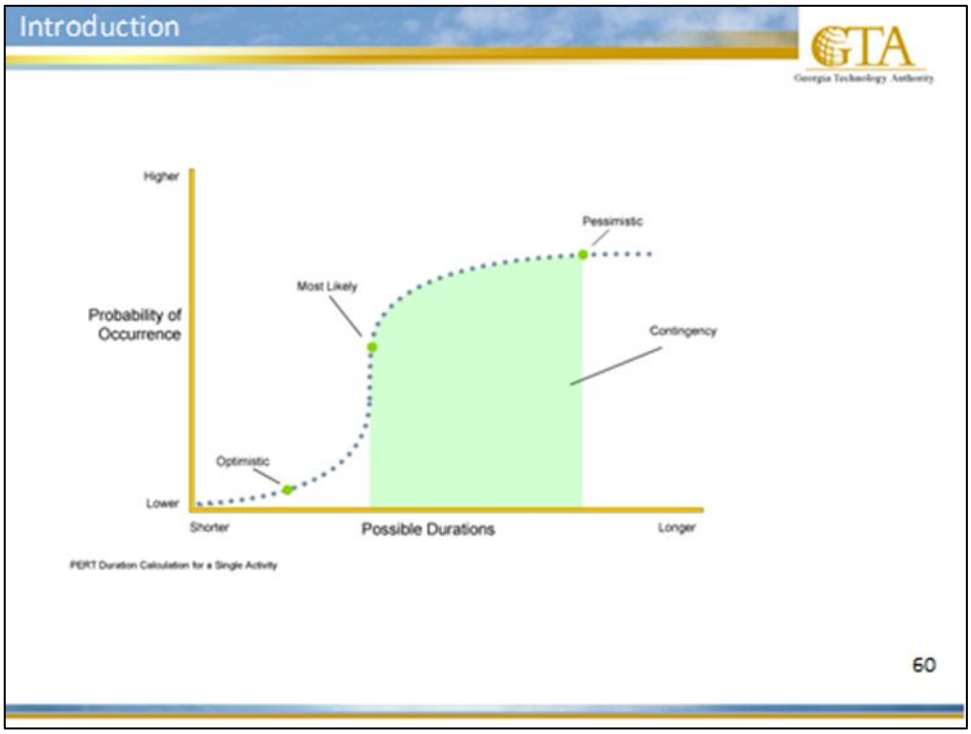
Topic 3: Presenting a Cost and Schedule Baseline

Student learning objectives

After completing this lesson, you should be able to

- describe what cost and time contingency is and explain how to apply it
- define what a cost budget is and how to construct one
- use the cost estimates to structure a cost baseline
- understand a cost and schedule baseline and explain how to produce them

Topic 1: Allocating Contingency



Contingency Activities

Project teams can choose to incorporate **contingency time or cost into an overall schedule or budget to allow for schedule risk**. For example, the contingency time can be a percentage of the estimated activity duration, a fixed number of work periods, or it can be developed by quantitative risk analysis. The **reserve** time or cost can be used completely or partially, and can later be reduced or eliminated as more precise information about the project becomes available. The **reserve time or cost** should be documented along with other data and assumptions.

Time contingency on critical path activities will affect the overall project duration, whereas contingency on non-critical path activities may move them onto the critical path and, in turn, affect project duration. This has an impact on the project deliverables and milestones.

Many estimators include contingency allowances for cost and time in activity estimates. There is an inherent problem with this approach, specifically, of not identifying the original activity estimates and thereby enabling the typical human response of consuming all assigned time and budget.

One possible solution to this problem is to combine the contingency time and resources, including cost for a group of related activities, into a single contingency activity (or contingency buffer) that is intentionally placed directly on the path for that group of activities.

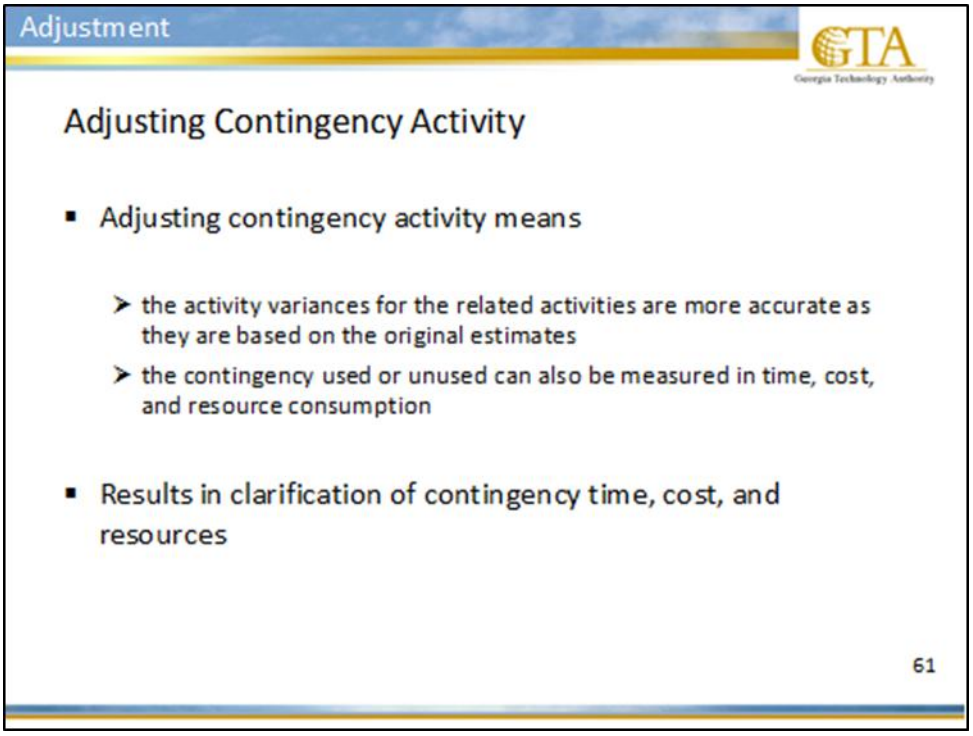
The diagram in the slide shows the expected funding for the project. The project manager can be invaluable in providing the information necessary to support funding requests that will ensure a positive funding flow in advance of expenditures.

Many projects, particularly larger ones, have **multiple cost baselines** to measure different aspects of cost performance. For example, management will require that the project manager track internal costs (employee labor) separately from external costs (subcontractors and construction materials).

Topic 1: Allocating Contingency (cont'd)

Private sector budget processes are very similar to the government budget processes. They must respond quickly to market challenges from competitors. Therefore, large private firms frequently delegate detailed budget decisions to smaller cost centers. The manager of each cost center has clear performance measures – make profit, satisfy customers, and obey the law.

Topic 1: Allocating Contingency (cont'd)

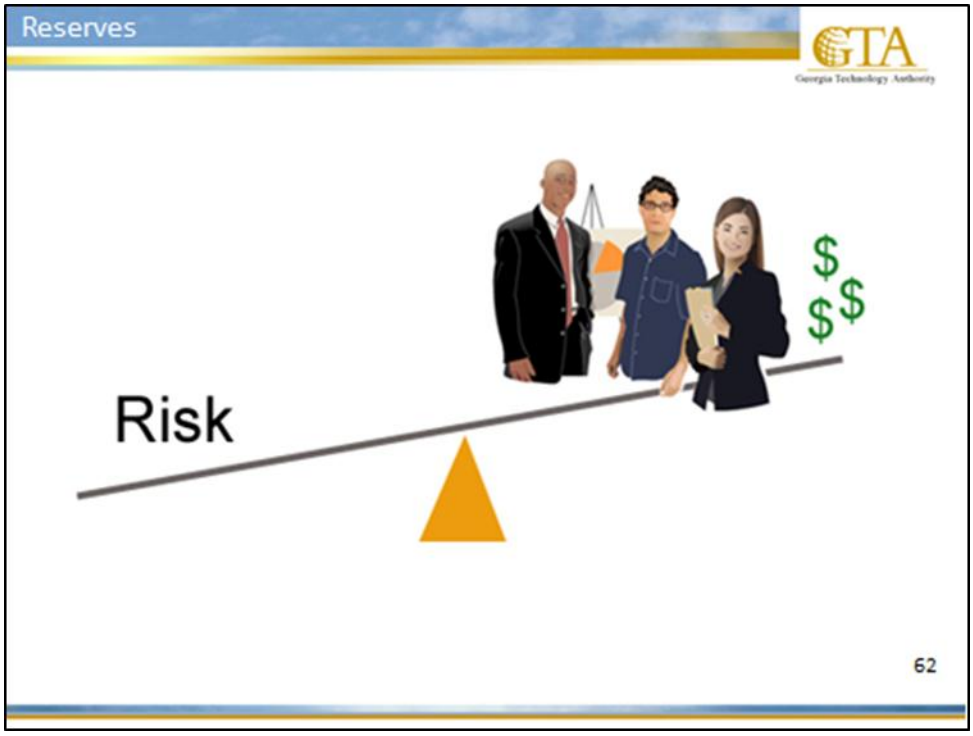


As the activities progress through execution, it is possible to adjust the contingency activity, as measured by the time, cost, and resource consumption of the activities.

This means that the activity variances for the related activities are more accurate as they are based on the original estimates, and the contingency used or unused can also be measured in time, cost, and resource consumption.

By using **contingency activities** in this way, there is a resultant clarification of contingency time, cost, and resources. These contingency activities can follow on from each activity for which a significant contingency is needed or as a composite contingency for all activities in a work package.

Topic 1: Allocating Contingency (cont'd)



Contingency reserve is the amount of money or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization.

Contingency reserves are budgeted costs that can be used at the direction of the project manager in order to deal with anticipated, but not certain, events. These are "known unknowns" and are part of the cost base line.

Contingency reserves are usually assigned at the work package level as a zero duration summary activity, spanning the start to the end of the work package sub-network.

On the next page, the optimistic, most likely and pessimistic estimates are displayed for the project to sign a contract. Given this data, and the **application of PERT**, the expected durations and standard deviation can be calculated.

Topic 1: Allocating Contingency (cont'd)

From the table below you can see that the standard deviation for the 'Select Vendors' activity is higher than any other activity. (The standard deviation is a measure of the dispersion of possible outcomes.)

Activity Number	Activity	Duration				Standard Deviation
		Optimistic	Most Likely	Pessimistic	Expected	
1	Identify Vendors	5	10	27	12	3.7
2	Identify Contract Requirements	15	15	33	18	3.0
3	Interview Vendors	5	20	23	18	3.0
4	Advertise Proposal	20	25	36	26	2.7
5	Select Vendors	10	10	46	16	6.0
6	Sign Contract	5	5	29	9	4.0

Contingency should be allocated to this activity within the expected and pessimistic boundaries (i.e. 16 weeks to 46 weeks).

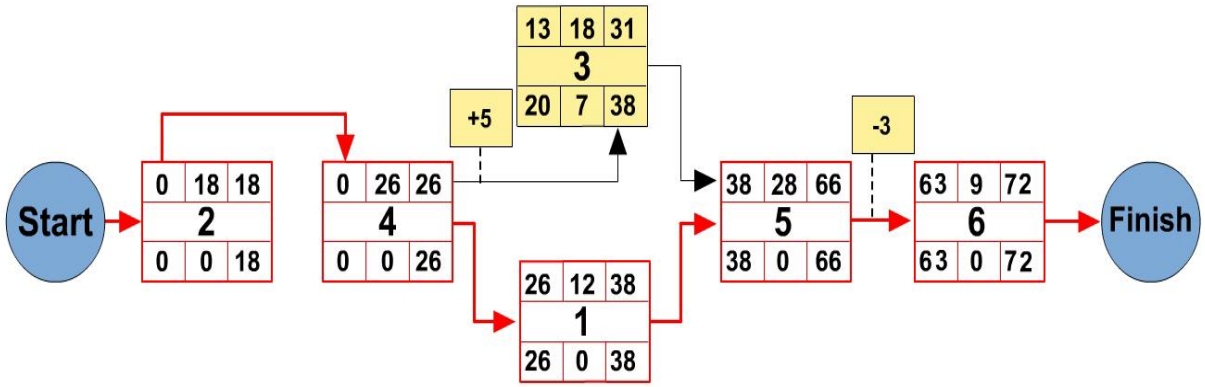
Based on PERT calculations, the higher the duration of the activity, the less risk is associated with it and in turn, the higher the confidence of completing the activity. For this activity, an extra 12 weeks is allowed – see table below. This is a selection based on high standard deviation associated with the activity. The project can select:

- one standard deviation of contingency = 6 weeks
- two standard deviation of contingency = 12 weeks
- three standard deviation of contingency = 18 weeks

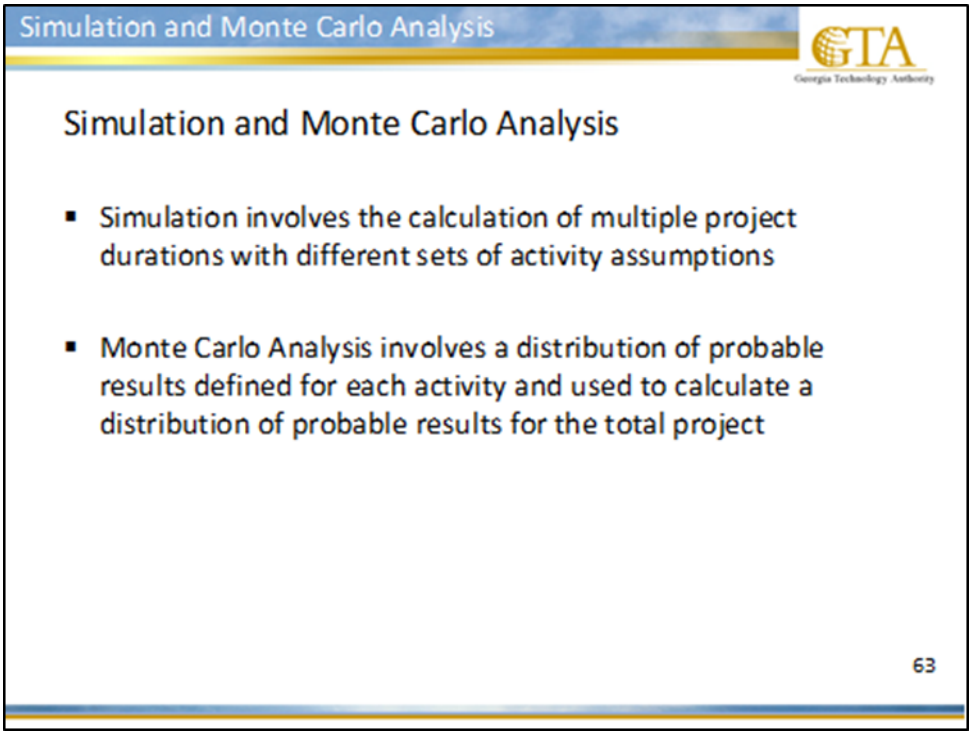
Activity Number	Activity	Duration				Contingency	New Expected
		Optimistic	Most Likely	Pessimistic	Expected		
1	Identify Vendors	5	10	27	12	-	12
2	Identify Contract Requirements	15	15	33	18	-	18
3	Interview Vendors	5	20	23	18	-	18
4	Advertise Proposal	20	25	36	26	-	26
5	Select Vendors	10	10	46	16	12	28
6	Sign Contract	5	5	29	9	-	9

Topic 1: Allocating Contingency (cont'd)

The project duration is now 72 weeks with the applied contingency:



Topic 1: Allocating Contingency (cont'd)



In the context of contingency activities, one of the most important techniques is that of simulation. **Simulation** involves the calculation of multiple project durations with different sets of activity assumptions. The most common simulation technique is Monte Carlo Analysis.

Monte Carlo simulation provides an alternative calculation method when there are

- many significant uncertainties and contingencies
- outcome probability distributions are required to compare risk-versus-value profiles
- complex profiling of time and cost distributions

Monte Carlo is a random number generating algorithm that is the basis of simulation. In a **Monte Carlo Analysis**, a distribution of probable results is defined for each activity and used to calculate a distribution of probable results for the total project.

