Production and Formative Evaluation of a Self-Instructional Workbook to Teach the Fundamentals of PERT

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ABSTRACT

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This thesis equivalent presents the design and evaluation of a self-instructional workbook on PERT, to be used in Educational Systems Analysis (ETEC 653), at Concordia University. The instructional goals of the workbook were to provide the learner with a comprehensive introduction to PERT and enable her to apply the technique to smaller scale projects without the aid of a computer programme.

The design of the workbook was carried out according to the methods advocated by Derek Rowntree (1986) and James Hartley (1985), that relate particularly to the design of instructional text.

The formative evaluation included a self-critique of the materials, followed by expert review and a small group field test using students in ETEC 653. The testers were the main source of feedback. This qualitative evaluation sought data on three levels: on the assessment of performance on self-assessment questions contained in the text and on post-test scores, on testers' responses to feedback questionnaires concerning the content, and on their attitudes towards various factors related to the design of the text. The feedback questionnaires are based on those examples provided by Derek Rowntree (1986).

Analysis of closed and open ended data was carried out using an algorithm developed by Nathenson and Henderson (1976). Based on the data collected, the text was modified to improve its instructional utility.

Dedication

This work is dedicated to the memory of my dog Duchess, whose constant companionship during the research and production of the workbook gave me the courage to continue and to the memory of my grandfather James Gray, who introduced me to the joy of learning.

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CHAPTER 1

Introduction

PERT

PERT is the acronym for Programme Evaluation Review Technique, a planning and control technique which is used in the accomplishment of large scale projects. Its purpose is the effective and efficient management of the project resources, specifically the allocation of funds, equipment, materials, facilities and manpower, in order to ensure the timely completion of a project. To achieve this, a number of mathematical calculations must be performed. PERT uses time as the common denominator for all the resources.

Planning and control are achieved through the accurate estimation of activity times and the provision of statistical information regarding the uncertainty of those estimates and the probability of meeting a scheduled date. This information, combined with the close monitoring of the project, periodic audits and the reporting of the results on a bi-weekly, monthly and quarterly basis, leads to the timely identification of potential trouble spots. PERT also provides the information necessary to identify alternative courses of action.

PERT has been extensively applied to development efforts in the aerospace, defense and construction industries. It has demonstrated its value in projects ranging from the development of the Polaris Weapon System in 1957-58, to the production of a Broadway play. It has been used in book publishing, new product introduction, organisational change and educational planning.

Many of the projects encountered by the educational technologist will involve the production of instructional materials (print, computer based or audio-visual), the administration of research projects or the implementation of educational or organisational change. PERT can be applied to experimental, historical and survey research, curriculum planning and course development. While these projects may differ in nature, they have one point in common. They all involve a large number of tasks that can be performed independently and simultaneously. They may also be one time only projects, involving unfamiliar tasks. PERT allows the project manager to plan, organise, schedule and control such complex projects.

There is no limit to the size or complexity of the projects to which PERT can be applied. A minimum capacity could be set at a project requiring one or two persons, working on between twenty and twenty five activities, over a period of two months. It has been said that an individual trained in the use of a desk calculator can manually process 200 activities in less than one working day.

A computer programme allows one to deal with much larger projects. However, an essential prerequisite for the educational technologist is a basic understanding of the central concepts, prior to using such a programme. The following project management software includes PERT functions. Microsoft Project, Timeline and Harvard Total Project Manager are available for the IBM PC. Mac Project, Micro Planner and Key Planner are designed for use on the Macintosh.

Statement of the Problem

PERT is one of the planning and problem-solving techniques taught in Educational Systems Analysis. While several computer programmes are currently available that will carry out PERT for the project manager, it is important to know how the different values are achieved and what function they serve.

The purpose of the workbook is to provide the learner with a comprehensive view of the technique, so that when given the opportunity to use a computer programme, she knows how the various values have been achieved and how to interpret them. She will then be able to identify potential trouble spots and make an informed decision about the re-allocation of resources.

A major drawback of the existing course materials that the learner must consult to teach herself PERT, is that there is no single comprehensive guide to carrying out the technique. The learner must consult several documents. At times this can lead to confusion, since authors may vary in the notational forms used to represent the values that must be calculated. This is the main reason for developing the workbook. Secondly, the majority of these works focus on projects carried out in the field of engineering and commerce. In both cases, the context in which the information is presented, is not one with which the learner is familiar. The context may interfere with learning, especially if prior knowledge of another field is required. It is preferable to learn from examples related to the field of education or educational technology.

From a very practical standpoint, learning from the available materials can be unnecessarily time-consuming. Access to the materials is somewhat restricted by the fact that all the students in the course are competing for a single set of articles. While upon a first glance this might seem like a minimal inconvenience, upon further consideration it becomes evident that a great deal of valuable time is consumed in acquiring the materials; time that could be better spent on learning.

In summary, the production of a self-instructional workbook provides a solution to a number of problems. First, it presents a comprehensive view of the technique. Secondly, whenever feasible, the content is related specifically educational projects. Thirdly it is designed more effective, efficient and pleasing to use than existing materials. Finally, it provides immediate access to learning materials.

Target Audience

Educational Level

This workbook was designed for a very specific target audience, that is, learners enrolled in Educational Systems Analysis (ETEC 653). The typical learner is enrolled in either the M.A. or Ph.D. programme in Educational Technology. Her selected option may be either production and evaluation or research. There are two reasons for enrollment in the course: a programme requirement or a specific interest.

Previous Exposure to Self-Instruction

It is safe to assume that as graduate students, they are familiar to a certain degree with self-instruction, if not with specifically designed self-instructional materials.

Previous Knowledge

One must anticipate that the learners, at any given time, will vary in their previous knowledge of PERT, though most probably will have no knowledge of it. While some basic statistical calculations are involved, a background in statistics is not a pre-requisite.

Language

It is anticipated that at any given time, English will not be the first language of some of the students. Their command of the language may vary.

Adult Learners

As adults and as students, a number of factors compete for their time and attention: work, family, other courses and time restrictions on student visas.

Instructional Goals

PERT is introduced to the learner under the broader categories of network analysis and resource allocation. The terminal performance objective for PERT is in keeping with the problem-solving nature of the entire course and is stated in the following manner:

Given a list of activities, specifying their relationships and dependencies, along with the related estimates of performance times, the learner will be able to:

a. construct a network flow diagram,

b. calculate all the values necessary to identify the critical path and determine the probability of meeting a previously established scheduled date,

c. identify activities that are likely to be completed ahead of schedule, on schedule or behind schedule,

d. discuss ways in which resources might be better allocated, with reference to the slack time associated with the events and the variance associated with the activities.

Appendix B contains the enabling objectives. The learner must be able to explain basic concepts (comprehension), construct a network and solve mathematical problems (application). The results are used to identify the critical path (analysis). The learner must be able to propose a plan for corrective action, given the probability of meeting the scheduled completion date (synthesis). The learner must be able to justify this plan (evaluation). This classification of objectives is based on Bloom's (1956) learning outcomes.

The overall instructional goal, in terms of performance criterion, is that 90% of the learners achieve 90% on the post test.

Media Selection Factors

In choosing to design a self-instructional workbook to teach PERT, the developer took into account the content of the instruction, the context in which the materials are to be used and the costs of production and to the learner. In the light of all these considerations, a self-instructional text seemed the most appropriate choice.

Attributes of the Printed Workbook

The workbook provides primarily direct, "hands on" active participation. It presents a structured organisation of the content, step-by-step sequencing, explicit objectives, opportunity for student response and immediate verification. The content can be easily repeated and re-ordered by the learner. It transcends the barriers of time, and group size. It can be used at any time and the selection and amount of time is controlled by the learner. It is ideal for use by individuals and by small or large groups.

Content

In the selection of the medium, the initial factor to be considered was the nature of the subject matter. First of all, the learner must learn a number of concepts that will require between 1 and 4 pages of explanation per concept, including examples and exercises. Since this involves quite a bit of reading, print was a logical choice. Secondly, one must use diagrams in order to teach PERT. The learner is required to construct, examine and add information to diagrams. Carrying out such actions is more easily accomplished with a pencil and paper than with a computer screen and a mouse. The latter requires prerequisite skills. Drawing with a pencil is a natural act that does not require the mastering of any technology which might frustrate the learner and interfere with learning.

In order to carry out PERT the learner must be able to construct a network diagram of a project, have a clear understanding of the concepts and principles, perform simple arithmetical and statistical computations, and construct a chart that presents all these values. The learner must then evaluate this information, identifying the values that reveal problems with resource allocation and the meeting or setting of a scheduled completion date.

Network construction is quickly accomplished by hand. The calculations can be performed mentally and with the use of a calculator that has a square root function. It is therefore possible for one to make all the calculations for a project containing 15-20 activities, in less than 2 hours. One of the general instructional goals is that the learner will be able to apply PERT to a small project, without the use of a computer. Print-based instruction was therefore a logical choice.

Context

In terms of context, one is referring specifically to how and when the materials will be used and the time available for learning. Self-instruction can occur in a variety of contexts. In this situation, the learner has access to both the course instructor and other learners.