Topic 2: Cost Budgeting and Baseline

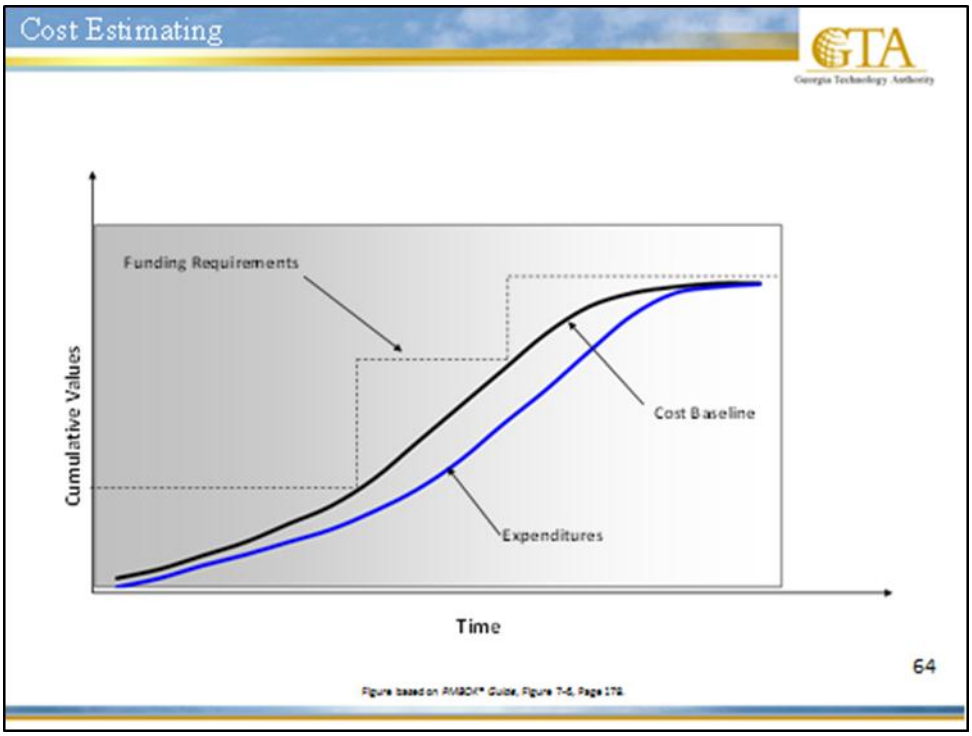


Figure based on *PMBOK® Guide*, Figure 7-6, Page 178.

Cost estimating is the development of an approximation (estimate) of the costs of the resources needed to complete project activities. In approximating cost, the estimator first needs to consider the causes of variation of the final estimate for purposes of better managing the project.

When a project is performed under contract, care should be taken to distinguish between cost estimating and pricing. Cost estimating involves developing an assessment of the likely quantitative result whereas pricing is the value that is placed on a market commodity. An estimate is the initial basis for deriving a price, however, a number of iterations of understanding the accuracy of estimates should be completed before presenting a price. A normal occurrence is with contracting, where a number of iterations of functionality / job estimation are performed before delivering a final price.

Cost Estimates

Cost estimates are quantitative assessments of the likely costs of the resources required to complete project activities.

Costs need to be estimated for all resources that will be charged to the project.

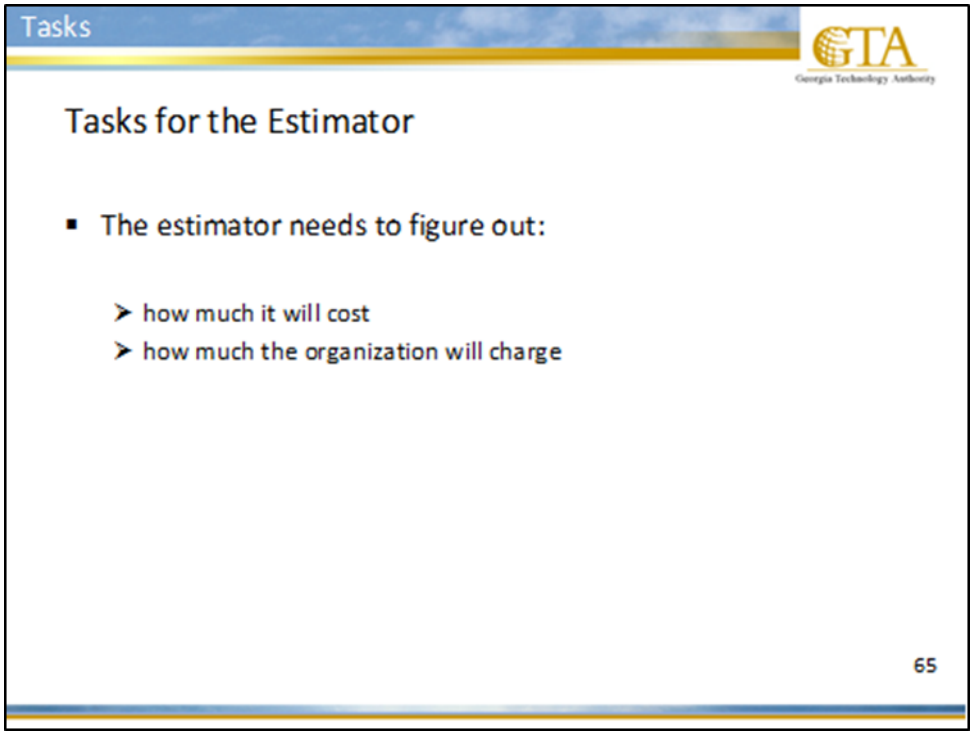
These include labor, materials, supplies, and special categories such as an inflation allowance or cost reserve to projects such as the implementation of e-voting systems in the state of Georgia, upgrading of the state employees retirement system or implementation of a unified state employee email system

Cost estimates are generally expressed in units of currency to facilitate comparisons both within and across projects. In some cases, the estimator may employ units of measure, such as staff hours or staff days, along with their cost estimates to **facilitate appropriate management control**.

Topic 2: Cost Budgeting and Baseline (cont'd)

Cost estimates may need to be refined during the project to reflect the additional detail available. In some application areas, there are guidelines for when such refinements should be made and what degree of accuracy is expected. It takes account of appropriate risk response planning, such as contingency plans.

Topic 2: Cost Budgeting and Baseline (cont'd)

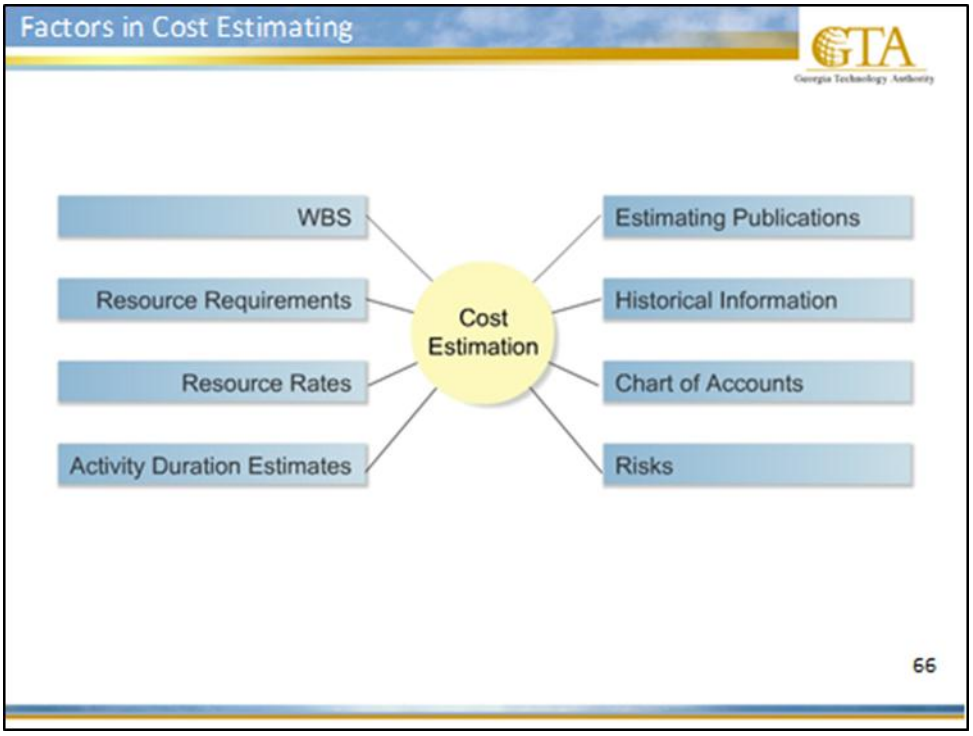


The **estimator** needs to figure out

- how much it will cost the performing organization to provide the product or service
- how much the performing organization will charge for the product or service

Cost estimating also involves **identifying and considering various costing alternatives**. For example, in most application areas, additional work during a design phase is widely held to have the potential for reducing the cost of the production phase. The cost-estimating process must take into account whether or not the cost of the additional design work will be offset by the expected savings.

Topic 2: Cost Budgeting and Baseline (cont'd)



Cost estimating involves developing an approximation (estimate) of the costs of the resources needed to complete project activities.

Estimation is a skill acquired over time. Project managers can achieve more realistic estimates if they take certain items into consideration. These include

- **the Work Breakdown Structure** – this is used to organize the cost estimates and to ensure that all identified work has been estimated
- **resource requirements** –the types of resources (people, equipment, materials) and the quantities required to perform project activities
- **resource rates** – the individual or group preparing the estimates must know the unit rates (e.g., staff cost per hour, bulk material cost per cubic yard) for each resource to calculate project costs. If actual rates are not known, the rates themselves may have to be estimated.
- **activity duration estimates –** these will affect cost estimates on any project where the project budget includes an allowance for the cost of financing (i.e., interest charges).

The tools and techniques involved in estimating costs include

- **analogous estimating** – uses the cost of previous, similar projects to estimate the cost of a similar project
- **parametric modeling** – uses project parameters in a mathematical model to predict project costs

Topic 2: Cost Budgeting and Baseline (cont'd)

- **bottom-up estimating** – involves estimating the cost of individual project activities and aggregating results to get total project cost

- **computerized tools** – project management software, spreadsheets, simulation and statistical tools are all widely used to assist with cost estimation

- **other cost estimating methods** – for example, vendor bid analysis

- **estimating publications –** commercially available data on cost estimating

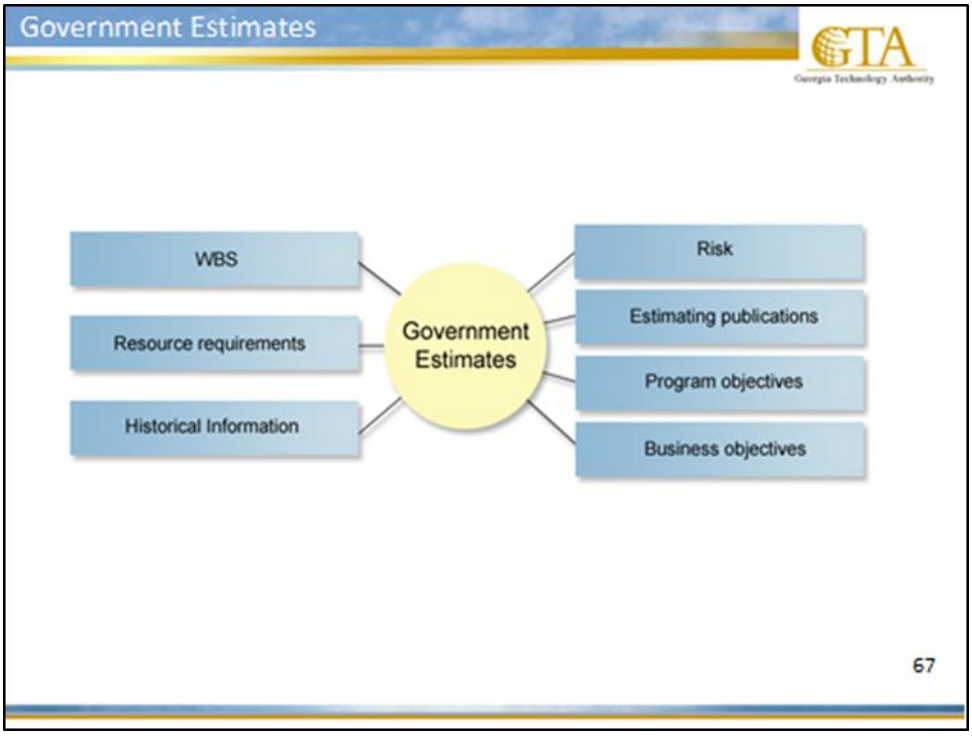
- **historical information –** information on the cost of many categories of resources is often available from one or more of the following sources:

  - **project files** – one or more of the organizations involved in the project may maintain records of previous project results that are detailed enough to aid in developing cost estimates. In some application areas, individual team members may maintain such records
  - **commercial cost-estimating databases** – historical information is often available commercially
  - **project team knowledge** – the individual members of the project team may remember previous actuals or estimates. While such recollections may be useful, they are generally far less reliable than documented results.

- **chart of accounts** – a chart of accounts describes the coding structure used by the performing organization to report financial information in its general ledger. Project cost estimates must be assigned to the correct accounting category.

- **risks** – the project team considers information on risks when producing cost estimates, since risks (either threats or opportunities) can have a significant impact on cost. The project team considers the extent to which the effect of risk is included in the cost estimates for each activity.

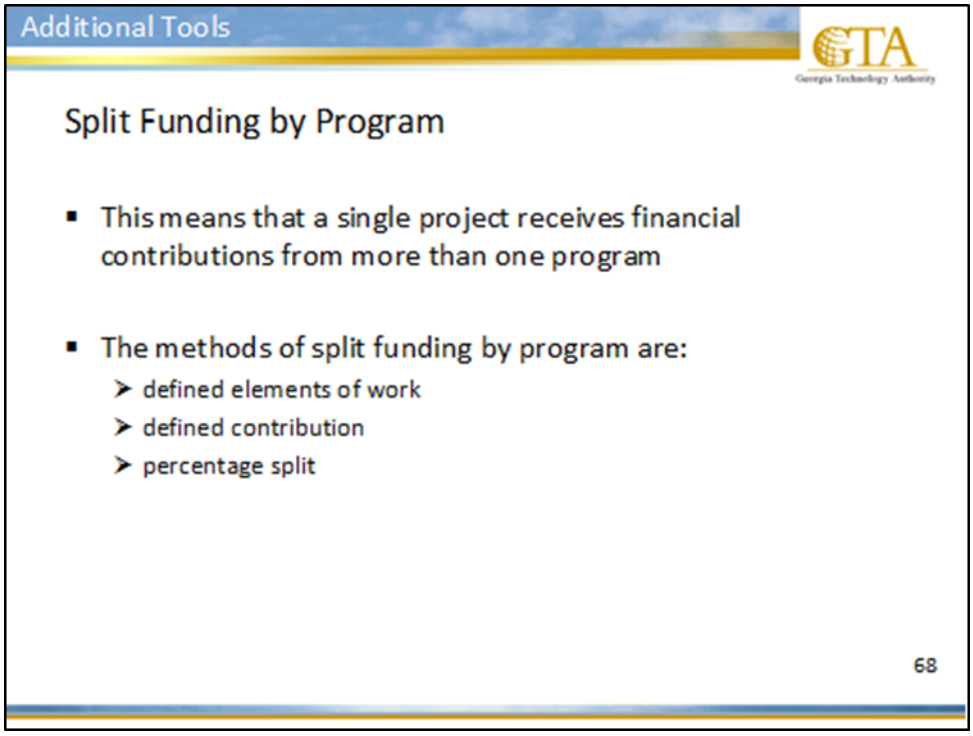
Topic 2: Cost Budgeting and Baseline (cont'd)



Representative bodies in large governments usually assign funds to programs rather than to individual projects (see *Government Extension to the PMBOK® Guide Third Edition*; Chapter 1). They set the rules for how funds are to be divided among individual programs. If the representative body budgets by program, each project must be funded from one or more of these programs.

Similar situations are common wherever new facilities are budgeted separately from rehabilitation. It generally makes sense to have a single contractor carry out both the new work and the rehabilitation at a particular location. This minimizes the overhead cost of developing and managing multiple contracts, as well as minimizing the disruption to the occupants of the facility.

Topic 2: Cost Budgeting and Baseline (cont'd)



On government projects, there are several additional tools used when cost budgeting (*Government Extension to the PMBOK® Guide Third Edition*; Chapter 7). These include:

- split funding by program
- matching funds
- split funding by fiscal year

Split funding means that a single project receives financial contributions from more than one program.

There are three possible methods of split funding by program.

- **Defined Elements of Work**
  In the Defined Elements of Work method, each program only pays for the elements that it wants. To the representative body, this would appear to make it the best choice. This method requires a detailed manual accounting system, however, because an automated system can seldom discern which elements are being worked on. Such a manual process is prone to inaccuracy, requires a large commitment of time for reporting and auditing, and has increased costs that generally outweigh the slight increase in the accuracy of charges.

  The Defined Elements of Work method also requires a far more detailed WBS than the other two methods. To capture each program's portion accurately, the WBS must be defined to a level where each program's portion maps uniquely to a set of WBS elements. This level of detail is generally far greater than what is needed to manage the project.

Topic 2: Cost Budgeting and Baseline (cont'd)

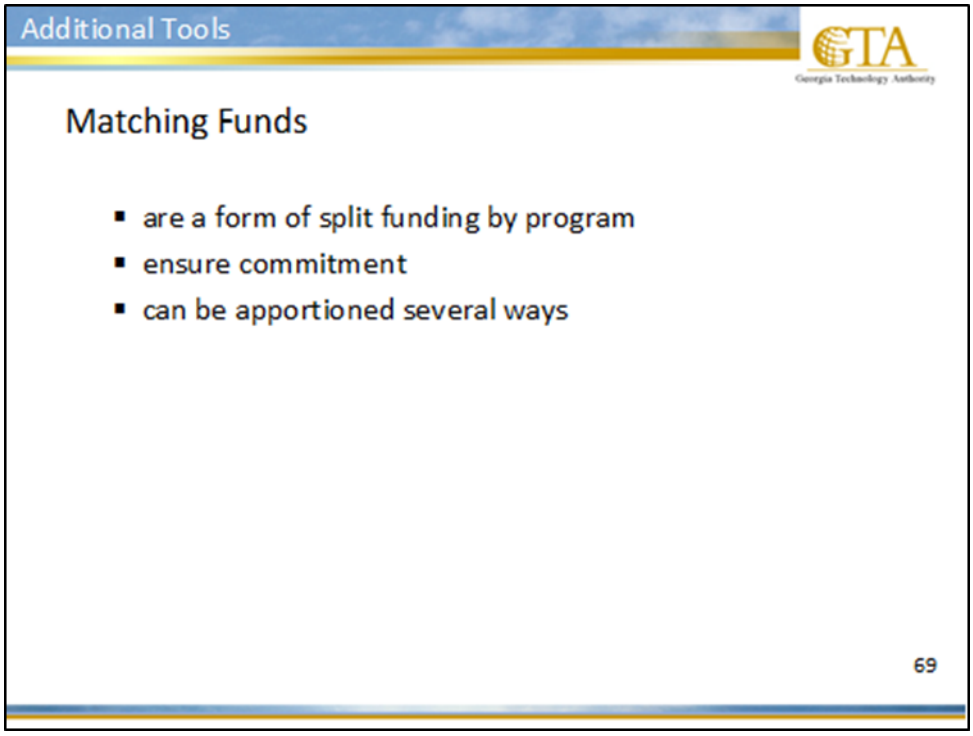
- **Defined Contribution**

  The Defined Contribution method does not require an amendment to the WBS. Usually, it is established as a "percentage split". When the limit is reached for the fixed programs, the split is changed to a 100 percent payment by the risk-bearing program. If the project is completed within budget, the change never occurs.

- **Percentage Split**

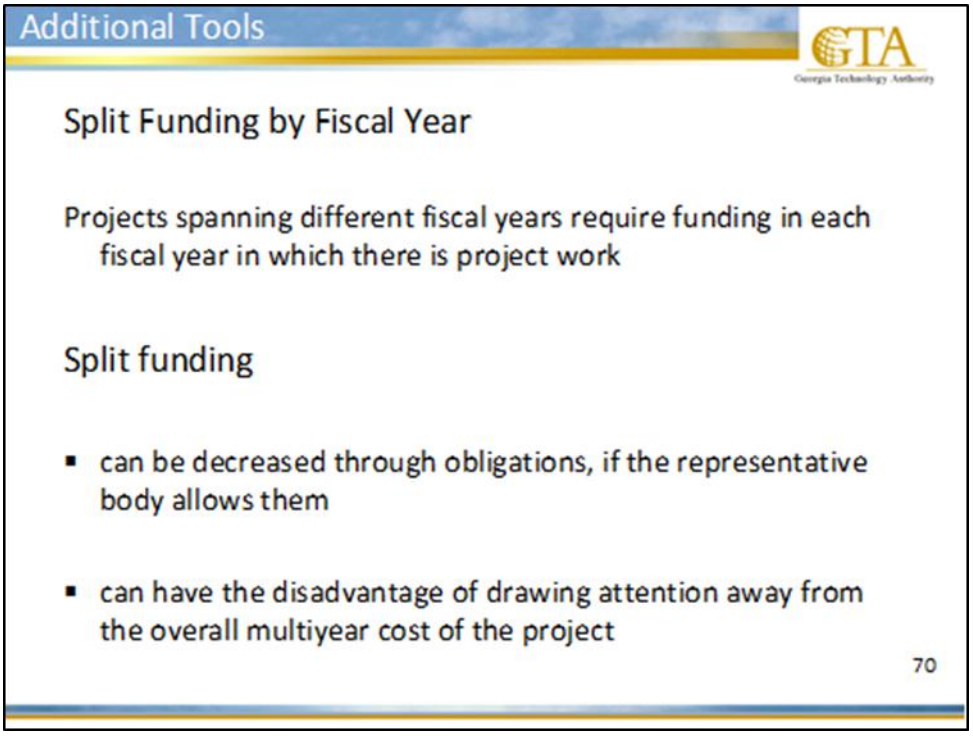
  Percentage Split is the simplest approach. The contribution of each program is estimated at the start of the project. On the basis of that estimate, each program bears its percentage of the project cost. As programs fund many projects, variances on one project will probably be counterbalanced by opposite variances on other projects.

Topic 2: Cost Budgeting and Baseline (cont'd)



Matching funds are a form of split funding by program. When governments delegate project selection to lower representative bodies, they often require those lower bodies to pay a portion of the project cost. This is designed to ensure that the lower government is committed to the project. Matching funds may be apportioned on a percentage basis or as a defined contribution.

Topic 2: Cost Budgeting and Baseline (cont'd)



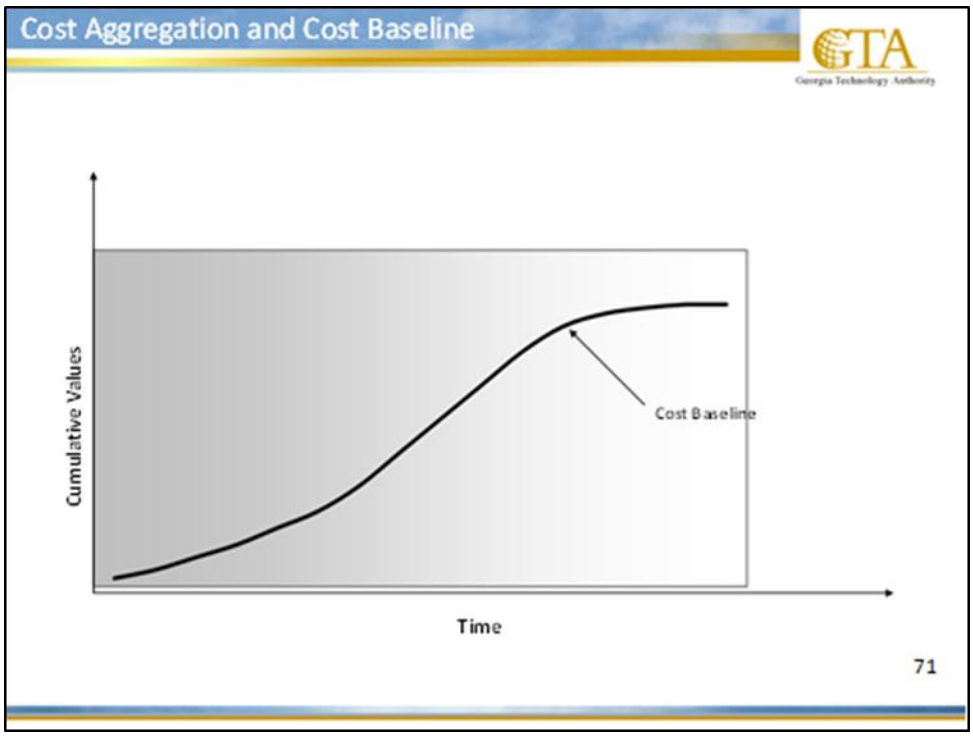
If a project begins in one fiscal year and ends in another, it will need **funding from the budget of each fiscal** year in which there is project work. This split funding by fiscal year can be decreased through obligations, if the representative body allows them.

Funding by fiscal year requires that project managers plan their work by fiscal year with great care. This is particularly true in large governments with many levels of review.

Fortunately, funds are generally appropriated to programs rather than individual projects. This means that project managers can use funds from projects that underrun their fiscal year budgets to fund the overruns in other projects. These are fiscal year variances, not variances in the total cost of the project.

However, **fiscal year funding** can occasionally have the opposite effect to what is intended. While annual budgets are intended to establish limits on the executive, a focus on fiscal years can also divert attention away from overall multi-year costs. This can result in projects incurring large overall cost overruns without the representative body being aware of the fact. To avoid this problem, representative bodies should demand multiyear reports.

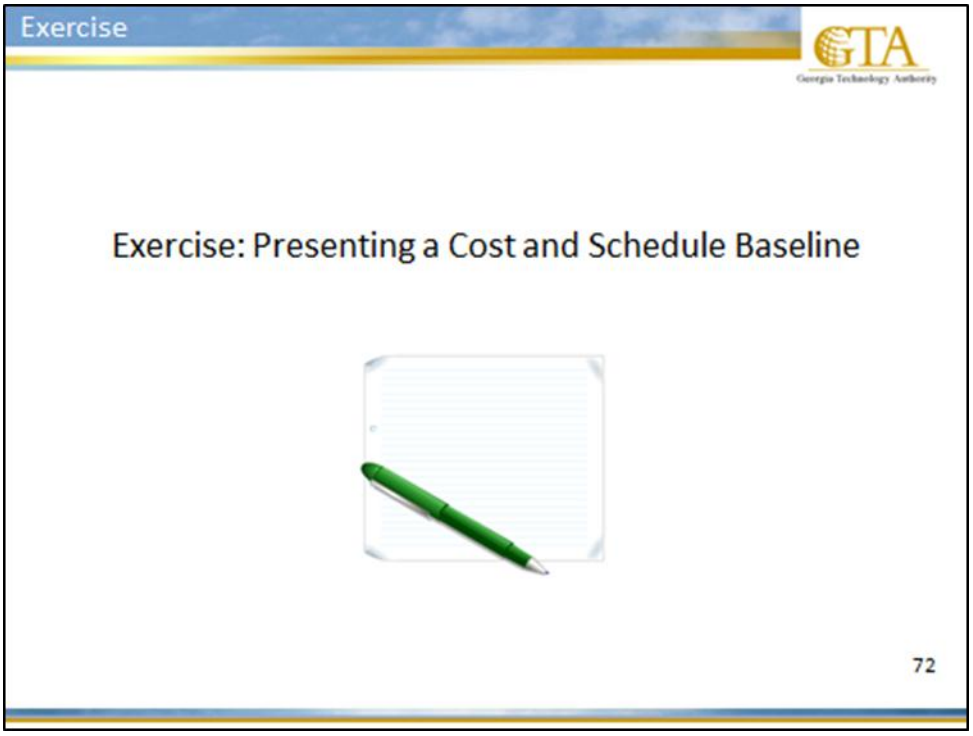
Topic 2: Cost Budgeting and Baseline (cont'd)



Cost Aggregation
The activity cost estimates are aggregated by work packages in accordance with the WBS. The work package cost estimates are then progressively aggregated for the higher component levels of the WBS and ultimately for the entire project.

Cost Baseline
The cost baseline is a time-phased budget that is used to measure and monitor overall cost performance on the project. It is developed by summing the estimated costs by period and is usually displayed in the form of an S-curve.

Topic 3: Exercise - Presenting a Cost and Schedule Baseline



You are in the middle of the planning phase for the light rail system project. You have being requested to identify the cost that would be involved in surveying and reviewing the site of the light rail system with the delivery of preliminary designs that can then be used to award a fixed-price contract to a civil-design vendor.

The following are the list of activities from the work breakdown structure (including expected durations), the latest network diagram, and a table of estimated costs.

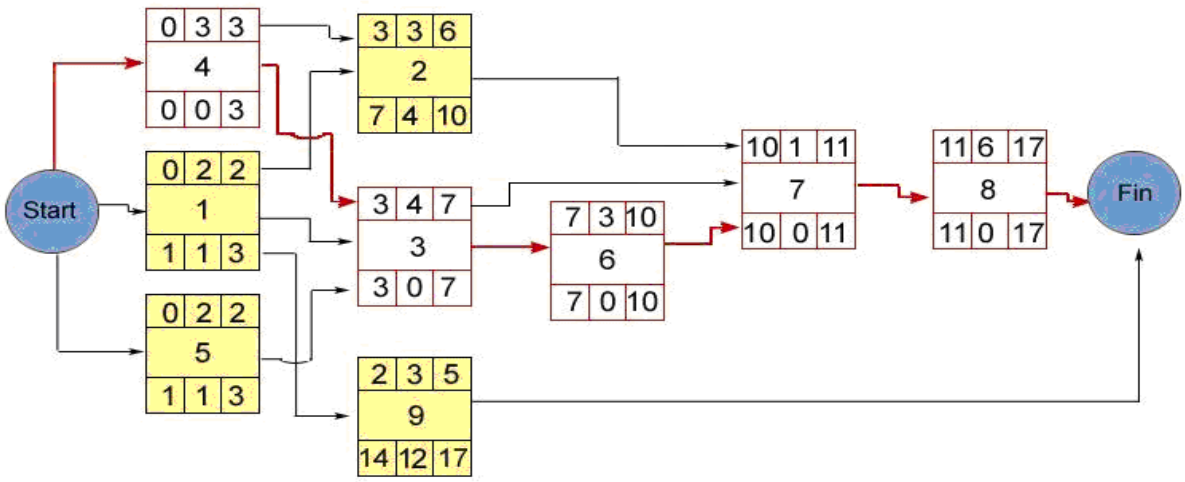
Your assignment is **to present a cost baseline budget** that represents the agreed price for this project, **plus the rate at which the budget will be spent over time**.