The duration of ETEC 653 is 13 weeks. During this period the learners are introduced to the tools and the techniques of systems analysis that can be used to design, manage and evaluate a variety of educational systems; materials, programmes, curricula, learning resource centres, research and development. The learner develops a number of skills and adds a variety of new tools to her problem solver's tool kit. Amongst those are, Linear Programming, Queuing Theory, the Markovian Decision Process and Network Analysis.

This is a considerable amount of ground to be covered in a short period. As a result, the learning of the various tools and techniques is by necessity and for the most part, self-instructional. Learners often work in pairs or as a group. This leaves the scheduled class time available for discussion and application of the techniques.

Due to the particular situation of the target audience, a basic requirement was that the instructional product be efficient to use, with regards to time. As adult learners, a number of demands compete for their time. Hence, a self-instructional text seemed the ideal alternative. An additional benefit is that print allows for flexible pacing. It can be used at any time, in any place and can serve as a reference tool for future use.

Cost

The costs of production were also considered. Print was the most economical medium and the easiest to produce. The cost to the learner of purchasing the materials is likely to be under $10.00 and she will have the text for future reference. While this is more than the price of photocopying existing materials in the library, it eliminates the transportation and time costs associated with going back and forwards to see if the materials have been returned and trips to the library to supplement the existing materials. There is also a nuisance factor associated with this, not to mention the issue of legality.

A breakdown of the time required to produce the workbook, along with a breakdown of direct and indirect costs appears in Appendix H.

CHAPTER 2

Teaching Strategy

Explanation, Example, Exercise

The actual teaching strategy is determined partly by the nature of the content. The application of PERT involves the construction of a network diagram and the calculation of a number of values which are then assembled and displayed in a chart. The chart is then analysed and used as an aid to decision-making.

The same teaching strategy was used in all four lessons. The new concepts are introduced by means of an explanation. In most cases, these concepts are mathematical in nature and require computation. The learner is introduced to the formula and its components are identified and explained. This is followed by an example or demonstration of how the formula is calculated and how the resulting value is used. This demonstration complements the explanation and ensures that the learner is aware of every step of the procedure. The example is examined in detail. The learner must then complete a set of exercises called self-assessment questions.

For the most part, the learner is performing simple arithmetical and statistical calculations. The purpose of the self-assessment questions is to determine whether or not the learner has understood the concepts and the method for achieving their associated numerical values. A second purpose is to provide practice in determining those values for networks which have increasingly complex configurations.

In Lesson 4 the learner is introduced to the decision-making process. It is here that everything that has been learned will come together. It is in this lesson that the problem-solving nature of the content becomes apparent. The self-assessment questions require that the learner calculate all the values contained in the Activity-Output Slack Sort Chart, evaluate the existing plan and outline how she would proceed in the given circumstances.

Verification of Answers to Self-Assessment Questions

As Rowntree suggests, answers to the self-assessment questions are located directly after the questions. These are detailed enough to allow the learner to identify her mistakes and to decide whether or not to review the explanation and example.

Design Factors

There are certain design factors that support teaching and encourage the learning. These might be referred to as the ergonomics of self-instructional text design. The presentation of text on a printed page has much in common with the way offices and factories are laid out. One must consider the effectiveness, efficiency and the human factors of the system layout as they relate to the accomplishment of the objective for which the system was designed. The basic premise of the study of human factors is that people are powerfully affected by their particular environment and that their behaviour is influenced by the environment in which it occurs. We can consider the self-instructional text as a learning environment. The aim of the developer is to make this environment as conducive to learning as possible. There should be no obstacles created by the verbal expression of ideas or by their physical presentation on the page. The task for the developer is one of taking teaching strategies such as explanations, example and exercises and conveying them through the printed word to create meaningful content. Secondly she must add structure or give form to the content through the use of access devices and the visual layout of the page. The learner then uses these same devices to find her way into and through the content and ultimately have it acquire form in her own mind.

This is the rationale behind the design of the proposed self-instructional workbook. It is a learning system or environment constructed out of the clear expression of ideas, access devices and activities, with the purpose of facilitating learning.

The following discussion focuses on the factors that were included in the design of the self-instructional workbook. They are based on the writings of Derek Rowntree (1986) and James Hartley (1985). Here the term design refers to the physical structuring of the information which is part and parcel of the of the instructional strategy.

Rowntree points out that if the teaching is well-structured, readers have a better chance of learning from it. Furthermore, if the structure is obvious, their chances of learning are much improved. Rowntree discusses a number of access devices that assist the reader in finding her way into and through the text. The access devices that were used are discussed in the following pages.