Topic 3: Exercise - Presenting a Cost and Schedule Baseline (cont'd)

Duration Estimates

Activity Number	Activity	Duration			
		Optimistic	Most Likely	Pessimistic	Expected
1	Identify Scope of Site Reviews	1	1	7	2.0
2	Environmental Review of Sites	3	3	3	3.0
3	Perform Site Surveys	3	3	9	4.0
4	Identify Vendors to Perform Surveys	1	3	5	3.0
5	Identify Rail Sites	1	2	3	2.0
6	Architecture Review	1	2	9	3.0
7	Review Surveys	1	1	1	1.0
8	Agree on Design Scope	4	6	8	6.0
9	Identify Vendors to Perform Design Contract	2	2	8	3.0

Network Diagram with Duration Applied



Cost Estimates

Activity Number	Activity	Duration			
		Optimistic	Most Likely	Pessimistic	Expected
1	Identify Scope of Site Reviews	$1,000	$1,000	$1,000	$1,000
2	Environmental Review of Sites	$3,000	$5,000	$8,000	$5,167
3	Perform Site Surveys	$5,000	$10,000	$25,000	$11,667
4	Identify Vendors to Perform Surveys	$5,000	$5,000	$10,000	$5,833
5	Identify Rail Sites	$1,000	$1,000	$1,000	$1,000
6	Architecture Review	$1,000	$1,000	$1,000	$1,000
7	Review Surveys	$500	$500	$1,000	$583
8	Agree on Design Scope	$10,000	$13,000	$30,000	$15,333
9	Identify Vendors to Perform Design Contract	$5,000	$5,000	$10,000	$5,833

Exercise Worksheet

Exercise Worksheet

Lesson 5: Summary

The lesson is now completed and the following topics have been covered:

Topic 1: Allocating Contingency

- Project teams can choose to incorporate contingency time or cost into an overall schedule or budget to allow for schedule risk.

- As the activities progress through execution, it is possible to adjust the contingency activity, as measured by the time, cost, and resource consumption of the activities.

- **Contingency reserve** is the amount of money or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization.

From this topic you should **take away** the following point:

- PERT (3-point estimation) can be used to demonstrate contingency allocation with a range of data (i.e. optimistic and pessimistic) to understand contingency

Topic 2: Cost Budgeting and Baseline

- **Cost estimating** is the development of an approximation (estimate) of the costs of the resources needed to complete project activities.

- Estimation is a skill acquired over time. Certain items can contribute in presenting realistic estimates. These include: the **work breakdown structure, resource requirements, resource rates, and activity duration estimates**

- The tools and techniques involved in estimating costs include **analogous estimating, parametric modeling, bottom-up estimating, computerized tools, estimating publications, historical Information, project files, commercial cost-estimating databases, project team knowledge, chart of accounts,** and **risks.**

- On government projects, there are several additional tools used when cost budgeting. These include **split funding by program, matching funds,** and **split funding by fiscal year.**

From this topic you should **take away** the following points:

- a cost budget is the aggregation of cost estimates against project durations
- a cost baseline is an agreed cost budget

Topic 3: Presenting a Cost and Schedule Baseline

- An exercise is presented to demonstrate how to present a cost and schedule baseline

From this topic you should **take away** the following point:

- several tools and techniques can be used to generate a cost budget and baseline

Lesson 6: Controlling the Project Plan

Topic 1: Using Cost and Schedule Baselines to Control Projects

Topic 2: Project Performance Measurement

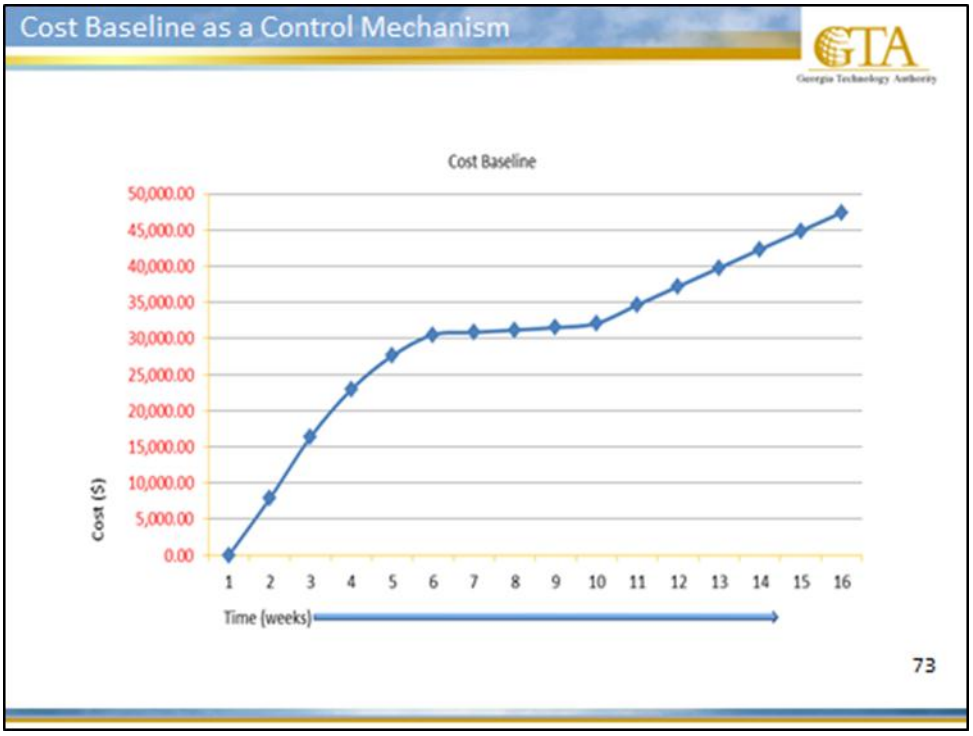
Topic 3: Forecasting Project Completion

Student learning objectives

After completing this lesson, you should be able to

- explain the significance of the cost baseline and how it is used to measure project schedule and budget performance
- describe efficient tools and techniques for controlling project performance
- describe how earned value can be used as a tool and technique to control schedules and budgets
- explain how to use performance measurement tools and techniques to forecast project completion

Topic 1: Using Cost and Schedule Baselines to Control Projects



Cost budgeting involves allocating the overall cost estimates to individual activities or work packages to establish a cost baseline for measuring project performance.

The cost baseline is a timed-phased budget that is used to measure and monitor cost performance on a project. It is developed by summing estimated costs by period. It is usually displayed in the form of an S-curve.

Schedule and cost control are the processes that are used to control changes to both the schedule and budget respectively. Schedule control involves

- influencing the factors that create schedule changes to ensure that changes are agreed upon
- determining that the schedule has changed
- managing the actual changes when and as they occur

Schedule control must be thoroughly integrated with the other control processes, such as cost control, scope change control, and quality control.

Two important **outputs from schedule control** are

- **schedule updates –** any changes to the schedule information used to manage a project. Any changes must be communicated to appropriate stakeholders. Schedule updates may also require changes to other aspects of a project plan.
- **revisions –** any changes to the schedule start and finish dates in the approved project schedule. Revisions are typically incorporated in response to scope changes or changes to estimates.

Topic 1: Using Cost and Schedule Baselines to Control Projects (cont'd)

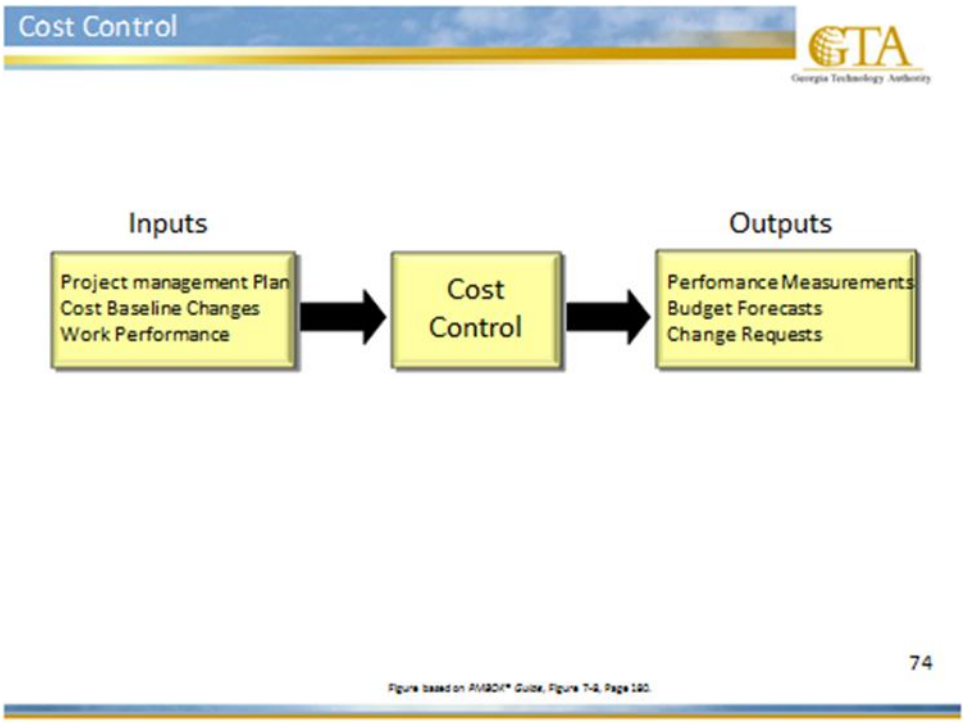


Figure based on *PMBOK® Guide*, Figure 7-8, Page 180.

Cost control involves

- **influencing** the factors that create changes to the cost baseline to ensure that changes are agreed upon
- determining that the **cost baseline** has changed
- **managing** the actual changes as and when they occur

Cost control activities include

- monitoring cost performance to identify and understand variances (both positive and negative) from plan
- making sure that all necessary changes are recorded correctly in the cost baseline
- preventing incorrect, inappropriate, or unauthorized changes from being included in the cost baseline
- informing stakeholders about authorized changes
- taking necessary action to bring expected costs within acceptable limits

Cost control must be thoroughly integrated with the other control processes, such as scope change control, schedule control, and quality control. For example, the wrong response to cost variances can result in quality or schedule problems, or lead to an unacceptable level of risk later in the project.

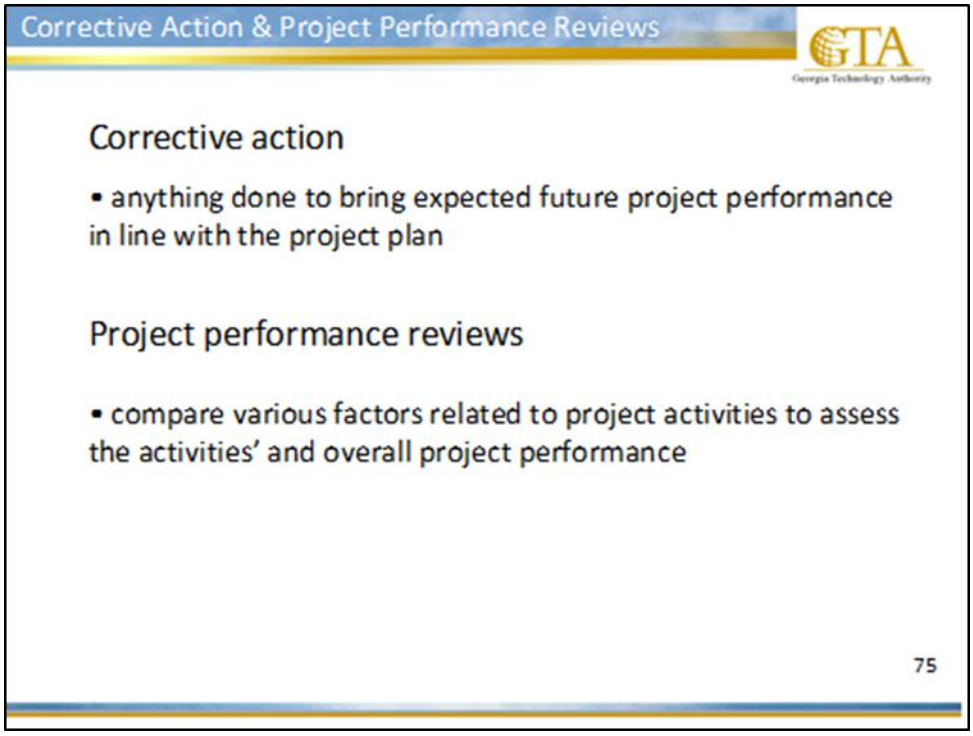
Two important **outputs from cost control** are

- **revised cost estimates** – these are changes to the cost information used to manage a project. Project managers must notify relevant stakeholders when such changes are required. Revised cost estimates may require changes to other aspects of a project plan.

Topic 1: Using Cost and Schedule Baselines to Control Projects (cont'd)

- **budget updates** – these are changes to an approved cost baseline that are required in response to scope changes. Cost variances may be so severe that rebaselining is required to provide a realistic measure of performance.

Topic 1: Using Cost and Schedule Baselines to Control Projects (cont'd)



Managing and maintaining cost and schedule control allows project managers to perform two important, related functions: taking corrective action and conducting project performance reviews.

Corrective action is anything done to bring expected future project performance in line with the project plan.

In the area of time management, corrective action often involves expediting: taking special action to ensure completion of an activity on time or with the least possible delay. It also frequently requires root-cause analysis to identify the cause of the variation.

Schedule recovery can be planned and executed for activities delineated in the schedule and need not only address the activity causing the deviation.

Project performance reviews compare various factors related to project activities to assess the activities' performance and the overall project performance. Comparisons made include

- planned start time versus actual start time
- planned completion time versus actual completion time
- number of early starts versus late starts
- activities over running and under running budget
- milestones due and milestones met

Performance reviews are generally used in conjunction with one or more of the following performance-reporting techniques:

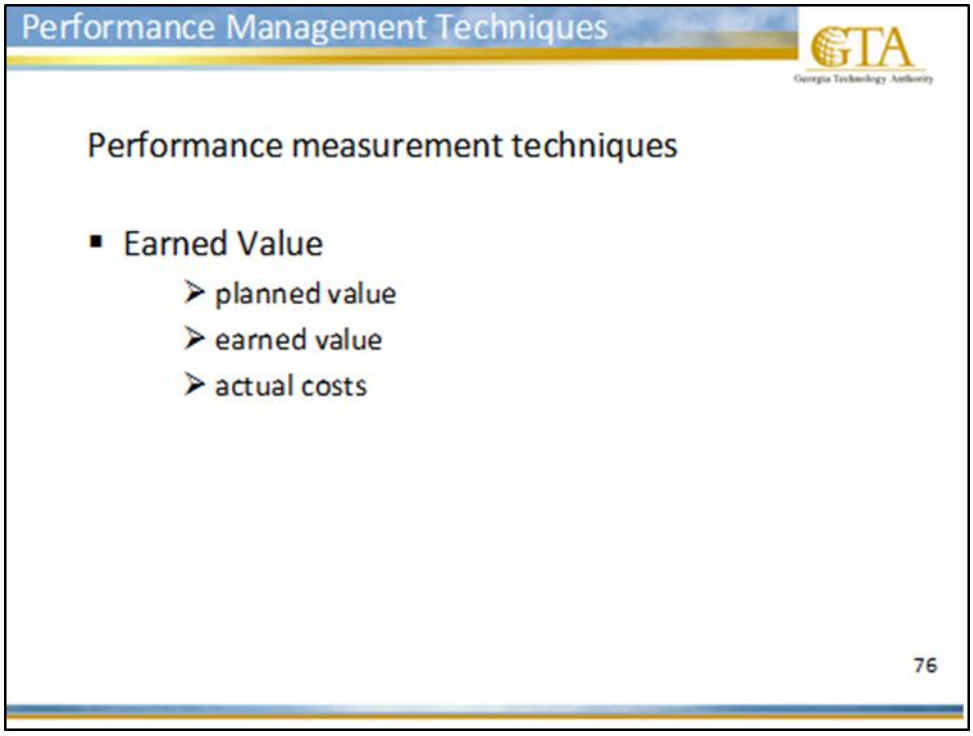
- **variance analysis** – involves comparing actual project results to planned or expected results. Cost and schedule variances are the most frequently analyzed, but variances from plan in the areas of scope, resource, quality, and risk are often of equal or greater importance.