1. Titles

Rowntree suggests that each lesson should be given a self-explanatory title, so that the learner knows what it is about. It was somewhat difficult to come up with a satisfactory self-explanatory title for each lesson, since each one dealt with a number of different concepts that are particular to PERT. Lesson breaks were based on clusters of concepts that could be taught together, rather than by topic. However, each page containing a discussion of a concept was given an explanatory title. This served a second function, as a glossary.

2. Table of Contents

Rowntree mentions that the Table of Contents can be placed, in its entirety, at the beginning of the book or be divided up by lesson and placed at the beginning of each lesson. Since it is intended that this workbook serve as a reference tool for later use, the Table of Contents appears at the beginning of the book, where it is easily accessed. It clearly reveals the structure of each lesson, indicating which pages are devoted to an explanation of the concept, an example of the concept, exercises and answers. Such a structured list is intended to provide a useful overview of the text as a whole and of each lesson in particular.

3. Lists of Objectives

It is often helpful to the learner to know in advance what she will be able to do at the end of each lesson. Rowntree points out that the list should not include so many objectives as to overwhelm the learner with the magnitude of the learning task that lies ahead. He also points out that objectives should not be expressed in technical language, as they will mean nothing to the learner until she has completed the lesson.

On the lesson title page, the main objectives for each lesson are identified and briefly introduced. The learner is told what she is about to learn, the purpose of this information and the type of task that she will encounter.

4. Introduction / Overview

An introduction or overview is important in alerting the learner as to what is to follow, whetting her appetite and convincing her that the subject matter is of value. Due to the nature of the subject matter, the developer has included a comprehensive overview rather than a concept map at the beginning of the workbook. One reason is the desire to convince the learner that PERT will be a useful and relatively simple technique to learn. The second reason is that in carrying out PERT, one must calculate a number of values, bits and pieces of the larger picture. A concept map, although it displays the relationships between concepts, might be somewhat meaningless to the learner if placed at the beginning of the instruction, as it would contain technical terms that require explanation. An overview, on the other hand, can better explain the concepts and reveal the function of those individual pieces of information and how they fit together.

The end products, that result from the identification and analysis of the individual tasks, are a network flow diagram and an activity-output slack sort chart. These have been included in the overview. This allows the learner can see the results of the learning experience in which she is investing her time and effort.

The overview is also designed to serve as a summary that the learner can consult prior to starting each lesson. Reading the overview permits the learner to review previously learned material and to see how it links up with what is to follow. It is structured in such a way as to show the learner how one moves from a network representation of a project, through a number of calculated values, to a chart that serves as an aid to making decisions that will lead to the re-allocation of resources in order to increase the probability of meeting the scheduled completion date.

5. Headings

Hartley points out that headings, written in the form of questions or statements and located in the margin or in the body of the text, aid search, recall and retrieval. Rowntree considers headings to be access devices and an aid to learning. They should help the learner to access the parts of the text that she wishes to read. They signify where one topic ends and the next begins.

Rowntree makes reference to two types of headings. Running headings run across the top of the page. In the workbook, running headings in the form of simple definitions, announce the introduction of a new topic. Each example and each exercise is introduced as such at the top of the page. The intention is to assist the reader in locating the start and end of each section. These headings are rendered in bold lettering.

Side headings which appear in the margin and comment on the change of topic serve to highlight issues and identify the main points. This is particularly useful to readers who want to quickly preview or review the materials. He advises against excessive use, which will deny the reader the opportunity to make her own margin notes. On the other hand, if the margin headings are few and far between, the reader will tend to ignore them.

The workbook contains margin headings, as it is very likely that the learner will want to go back and locate certain information for review purposes. They are rendered in italics in order to differentiate them from the main body of the text. This makes them easier to access. The feedback questionnaires in the formative evaluation addressed this subject.

6. Summaries

Hartley discusses the functions of beginning summaries. They serve three main functions. They tell the readers what the text is about, as in the overview and help them organise what they are reading. Summaries also help readers decide whether or not they want to read the text. Interim summaries fulfil a different function. They summarise the argument so far and indicate what is to come. Summaries can be typeset in different ways but there is no research on the effect of typographical variables in this context.

At the beginning of each lesson the learner is advised to read the overview before continuing. However, an interim summary has been included in Lesson 3. This seemed an appropriate place to draw the learners attention to the values she has calculated in the previous lesson and how they feed into each other. This is a more concise treatment of the information than is contained in the overview.

7. Floating Baseline

Hartley points out that when a floating baseline is used, the text does not stop at the same point on every page. The last line of each page is determined by the content. Headings do not appear as the last item on a page.