Topic 1: Using Cost and Schedule Baselines to Control Projects (cont'd)

- **trend analysis** – involves examining project results over time to determine if performance is improving or deteriorating

- **earned value analysis** – involves comparing planned results to actual performance results and actual costs

Topic 2: Project Performance Measurement



Performance measurement techniques are used to assess the magnitude of any variances in project performance. The **earned value management (EVM)** technique is used to compare the value of work completed at the original allocated budget amount to both the budgeted cost of the work planned, and to the actual cost for completed work. EVM is particularly useful for cost control.

There are two primary methods of measurement:

- **measurable effort –** discrete increments of work with a definable schedule for accomplishment, whose completion produces tangible results

- **level of effort** – work that does not lend itself to subdivision into discrete scheduled increments of work, such as project support and project control

Earned value (EV) analysis calculates three key values for each project activity:

- **planned value (PV)** – the total budgeted planned amount to be spent on an activity up to a certain point in time. The budgeted cost for work scheduled is the budgeted amount of cost for work scheduled to be accomplished, plus the amount or level of effort or apportioned effort scheduled to be accomplished in a given time period.

- **actual cost (AC)** – the total cost incurred in achieving work on the activity during a certain period of time. AC must correspond in definition and coverage to the budgeted amount for PV and EV. The actual cost for work performed is the amount reported as actually expended in completing the work accomplished within a given time period.

- **EV** – the budgeted amount for the work actually completed. Budget cost for work performed is the budgeted amount of cost for completed work, plus budgeted for level of effort or apportioned effort activity completed within a given time period.

Topic 2: Project Performance Measurement (cont'd)

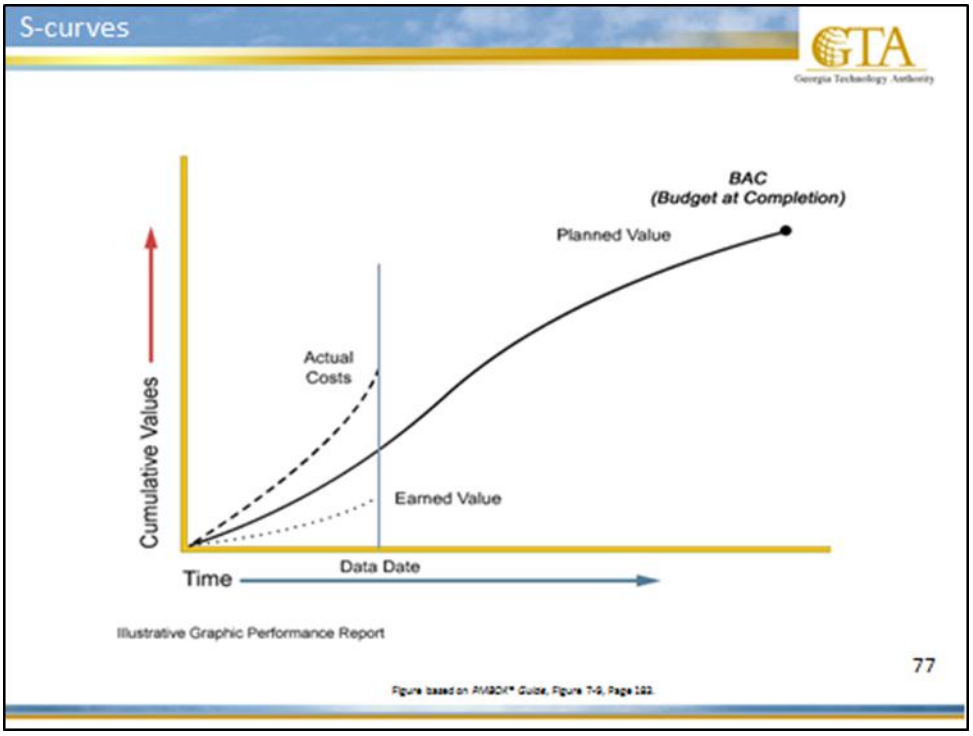


Figure based on *PMBOK® Guide*, Figure 7-9, Page 183.

Project managers use these three values in combination to determine whether or not work is being achieved as planned. The most commonly used measures are

- **cost variance (CV) [CV = EV – AC]**
- **schedule variance (SV) [SV = EV – PV]**

CV and SV can be converted to efficiency indicators to reflect the cost and schedule performance of any project. SV will ultimately = 0 when the project is completed because all of the planned values will have been earned.

The most frequently used cost-efficiency indicator is the Cost Performance Index (**CPI = EV/AC**). A **CPI** value less than 1.0 indicates a cost overrun of the estimates, whereas a value greater than 1.0 indicates a cost under run of the estimates.

The Schedule Performance Index **(SPI = EV/PV)** is used to estimate the completion date and is sometimes used in conjunction with the **CPI** to forecast the project completion estimates.

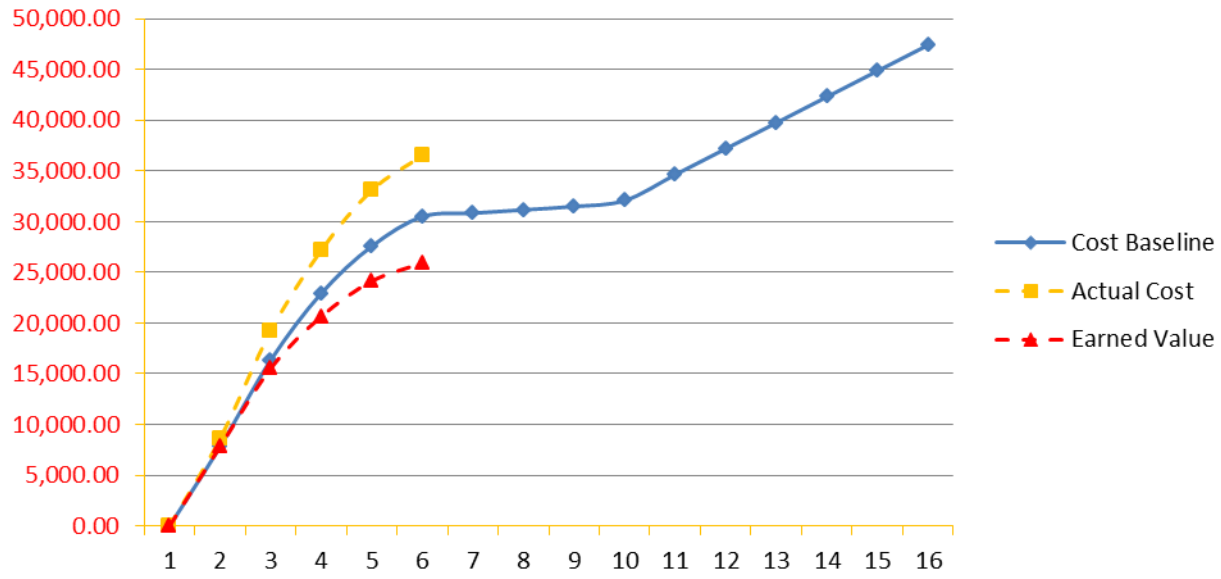
S-curves are used to display cumulative **EV** data for a project that is over budget and behind the work plan (worst case).

Earned value analysis in the various forms integrates scope, cost (or resource), and schedule measures to enable the project management team determine project performance.

Topic 2: Project Performance Measurement (cont'd)

Example

Six weeks into the project, you find that the actual costs are $16,256 and only 85% of the required work has been completed. The following graph demonstrates the status of the project:



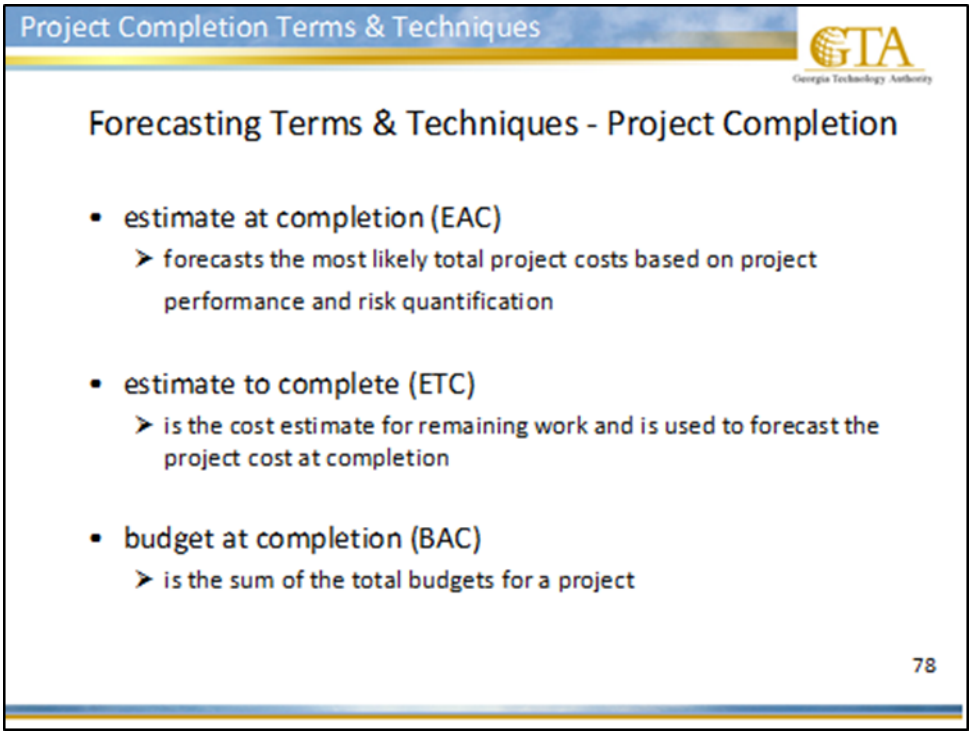
From this information it is apparent that the situation is not good. However, only the CPI and SPI show the exact position:

Schedule Variance = EV - PV	$-4,575.00
Schedule Performance Index = EV/PV = $25,925/$30,500	.85

Schedule Variance = EV - PV	$-4,575.00
Schedule Performance Index = EV/PV = $25,925/$30,500	.85

From this data, it is clear that the project is behind schedule and over-budget.

Topic 3: Forecasting Project Completion



Most projects will have someone responsible for performing work on project controls, management controls and so on. Anytime the physical work was actually accomplished on payment invoices being processed prior to paying a supplier, the cost engineer is utilizing a simple form of **earned value**. He or she is focusing on the critical relationship between the actual costs being expended against the physical work actually done on the project.

A cost center will focus on the **true cost performance**: what we got ...for what we spent. The earned value concept requires that a project performance measurement plan be created, called the **planned value**, typically defined with use of the project's scheduling system, and then the earned value measured against the planned value, also with use of the project's scheduling system.

The physical earned value performed is then related to the actual costs spent to accomplish the physical work, providing a measure of the project's true cost performance.

Earned value provides project managers with a type of “early-warning" buzzer that sounds, allowing them to take the necessary corrective action should the project be spending more than it is physically accomplishing.

Such warning signals become available to management as early as 15 to 20 percent into a new project, in ample time to take corrective measures to alter an unfavorable outcome.

An **estimate at completion (EAC)** forecasts the most likely total project costs based on project performance and risk quantification.

Topic 3: Forecasting Project Completion (cont'd)

EAC forecasting techniques include some variation of the following:

- **EAC** = actual costs to date plus a new estimate for all remaining work

  This technique is used when past performance indicates that the original estimating assumptions were fundamentally flawed, or that they are no longer relevant to a change in conditions.
  Formula: **EAC = AC + ETC**

- **ETC** = the amount of money and time that is required to complete the project from the actual cost
  Formula: **EAC- AC**

- **EAC** = actual costs to date plus remaining budget (**BAC – EV**)

  This technique is used when current variances are regarded as atypical and the project management team expectations are that similar variances will not occur in the future.
  Formula: **EAC = AC + BAC – EV**

- **EAC** = actual cost to date plus the remaining project budget (**BAC – EV**) modified by a performance factor, frequently the cumulative cost performance index (**CPI**)

  This technique is used when current variances are regarded as typical of future variances.

  Formula: **EAC = AC + ((BAC – EV)/CPI)** – this CPI is the cumulative CPI

Each of these techniques can be the correct approach for any given project and will provide the project management team with a signal if the EAC forecasts exceed acceptable tolerances.

Topic 3: Forecasting Project Completion (cont'd)

Example

To complete our analysis of the status of a project, we must calculate the budget at completion (BAC) and the estimate at completion (EAC). The parameters for this analysis can be determined by asking the following questions for the Georgia Light Rail project:

- **how much work should be done to get the preliminary designs completed?** – i.e., what is the PV?
- **how much work is completed at the present moment?** – i.e., what is the EV?
- **how much did the actual completed work done cost?** – i.e., what is the AC?
- **what was the total job of completing the preliminary designs supposed to cost?** – i.e., what is the BAC?

The BAC is the sum of the total budgets allocated to the project and is equivalent to the final point on the project baseline. For the Georgia Light Rail project, the BAC to deliver the preliminary designs is approximately $50,000. It is what the project effort should cost.

The estimate at completion identifies either the hours or the dollars that represent a realistic appraisal of the work when performed. It is equal to the sum of all costs to date, plus the estimate of all remaining work.

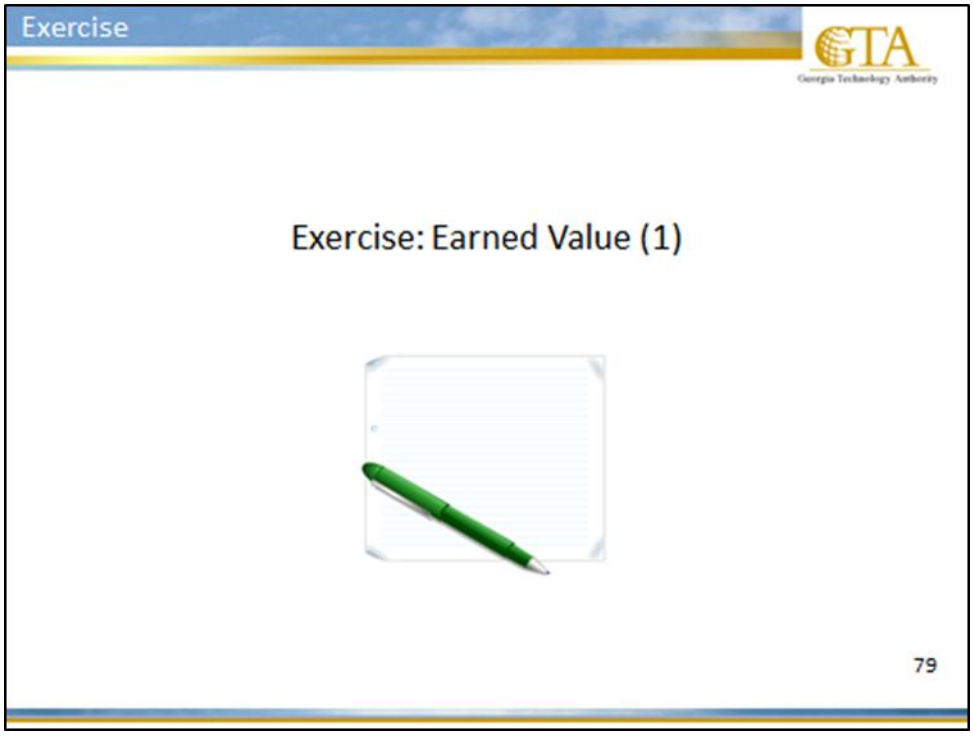
At week 4, the AC is $16,256 and the EV is $11,617. Using the current variances, regarded as typical of future variances, the formula AC + ((BAC – EV)/CPI) can be used to determine the EAC (where the CPI is 0.71 or 71%)

The EAC is AC + ((BAC – EV)/CPI)
$16,256 + (($50,000 - $11,617) / 0.71)
$16,256 + $54,061
$70,317

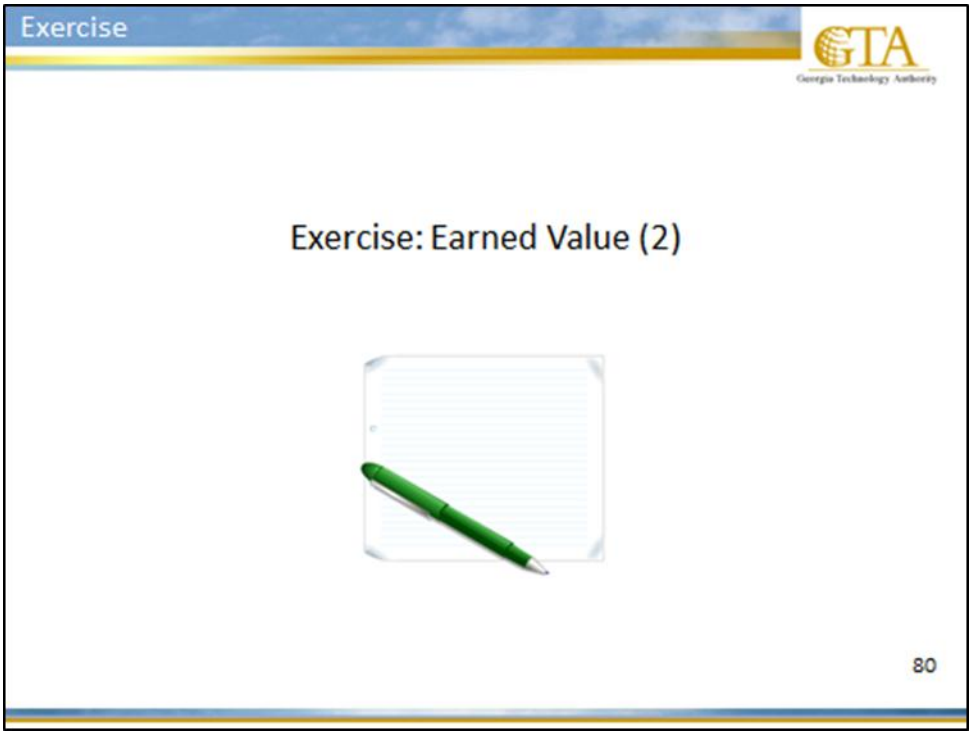
The EAC indicated the amount of dollars required to complete the project. The estimate at completion is the best estimate of the total cost of the project as it is based on current performance

It is a periodic evaluation of project status, usually on a monthly basis or until a significant change has been identified.

Topic 3: Exercise – Earned Value (1)



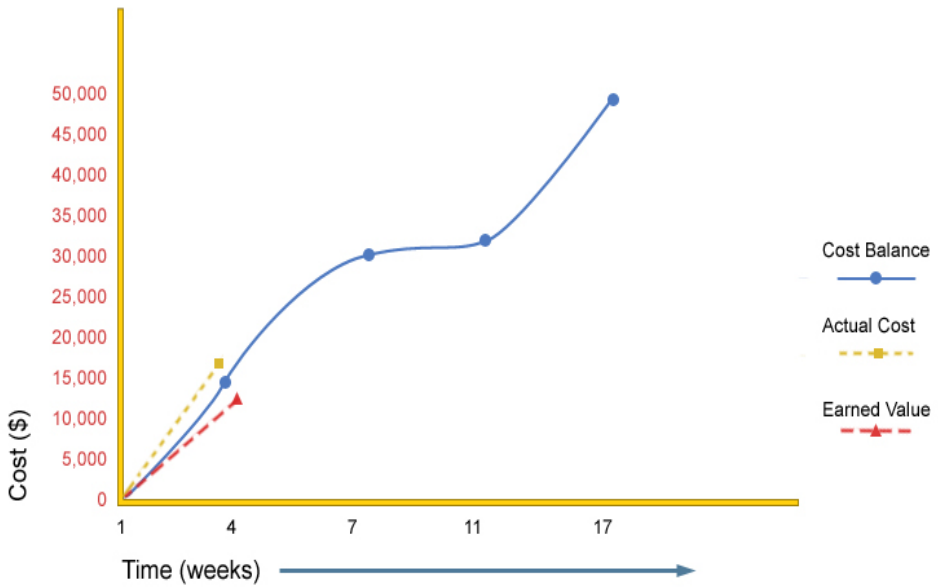
Topic 3: Exercise – Earned Value (2)



You are in the middle of the planning phase for the light rail system project. You have been requested to identify the cost that would be involved in surveying and reviewing the site of the light rail system with the delivery of preliminary designs that can then be used to award a fixed-price contract to a civil-design vendor.

The budget at completion is $47,500.

Topic 3: Exercise – Earned Value (2) (cont'd)



After 7 weeks, the planned value is $30,000 with the actual cost running at $33,000 and the earned value at $27,000. However at week 11, the planned value is $32,000 and the actual costs is $34,000 with the earned value at $30,000.

Use the following table and formulas to comment on the performance of the project between week 7 and week11.

Week Number	Planned Value	Actual Cost	Earned Value	Cost Performance Index (CPI)	Schedule Performance Index (SPI)
7	$30,000	$33,000	$27,000		
11	$32,000	$34,000	$30,000		

CPI = EV/AC
SPI = EV/PV

Estimate the cost at completion (referenced as estimate at completion (EAC)) at week 11 using the formula **EAC = AC + ((BAC – EV)/CPI)**

Lesson 6: Summary

The lesson is now completed and the following topics have been covered:

Topic 1: Using Cost and Schedule Baselines to Control a Project

- **Schedule and cost control** involves influencing the factors that create schedule changes to ensure that changes are agreed upon, determining that the schedule or cost baseline has changed, and managing the actual changes when and as they occur.

- Two important **outputs from schedule control** are **schedule updates** and **revisions.** Two important **outputs from cost control** are **revised cost estimates** and **budget updates.**

- **Corrective action** is anything done to bring expected future project performance in line with the project plan.

From this topic you should **take away** the following point:

- linking schedule and cost control to performance measurements with an efficient tool and technique (i.e. earned value) is an effective method of performance measurement

Topic 2: Project Performance Measurement

- Performance measurement techniques are used to assess the magnitude of any variances in project performance.

- The **earned value management (EVM)** technique is used to compare the value of work completed at the original allocated budget amount to both the budgeted cost of the work planned, and to the actual cost for completed work.

- **Earned value (EV) analysis** calculates three key values for each project activity:
    - planned value **(PV)**
    - actual cost **(AC)**
    - earned Value **(EV)**

- Project managers use these three values in combination to determine whether or not work is being achieved as planned. The most commonly used measures are
    - **cost variance (CV) [CV = EV – AC]**
    - **schedule variance (SV) [SV = EV – PV]**

From this topic you should **take away** the following point:

- several formulas are associated with earned value as a schedule and budget control tool

Topic 3: Forecasting Project Completion

- An **estimate at completion (EAC)** forecasts the most likely total project costs based on project performance and risk quantification.

Lesson 6: Summary (cont'd)

- EAC forecasting techniques include some variation of the following:

  - **EAC** = actual costs to date plus a new estimate for all remaining work.
    The formula is **EAC = AC + ETC**

  - **ETC** = the amount of money and time that is required to complete the project from the actual cost.
    The formula is **EAC- AC**

  - **EAC** = actual costs to date plus remaining budget.
    The formula is **EAC = AC + BAC – EV**

  - **EAC** = actual cost to date plus the remaining project budget.
    The formula is **EAC = AC + ((BAC – EV) / CPI)** – this CPI is the cumulative CPI.

From this topic you should **take away** the following points:

- calculating earned value indices and variances are part of EAC
- earned formulas are used for forecasting estimate at completion

Appendix 1: Sample Answers

Lesson 1, Topic 1: Question – Introduction to Project Time and Cost Management

Lesson 1, Topic 4: Exercise - Producing and Using a Project Deliverable

Lesson 2, Topic 1: Exercise – Constructing a Logic Diagram

Lesson 2, Topic 5: Exercise – Producing an Activity Sequence

Lesson 3, Topic 4: Exercise – Compressing a Schedule

Lesson 4, Topic 5: Exercise – Delivering a Project Estimate

Lesson 5, Topic 3: Exercise - Presenting a Cost and Schedule Baseline

Lesson 1, Topic 1: Question – Introduction to Project Time and Cost Management

Question

Both schedules and budgets are necessary parts of any project plan.

What do you think is the backbone of any good schedule or budget?

Sample answer
The backbone of any good schedule or budget is a well-rounded work breakdown structure that includes all work packages to fulfill the scope of the project requirements. A well-rounded work breakdown structure has the following characteristics:

- the entire scope of work is included
- the agreed work packages can be associated with both a cost (i.e. resourcing, materials, etc.) and a time (i.e. a start and finish time can be interpreted)
- the work package can be identified at the lowest level and each preceding level is within the scope of the project

Effective time and cost management is necessary to create a well-rounded WBS, which in turn is necessary for successful completion of the project. As each time and cost management process is completed, the WBS is updated and refined. The main processes of time management are activity definition, duration estimation, schedule development, and control. The main processes of cost management are estimation, budgeting, and control.

Lesson 1, Topic 4: Exercise - Producing and Using a Project Deliverable

Exercise

You are about to commence the planning phase for the light rail system project. Because it is such a large project, the team has decided to break up the planning according to various functions. You have been requested to identify the work involved in surveying and reviewing the site of the light rail system, including the delivery of preliminary designs that can be used to award a fixed-price contract to a civil-design vendor.

Your first task is to define the scope of work through a work breakdown structure.

Sample answer

The following is a sample work breakdown structure for the light rail system.

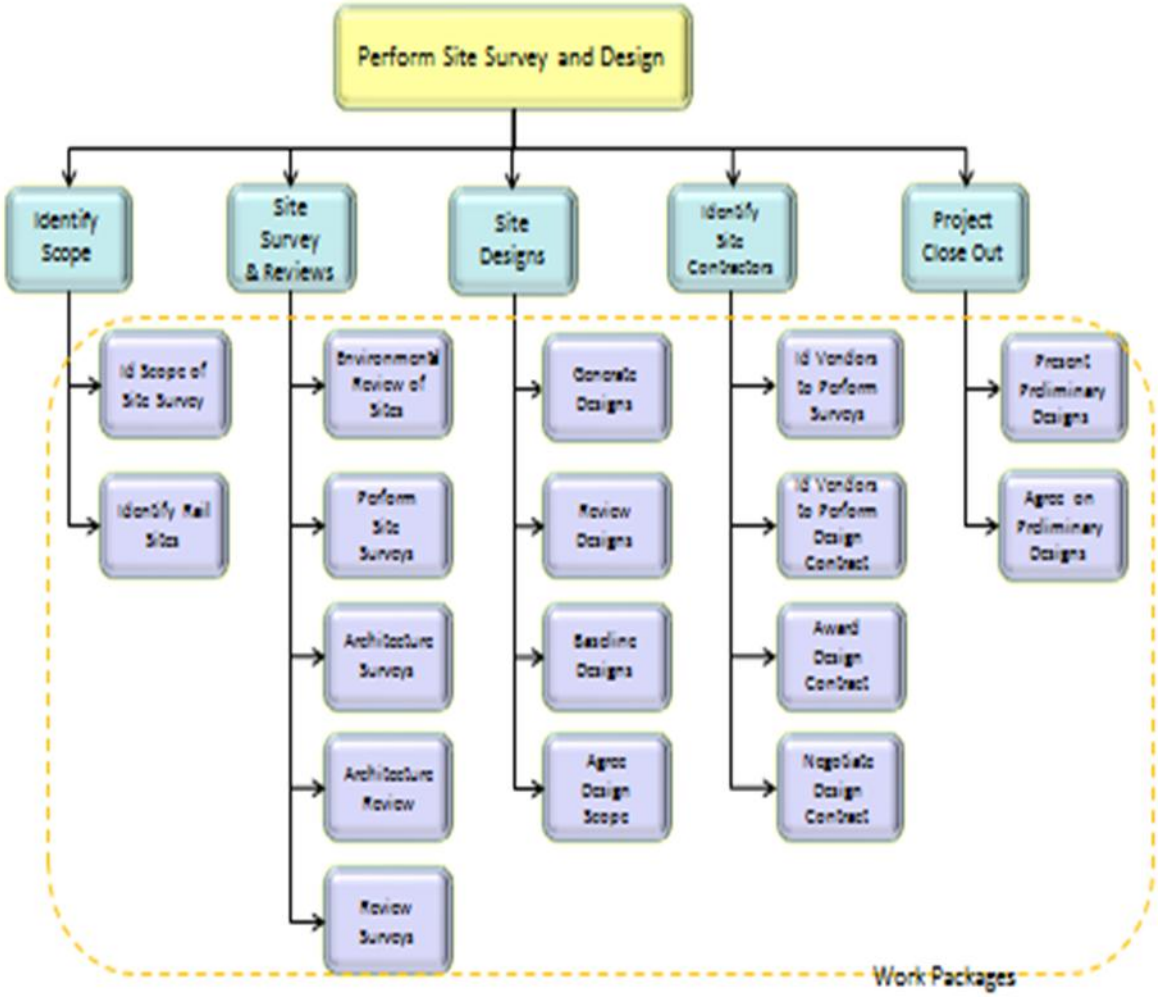


Figure based on the Project Management Institute, *A Guide to the Project Management Body of Knowledge, (PMBOK® Guide) – Fourth Edition, Project Management Institute, Inc., 2008.*

Lesson 2, Topic 1: Exercise – Constructing a Logic Diagram

Exercise

You are about to commence the planning phase for the light rail system project. Due to the large nature of the project, the project team has decided to break up the planning according to the various functions. You are requested to identify the work that would be involved in surveying and reviewing the site of the light rail system and to deliver preliminary designs that can then be used to award a fixed-price contract to a civil design vendor.

Your first task was to define the scope of work through a work breakdown structure. This is completed, and you are now requested to extract the activities and construct a logic diagram with a subset of these activities.

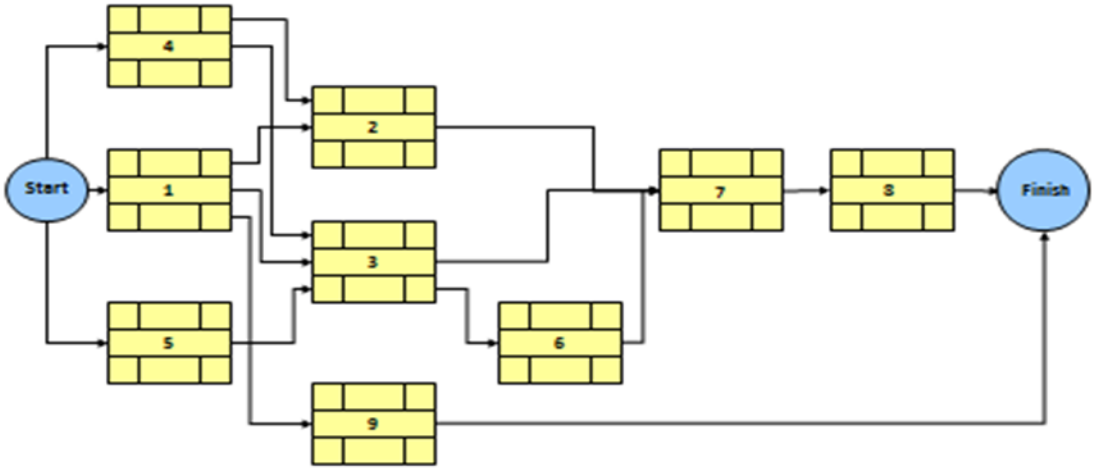
Sample answer
A sample activity list and corresponding logic diagram for the light-rail system is shown below and on the following page.