The floating baseline has been used in the workbook as it is the developer's concern that the learner's train of thought be interrupted as little as possible and that whenever possible, the entire content of an explanatory section be presented on a single page.

8. Identification of New Paragraphs

When designing instructional text, Hartley advocates the use of a line space rather than indentation, to denote new paragraphs. This is a simple and useful way of manipulating the vertical spacing to clarify the structure of the text. This method has been used in the workbook, as it makes it easy to locate new paragraphs, clearly signals the introduction of a new topic and adds some visual relief (white space) to a page of text. As such, it will perhaps cue the learner to pause and reflect upon what she has just read.

9. Sequencing Lists

According to Hartley, research has indicated that readers prefer text which has lists or numbered sequences spaced out and separated, rather than continuous text. This approach was used, in the form of numbered lists and steps or items of information preceded by bullets.

10. Line Justification

Another issue, in the literature related to the design of instructional text, is the use of right justification. Hartley points out that the research on text justification is somewhat inconclusive, although there are indications that unjustified text is more helpful to less able readers.

Gorman, Gorman and Bibel (1986) found that comprehension scores were lower for those who read right justified text and good readers were more affected than poor readers. On the other hand, Trollip and Sales (1986) compared 2 groups, one read a justified passage (right and left margins are straight) the other group read a passage with ragged right margins. While reading time was reduced for the justified group, there were minor increases in post-test scores. Muncer, Carpenter, Marchetti and Mewhort (1981) carried out tests on university students using ragged right margins and two different forms of right justification. The variable spacing right justification technique improved reading speed and comprehension scores. The issue is unresolved.

The original version of the workbook which was used in the formative evaluation was prepared on an IBM Displaywriter, using proportional text. It was intended that all the line endings be right justified. The page format differed depending on the contents of the page. Explanations of concepts appeared on pages with three inch left hand margins containing margin notes. Examples of those concepts were presented on pages with one inch margins on either side, allowing diagrams, charts and text to be presented on a single page. As a result of an error in coding only those pages with one inch margins had justified line endings. Due to printer failure, this could not be corrected prior to the formative evaluation. The final version was produced using WordPerfect 5.1 which was then converted to Pagemaker 4.0. This made the difference in spacing, between words, less obvious.

11. Typographic versus Spatial Cues

Hartley suggests printing new terms in italics or bold or underlining them when they are first introduced into the text. It is the developer's belief that providing too many cues imposes a learning strategy on the learner and takes away the opportunity to work with the text, imposing her own structure on the content. Graduate students are sophisticated learners with their own successful strategies for structuring and remembering information.

Hartley points out that too many cues can be confusing. Spatial cues are more important than typographic ones in presenting list-like materials. It was the developer's concern not to overwhelm the learner with typographical cues. Therefore, spacing was used to structure the content. As previously mentioned, through the use of a floating baseline an attempt was made to include the entire explanation of a concept on a single page. Extra line space was used to identify new paragraphs.

Text Factors

It is not only the structuring of the content through access devices and typographical cues that facilitates learning. Meaning is carried by the word and by the sentence. Whether or not the learner has difficulty with the material is largely dependent on how the content is expressed. One should strive to make the message easy to read and to comprehend. The writer should be attempting to engage and maintain the reader's attention. The following factors have been given attention in the workbook.

1. Tone

Rowntree states that the tone of the lesson should take on the conversational style of a one-to-one tutorial and not that of a textbook or lecture. This involves writing conversationally and writing plainly, using familiar words. Another suggestion that he makes is to use personal pronouns. This helps avoid the possibility of alienating the reader. To avoid monotony, one should also try to vary one's tone.

The developer kept these suggestions in mind. The text is written in a conversational style, using personal pronouns and familiar words.

2. Sentence and Word Length

The text was produced, keeping in mind the suggestions made by Rowntree and Hartley. Rowntree and Hartley state that when writing instructional material, to avoid using long sentences that overload the memory system. They suggest that whenever possible, one should use short and familiar words and keep the sentences short and simple. Rowntree points out that the more often one uses a full stop, the more often the reader will pause for thought. It is during those pauses that the content begins to take shape in the learner's mind. He also suggests that one should make an effort to avoid a monotonous repetition of sentence structure. Quite often, varying the length and rhythm of the sentences will help clarify the relationship among the ideas presented in a paragraph.

CHAPTER 3

Formative Evaluation

Constraints

While Rowntree (1986) and Dick and Carey (1985) provide comprehensive models for evaluating instructional materials, these models are often somewhat difficult to carry out in a real situation. At the outset, it must be mentioned that the evaluation design is a response to two major constraints: a small tester population and cost.