Activity List:

Activity Number	Activity	Activity Predecessor
1	Identify Scope of Site Reviews	-
2	Environmental Review of Sites	1,4
3	Perform Site Surveys	1,4,5
4	Identify Vendors to Perform Surveys	-
5	Identify Rail Sites	-
6	Architecture Review	3
7	Review Surveys	2,3,6
8	Agree on Design Scope	7
9	Identify Vendors to Perform Design Contract	1

Lesson 2, Topic 1: Exercise – Constructing a Logic Diagram (cont'd)

Network Diagram:



Lesson 2, Topic 5: Exercise – Producing an Activity Sequence

Exercise

You are about to commence the planning phase for the light rail system project. Due to the large nature of the project, the project team has decided to break up the planning according to the various functions. You are requested to identify the work that would be involved in surveying and reviewing the site of the light rail system and to deliver preliminary designs that can then be used to award a fixed-price contract to a civil design vendor.

A logic diagram, sequencing the identified activities, is in place. You have been requested to identify the project duration and the critical path given the following activity durations

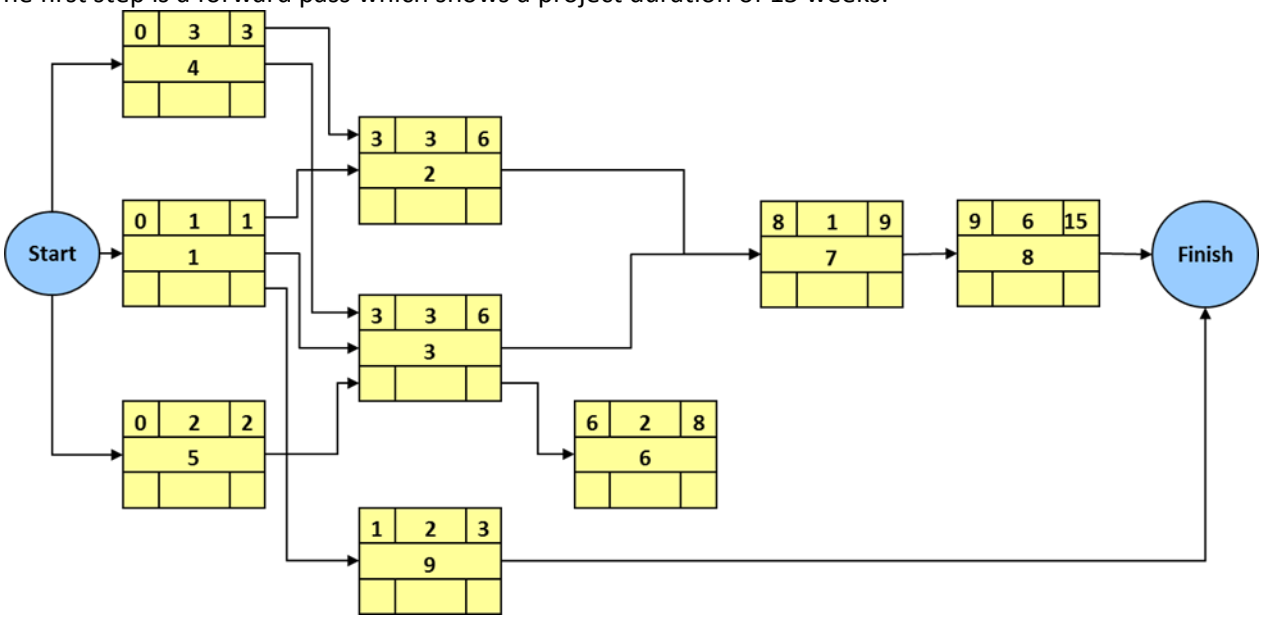
Activity List:

Activity	Activity Predecessor	Duration (in weeks)
Identify Scope of Site Reviews	-	1
Environmental Review of Sites	1,4	3
Perform Site Surveys	1,4,5	3
Identify Vendors to Perform Surveys	-	3
Identify Rail Sites	-	2
Architecture Review	3	2
Review Surveys	2,3,6	1
Agree on Design Scope	7	6
Identify Vendors to Perform Design Contract	1	2

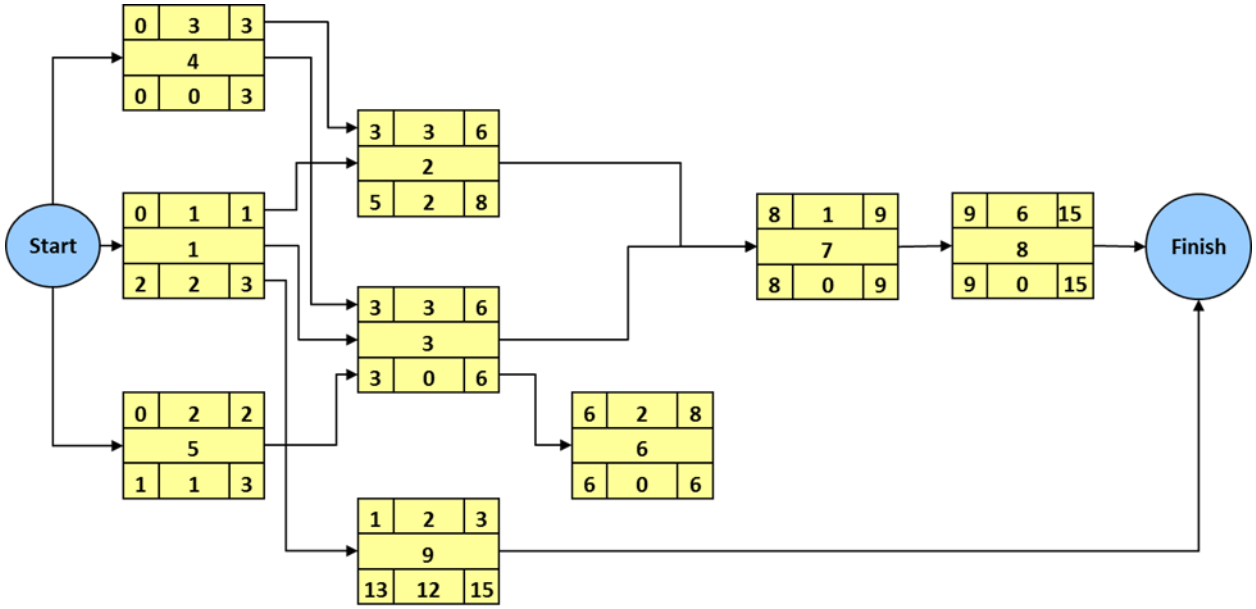
Lesson 2, Topic 5: Exercise – Producing an Activity Sequence (cont'd)

Sample answer

The first step is a forward pass which shows a project duration of 15 weeks:



The second step is a backward pass:



Lesson 3, Topic 4: Exercise – Compressing a Schedule

Exercise

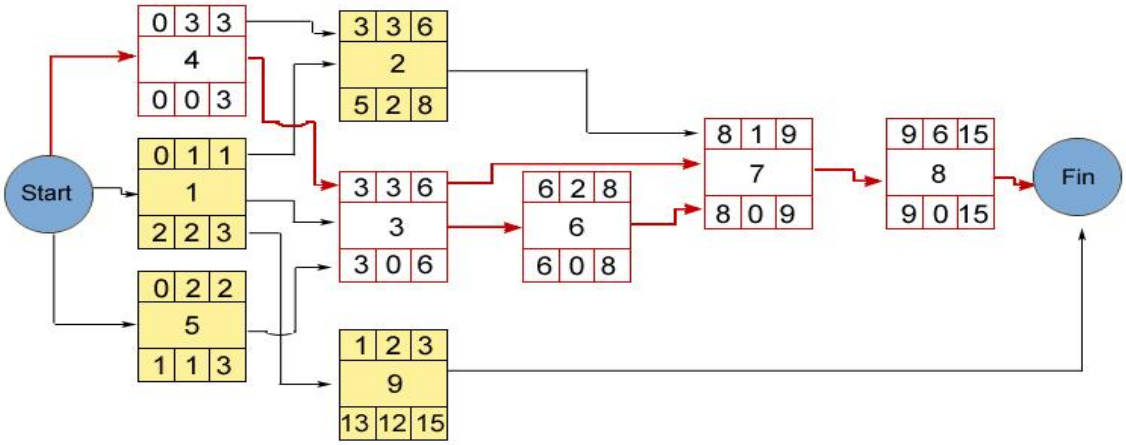
You are in the middle of the planning phase for the light rail system project. Due to the large nature of the project, the team has decided to break up the planning according to various functions. You have been asked to identify the work that would be involved in surveying and reviewing the site of the light rail system and delivering preliminary designs that can then be used to award a fixed-price contract to a civil-design vendor.

The following are the list of identified activities and the corresponding network diagram critical path:

Activity List:

Activity Number	Activity	Duration (weeks)
1	Identify Scope of Site Reviews	1
2	Environmental Review of Sites	3
3	Perform Site Surveys	3
4	Identify Vendors to Perform Surveys	3
5	Identify Rail Sites	2
6	Architecture Review	2
7	Review Surveys	1
8	Agree on Design Scope	6
9	Identify Vendors to Perform Design Contract	2

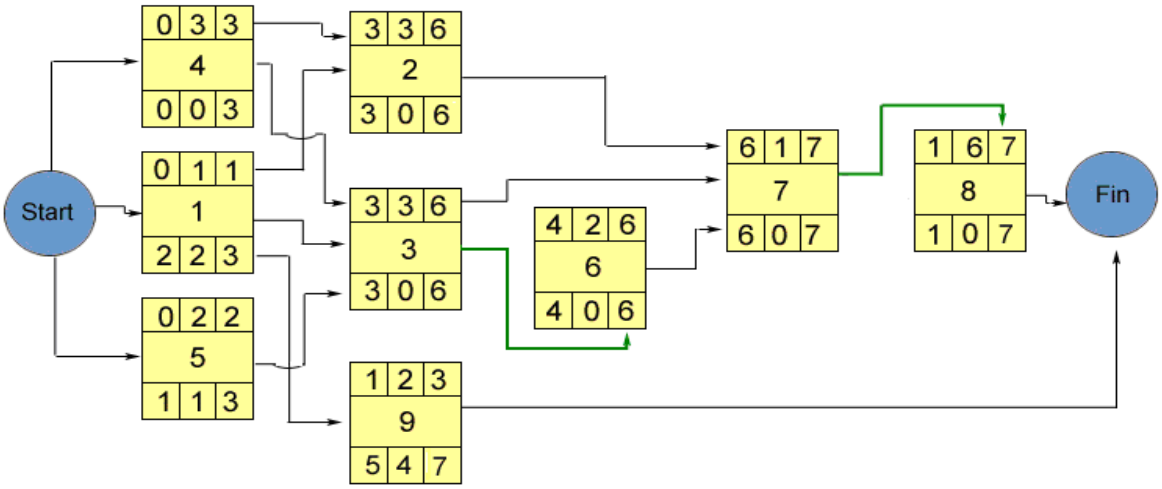
Network diagram:



Lesson 3, Topic 4: Exercise – Compressing a Schedule (cont'd)

Sample answer

The following is a proposal for how the project duration can be compressed:



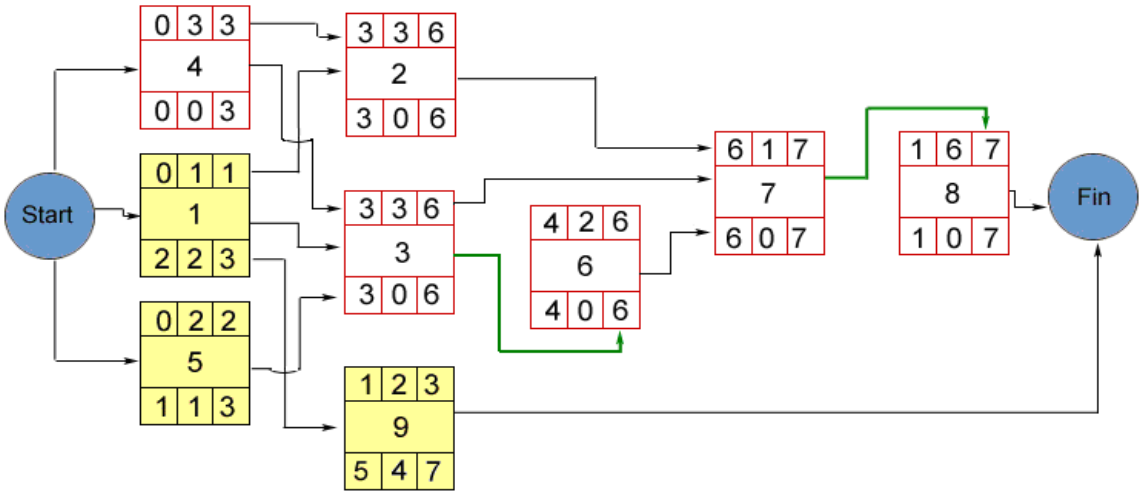
- The architecture review will be finishing at the same time as the site surveys. The risk is that the architecture review will not be completed for the site surveys but will be running in parallel

  Impact: - Risk Increases as anything uncovered as part of the site surveys will not be included in the architecture review

- As the team are review the surveys, the scope of the design will be finished at the same time.

  Impact: - Risk increases as there is a reduction on feedback from the survey reviews being included in the design scope.

The above readout shows there is an increase in risk due to the fast-tracking. The critical path is changed to include the majority of tasks:


Start
0 3 3
4
0 0 3
0 1 1
1
2 2 3
0 2 2
5
1 1 3
3 3 6
2
3 0 6
3 3 6
3
3 0 6
4 2 6
6
4 0 6
1 2 3
9
5 4 7
6 1 7
7
6 0 7
1 6 7
8
1 0 7
Fin

Lesson 4, Topic 5: Exercise – Delivering a Project Estimate

Exercise

You are in the middle of the planning phase for the light rail system project. You have been requested to identify the work that would be involved in surveying and reviewing the site of the light rail system and delivering preliminary designs that can then be used to award a fixed-price contract to a civil-design vendor.

The list of identified activities and the corresponding network diagram with critical path are displayed on the next page.