At any given time there may be anywhere from five to twelve students enrolled in the course. This limits the number of available testers and makes it difficult to carry out one-to-one trials, small group and field testing.

The second constraint is the cost associated with reproducing the materials for a large number of testers. The cost will be between $7.00 to $10.00 per tester. This is a workbook and testers received it free of charge in exchange for their participation. The workbook cannot be recycled for future testers.

According to Weston (1986), the approaches to formative evaluation are varied. While there is agreement that formative evaluation improves instructional materials, there is some doubt about the best way to carry it out. The developer can conduct a self-critique, engage an expert to review the materials or conduct student tryouts. Formative evaluation is a test-revise-test cycle that terminates when the materials consistently produce satisfactory results.

In the literature on formative evaluation, the term developmental testing appears quite often. Weston defines developmental testing as the narrowest form of formative evaluation, consisting of one-to-one and /or group testing. It excludes field testing. Since the data collection methods used in developmental testing, as described by Rowntree (1986) and Nathenson and Henderson (1976), were used in the proposed evaluation, some explanation of the term is warranted.

Geis (1987), in his article on formative evaluation, refers to developmental testing and expert review as two approaches to formative evaluation. Developmental testing is defined as a discrete step in the developmental process. It is a cycle of testing and revision to be carried out until a satisfactory product emerges. Only then is the formative evaluation complete.

Geis differentiates developmental testing from field-testing. In field-testing, the materials are further along in the development process, and larger segments of instruction are used. The population of learners is larger. The data that is collected is objective (test results) and written comments. Rowntree provides a useful discussion of developmental testing but unlike Geis, includes field-testing in his model.

Nathenson and Henderson developed a comprehensive system for the developmental testing of self-instructional materials. To properly developmentally test a course, one must analyse the content and structure individual units, along with the inter-relationship of the units. Performance measures on assignments must be examined in order to determine whether or not the instruction has been effective. Responses to self-assessment questions should be evaluated in order to determine their role in the learning process. A comprehensive developmental testing scheme should thoroughly and systematically evaluate the whole process of learning.

Procedure

The following discussion focuses on the procedure that was used. Due to the nature of the content and the time available for production, the workbook had to be evaluated in its entirety. Each lesson was a prerequisite to the following one. As previously mentioned, the tester population was small. The individuals who participated in this evaluation were at the same time testers and learners. They were evaluating the material while at the same time, learning a portion of the normal course content. Due to time constraints on the testers, the evaluation period had to fit in with their schedules, taking no more time than they would normally allot to learning PERT. As a result, it would have been neither feasible nor fair, to have the testers proceed lesson by lesson as the workbook was developed or to interrupt their learning in any way. The time constraints and the limited number of testers made it impossible to set up focus groups to analyse particular explanations or exercises.

1. Self-Critique

The workbook was subjected to a rigorous self-critique and was revised twice prior to review by an expert. The self-critique has its limitations in that it is difficult for the developer to see gaps and inconsistencies in her own work but it served to identify the most obvious errors and omissions.

2. Expert Review

In Weston's review of the formative evaluation literature, she points to a growing interest in expert review that is due to the fact that it is more cost-effective than approaches which require that data be gathered from a number of learners.

The expert in this case was an engineer with extensive experience in project management. The materials were in an almost final form when they were reviewed by the expert. The expert worked independently with the materials. This was followed by discussion, with the developer, focusing on potential problem spots.

In the Rowntree model, the materials are subjected to critical commenting prior to developmental testing. Rowntree clearly defines the two main aspects upon which one might invite critical comments; subject matter and teaching effectiveness. In terms of subject matter content, information sought concerned the:

. explicitness of the aims and objectives

. relevance of the aims and objectives to learners' needs

. possibility of any important omissions

. redundancy of material

. logical coherence of the material

. presence of unsatisfactory examples

In reference to the teaching effectiveness of the material, the questions focused on the:

. adequacy of the study guidance

. length of time needed to complete the lesson

. appropriate level of difficulty and interest

. relevancy of the examples to the learners' interests

. identification of potential problem areas

. explanations of new terms

. number and distribution of activities and/or self-tests

. relevancy and practicability of activities

. any further ideas for activities, tests or assignments

3. Small Group Field Test

The testers played an active role, going through the complete workbook as normal learners would, while at the same time responding to feedback questions and commenting on the explanations, examples and exercises related to each concept. Normally, during a field test the testers would be passive. According to Weston, it is usually at the one-to-one and small group stage that they are most active. However, since those two stages had to be omitted, this was the only opportunity to acquire extensive feedback.