You need to update the estimate for the time duration of the project. The current time estimates are one point (i.e. most likely), but your project stakeholders would like to see the expected duration, using the following formulae:

- to find the expected time (t*e*) between events

$$t_e = \frac{to + 4tm + tp}{6}$$

t_e = expected time
to = most optimistic time
tp = most pessimistic time
tm = most likely time

- the standard deviation of each activity

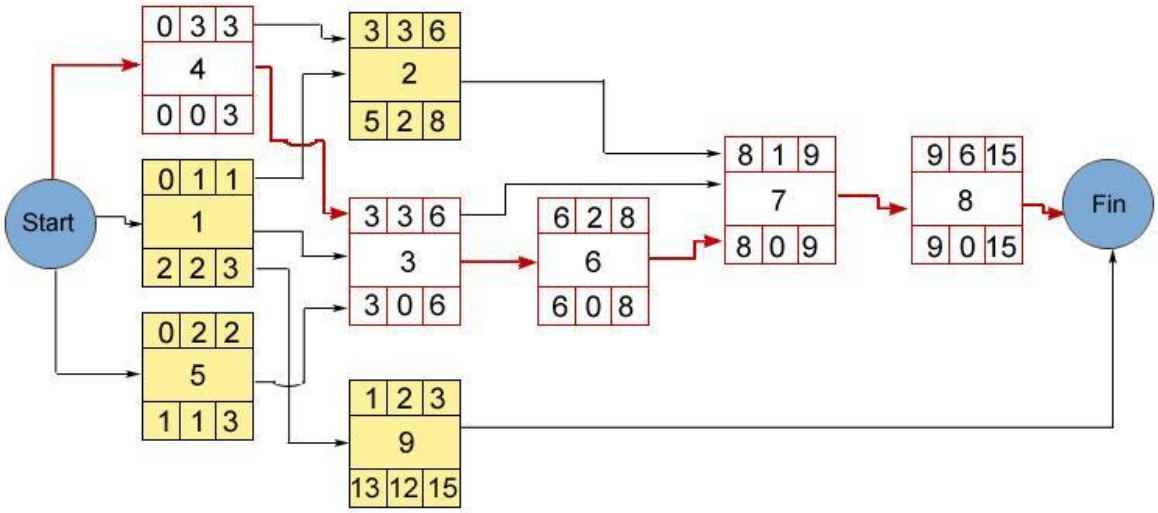
$$\sigma t_e = \frac{tp - to}{6}$$

σ = standard deviation of expected time te

Activity List:

Activity Number	Activity	Duration			
		Optimistic	Most Likely	Pessimistic	Expected
1	Identify Scope of Site Reviews	1	1	7	
2	Environmental Review of Sites	3	3	3	
3	Perform Site Surveys	3	3	9	
4	Identify Vendors to Perform Surveys	1	3	5	
5	Identify Rail Sites	1	2	3	
6	Architecture Review	1	2	9	
7	Review Surveys	1	1	1	
8	Agree on Design Scope	4	6	8	
9	Identify Vendors to Perform Design Contract	2	2	8	

Network Diagram:


Start
0 3 3
4
0 0 3
0 1 1
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2 2 3
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1 1 3
3 3 6
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5 2 8
3 3 6
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13 12 15
8 1 9
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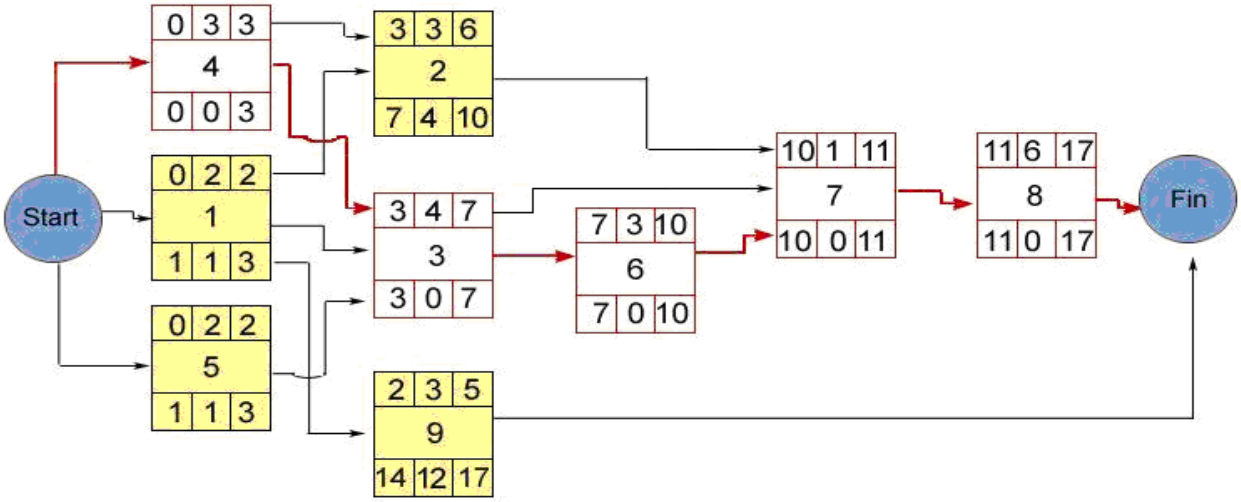
Fin

Lesson 4, Topic 5: Exercise – Delivering a Project Estimate (cont'd)

Sample answer

The following is a proposal on the project duration using a three point estimate. The expected duration for the project is 17 weeks (an increase of 2 weeks)

Activity Number	Activity	Duration				Standard Deviation
		Optimistic	Most Likely	Pessimistic	Expected	
1	Identify Scope of Site Reviews	1	1	7	2.0	1.0
2	Environmental Review of Sites	3	3	3	3.0	0.0
3	Perform Site Surveys	3	3	9	4.0	1.0
4	Identify Vendors to Perform Surveys	1	3	5	3.0	0.7
5	Identify Rail Sites	1	2	3	2.0	0.3
6	Architecture Review	1	2	9	3.0	1.3
7	Review Surveys	1	1	1	1.0	0.0
8	Agree on Design Scope	4	6	8	6.0	0.7
9	Identify Vendors to Perform Design Contract	2	2	8	3.0	1.0



Lesson 5, Topic 3: Exercise - Presenting a Cost and Schedule Baseline

Exercise

You are in the middle of the planning phase for the light rail system project. You have being requested to identify the cost that would be involved in surveying and reviewing the site of the light rail system with the delivery of preliminary designs that can then be used to award a fixed-price contract to a civil-design vendor.

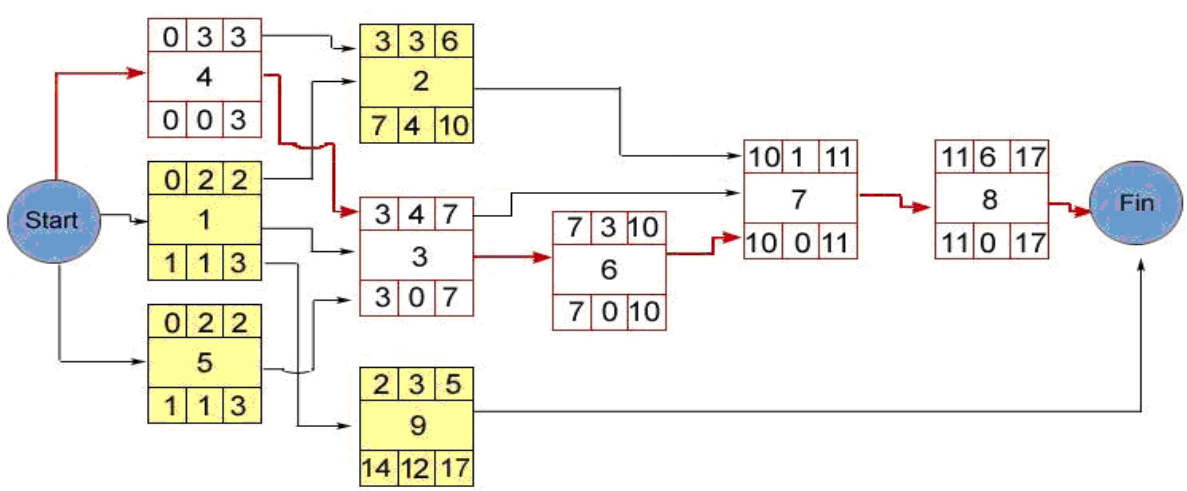
The following are the list of activities from the work breakdown structure (including expected durations), the latest network diagram, and a table of estimated costs.

Your assignment is to present a cost baseline budget that represents the agreed price for this project, plus the rate at which the budget will be spent over time

Duration Estimates

Activity Number	Activity	Duration			
		Optimistic	Most Likely	Pessimistic	Expected
1	Identify Scope of Site Reviews	1	1	7	2.0
2	Environmental Review of Sites	3	3	3	3.0
3	Perform Site Surveys	3	3	9	4.0
4	Identify Vendors to Perform Surveys	1	3	5	3.0
5	Identify Rail Sites	1	2	3	2.0
6	Architecture Review	1	2	9	3.0
7	Review Surveys	1	1	1	1.0
8	Agree on Design Scope	4	6	8	6.0
9	Identify Vendors to Perform Design Contract	2	2	8	3.0

Network Diagram with Duration Applied



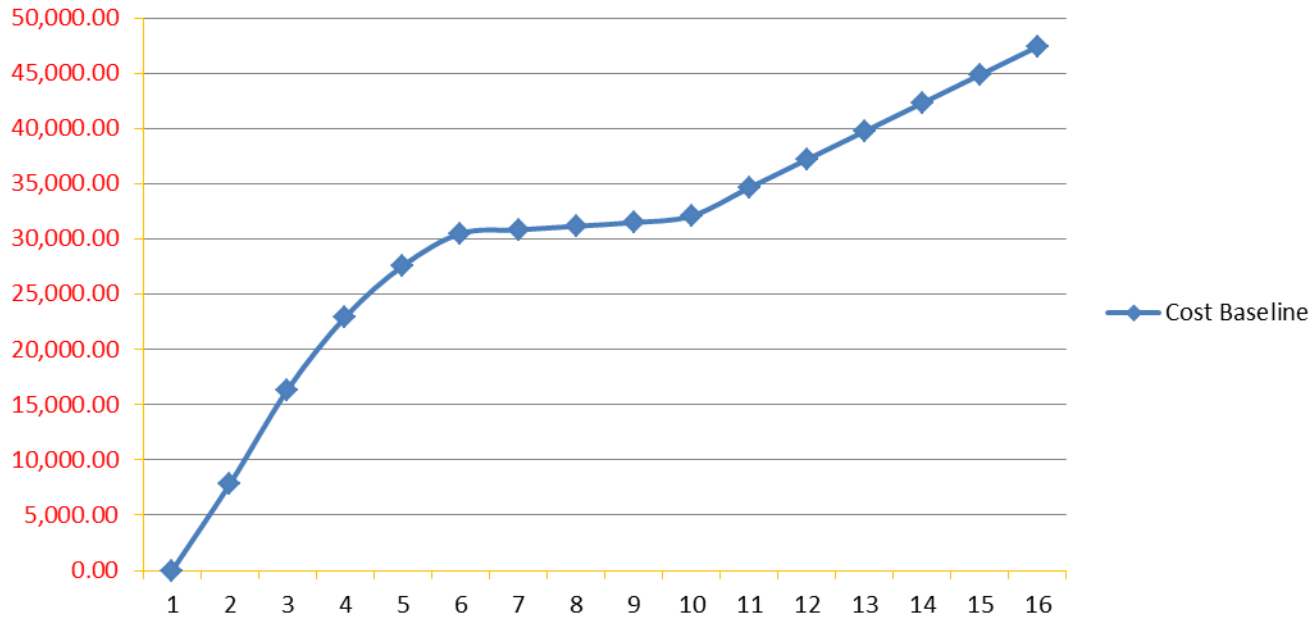
Lesson 5, Topic 3: Exercise - Presenting a Cost and Schedule Baseline (cont'd)

Cost Estimates

Activity Number	Activity	Duration			
		Optimistic	Most Likely	Pessimistic	Expected
1	Identify Scope of Site Reviews	$1,000	$1,000	$1,000	$1,000
2	Environmental Review of Sites	$3,000	$5,000	$8,000	$5,167
3	Perform Site Surveys	$5,000	$10,000	$25,000	$11,667
4	Identify Vendors to Perform Surveys	$5,000	$5,000	$10,000	$5,833
5	Identify Rail Sites	$1,000	$1,000	$1,000	$1,000
6	Architecture Review	$1,000	$1,000	$1,000	$1,000
7	Review Surveys	$500	$500	$1,000	$583
8	Agree on Design Scope	$10,000	$13,000	$30,000	$15,333
9	Identify Vendors to Perform Design Contract	$5,000	$5,000	$10,000	$5,833

Sample answer

Based on the cost estimates, and when applied to the network diagram, the following is the cost baseline:



This baseline represents the expenditures for this project and the rate at which the budget will be spent over time.

Activity	Expected	1	2	3	4	5	6	7	8
Identify Scope of Site Reviews	$1,000.00	$500.00	$500.00						
Environmental Review of Sites	$5,166.67			$1,722.33	$1,722.33	$1,722.33			
Perform Site Surveys	$11,666.67			$2,916.75	$2,916.75	$2,916.75	$2,916.75		
Identify Vendors to Perform Surveys	$5,833.33	$1,944.33	$1,944.33	$1,944.33					
Identify Rail Sites	$1,000.00	$500.00	$500.00						
Architecture Review	$850.00							$333.33	$333.33
Review Surveys	$583.33								
Agree on Design Scope	$15,333.33								
Identify Vendors to Perform Design Contract	$5,833.33		$1,944.33	$1,944.33	$1,944.33				
	weekly	$2,944.33	$4,888.67	$8,527.75	$6,583.42	$4,639.08	$2,916.75	$333.33	$333.33
	PV	$0.00	$7,833.00	$16,360.75	$22,944.17	$27,583.25	$30,500.00	$30,833.33	$31,166.67

Lesson 5, Topic 3: Exercise - Presenting a Cost and Schedule Baseline (cont'd)

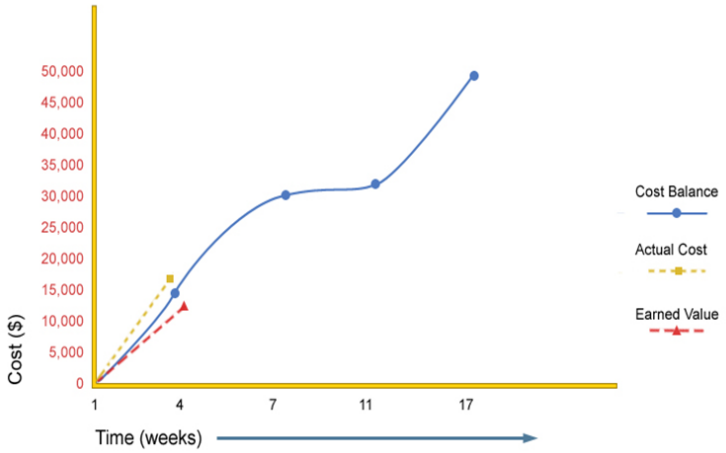
Activity	Expected	9	10	11	12	13	14	15	16	Total
Identify Scope of Site Reviews	$1,000.00									$1,000.00
Environmental Review of Sites	$5,166.67									$5,167.00
Perform Site Surveys	$11,666.67									$11,667.00
Identify Vendors to Perform Surveys	$5,833.33									$5,833.00
Identify Rail Sites	$1,000.00									$1,000.00
Architecture Review	$850.00	$333.33								$1,000.00
Review Surveys	$583.33		$583.00							$583.00
Agree on Design Scope	$15,333.33			$2,555.50	$2,555.50	$2,555.50	$2,555.50	$2,555.50	$2,555.50	$15,333.00
Identify Vendors to Perform Design Contract	$5,833.33									$5,833.00
	weekly	$333.33	$583.00	$2,555.50	$2,555.50	$2,555.50	$2,555.50	$2,555.50	$2,555.50	$47,416.00
	PV	$31,500.00	$32,083.00	$34,638.50	$37,194.00	$39,749.50	$42,305.00	$44,860.50	$47,416.00	

The chart above depicts the detail of how the cost baseline was determined using the expected total cost of the activity spread across the duration as noted in the network diagram above.

Lesson 6, Topic 3: Exercise – Earned Value (2)

You are in the middle of the planning phase for the light rail system project. You have been requested to identify the cost that would be involved in surveying and reviewing the site of the light rail system with the delivery of preliminary designs that can then be used to award a fixed-price contract to a civil-design vendor.

The budget at completion is $47,500.



After 7 weeks, the planned value is $30,000 with the actual cost running at $33,000 and the earned value at $27,000. However at week 11, the planned value is $32,000 and the actual costs is $34,000 with the earned value at $30,000.

Use the following table and formulas to comment on the performance of the project between week 7 and week11.

Week Number	Planned Value	Actual Cost	Earned Value	Cost Performance Index (CPI)	Schedule Performance Index (SPI)
7	$30,000	$33,000	$27,000		
11	$32,000	$34,000	$30,000		

CPI = EV/AC
SPI = EV/PV

Estimate the cost at completion (referenced as estimate at completion (EAC)) at week 11 using the formula **EAC = AC + ((BAC – EV)/CPI)**

Answer

Week Number	Planned Value	Actual Cost	Earned Value	Cost Performance Index (CPI)	Schedule Performance Index (SPI)
7	$30,000	$33,000	$27,000	82%	90%
11	$32,000	$34,000	$30,000	88%	94%

The project performance has improved between week 7 and 11 as the indices (both CPI and SPI) have increased.

The EAC (week 11) is AC + ((BAC – EV)/CPI) $34,000 + (($47,500 - $30,000) / 0.88)
$34,000 + $19,886
$53,886

The EAC is $53,886, which is an increase on the original budget.