One advantage of this particular evaluation was that the testers were educational technology students and quite forthcoming and specific in their comments. Weston points out that highly verbal individuals, who have no qualms about expressing their opinion, are desirable. They are more willing to offer criticism. While these testers can be considered as high aptitude learners, they varied in their attitude or perceived ability in working with numbers.

Unless a high level of motivation is maintained, it is unlikely that the testers will conscientiously provide the necessary feedback. According to Nathenson and Henderson, paid testers are less motivated than students studying for credit. They spend less time on the materials and study them less seriously. Drop out rates are high and the quality of feedback is low. What does work is a credit or credit exemption. They point out that it is difficult to deny credit to any tester who has worked through the course and performed successfully on the examination. If a student fails the course, she should be eligible for retake. Since the tester is using a non-glossy version of the course, fees should be waived and a portion of their books be provided free.

Testers were students enrolled in the course and received the normal credit associated with this portion of the course. This ensured that they would study the materials seriously. No financial incentive was used. Materials were provided free of charge. The novelty of the materials appeared to be an additional motivator, as they all commented informally on how they enjoyed working through the workbook and receiving the material in this format.

Dick and Carey point out that the entry behaviour and pre-test are not necessary if the learners have the required skills and are known to lack the knowledge. There was no pre-test as the developer felt that it would serve very little purpose. One either knows or does not know how to carry out PERT. Testers were asked whether or not they know the technique. The three testers who were somewhat familiar with the technique were not excluded from the evaluation, as they agreed to go through the learning materials the same way as the others. Since the workbook is to have an extended life as a reference tool and simply to see how it functions for the purpose of review, their input is warranted. Knowledgeable testers served much the same function as experts. One tester, who had never used PERT, admitted to being rather poor performer given mathematical tasks. Her input was crucial to some of the modifications.

There appeared to be very little need for an entry behaviour test to determine whether or not the learner has the skills required to tackle the learning materials. An analysis of the task revealed that while some statistical procedures were to be carried out, they were simple enough to be performed by a learner who has not received previous instruction in statistics. Only one of the testers had not followed a course in statistics.

According to Dick and Carey, small group evaluation is carried out with a group of between eight to twenty learners. Its chief value is in determining whether or not the learner can work through the course without assistance. Areas of common difficulty, that even when revised might require assistance from the instructor, will become apparent. At the field trial stage a sample group, of between twenty and thirty learners, uses the materials in much the same circumstances as the learners for whom it is intended.

The target audience for which this material was designed is rather small in number, due to the fact that the course is a pre-requisite to the doctoral programme and is not on the list of core courses for the M.A. or Diploma. This put a limit of the number of testers that could be used in the evaluation. It is important, in terms of maintaining their interest and motivation with regards to the evaluation, that the testers had an interest in and orientation to systems analysis.

The testers were given the choice of participating in the formative evaluation. In exchange for their participation they received the workbook free of charge. They were also given a percentage of their final grade for successfully completing the post-test. Seven students agreed to participate in the formative evaluation. However, one could not participate due to illness. The data received from a second student had to be discarded. This student has an MBA. While he agreed to participate, he did not work through the entire workbook as requested and therefore his responses to the attached questionnaires were invalid.

Students received the workbook along with the attached questionnaires and instructions on how to proceed. They worked independently, without consulting the author. The testers were given two weeks to go through the materials. The workbooks and questionnaires were returned to the developer.

After the workbooks were examined and the responses to the questionnaires were analysed, a short debriefing session was held. The workbooks were returned to the testers. As a courtesy related to their participation, the learners received a copy of the data resulting from the field test. An additional questionnaire was distributed in order to gain information about how the tester's used the workbook.

This session related back to the written feedback and provided the testers with an alternative way of expressing themselves and an opportunity for an in depth examination of the problems identified in the feedback questionnaires. Their comments were discussed. This was a rather short session as the testers felt that they had made all their comments on the questionnaires.

4. Expert Review

Due to the fact that there were alterations and additions to the content , a second expert was engaged to examine the content. This individual was an expert in the field of mathematics and had previous experience using PERT.

Data Collection Instruments

1. Self-Assessment Questions

SAQs followed each explanation and example of a concept. They were designed to test the learners understanding of a concept and their ability to apply it. Since these were part of the instructional strategy, they had to be analysed in terms of their clarity, their consistency in association with the preceding explanation and their level of difficulty.

2. Post-test

Due to time constraints on the students and conflicts with other exams and projects, the post-test was administered approximately three weeks after the evaluation. In keeping with the established practice of the course, the post-test took the form of a take-home exam. When evaluating materials within the context of the actual course, it seemed unethical to the developer to submit the learners to the stress of an in-class exam, particularly when this is not the established procedure in the course. Under normal circumstances, these students would not be examined on this material until much later in the course. One must also remember that participation in the formative evaluation required the testers to do extra work.

The purpose of the post-test was to determine whether or not the workbook contained the information necessary to correctly construct a network flow diagram, calculate all the necessary values to determine whether or not the project will meet the scheduled completion date and to evaluate the data. A second purpose was to determine whether or not the learner's understood the material. The post test can be found in Appendix C.

3. Feedback Questionnaires (FBQs)

Nathenson and Henderson found large variations between testers in the extent of their commenting. Also, any one tester's level of commenting tended to decline as she worked through each unit. They solved the problem by building Feedback Questionnaire's (FBQ's) into each unit, following a section of instruction on a concept or set of concepts. The answers represent the tester's subjective evaluation of the instruction just completed. They assess the tester's understanding of the concept along with the strategy used to teach that concept. Their value lies in their ability to identify specific problems in instruction and to suggest possible solutions. They are closely linked physically and temporally to the related instructional material, creating an integrated feedback system. A self-assessment review exercise was included at the end of each unit in order to help determine whether the instruction was successful in accomplishing the unit objectives and to help the students assess themselves on the unit objectives before moving on to the next unit.

Rowntree elaborates on the data collection instruments that can be used to determine how the learners worked through the lesson and their feelings about it. His sample questionnaires served as a model for the this evaluation. Samples of the questionnaires and the results appear in Appendices C to F. These were printed on pink paper and presented as a separate document.

The FBQ's replaced the developer/ evaluator who would in the small group session, encourage the learners to respond and comment. Testers were asked to complete the following questionnaires.

Log Sheet

The purpose of the Log Sheet is to determine how long it took the testers to go through the workbook, so that this information can be added to the study guide. During the field testing, the testers worked with the materials as learners. The time they take is likely to be different from that of developer and the expert who initially reviewed the materials.

End of Lesson Questionnaire

The end of lesson questionnaire provides the most useful information and serves as a guideline for making alterations to the materials. The questions were designed with the purpose of identifying particular areas of difficulty. The questions are related to each concept and focus on the clarity of the explanation and examples, the difficulty of the exercises and the sufficiency of the answers. In addition the learner is asked to provide the numbers of the pages where the difficulties appear. Testers are asked to specify what might have been helpful with regards to the problem areas. Since the workbooks and the questionnaires are returned to the developer, this information is helpful in analysing how each tester worked through the problem.

End of Workbook Questionnaire

This questionnaire asks the tester to comment on the overall level of difficulty, the amount of practice in using the concepts, the facility of accessing information and how much they learned in comparison to the amount of time and effort invested. In addition, testers were asked their opinions on page layout and whether or not they were comfortable with it.

Debriefing Session Questionnaire

The purpose of this questionnaire was to gather additional attitudinal information about the margin notes and underlining and to pursue some of the comments. By leaving the question about margin notes until after the learners have worked through the text, the developer is able to determine how they used them instinctively rather than to prompt them to use them. Since this was an issue of particular interest to the developer, it was important to get the testers' response. Setting these questions aside for the debriefing session, ensured that they had time to answer them.

Data Analysis

Nathenson and Henderson developed a useful algorithm for analysing closed and open ended data. The data are processed through any one of 5 possible routes.

1. If performance data (self-assessment exercise) is available one can determine whether an acceptable proportion of testers have successfully met the criterion for the item. If this has been achieved, examine the related open-ended FBQ's and free comments to determine whether process or learning problems have been identified. If none are identified, the instruction is accepted as written.

2. If performance data is available and the specified proportion of the testers meet the

criteria, but an examination of the FBQ's identifies a process problem and reveals a potential solution, then the instruction is altered based on this information.

3. If performance data is unavailable on a given concept or set of concepts, then focus on the FBQ's which specifically relate to that concept. If they do not indicate a process problem, the unit remains unchanged.

4. If there is no performance data and the FBQ's indicate a process problem and free comments suggest an alternative solution for the instruction, then the instruction is altered.

5. If available performance data indicates that less than the specified proportion of the testers have reached the criterion on the item, then examine the test item itself for clarity. Second, consider the validity of the item. If the item is either unclear or invalid, feedback analysis would proceed as if there had been no performance measure.

   If the test item communicates and is valid, examine the related FBQ's for an explanation of the low performance level. If there is a clarity problem, alter the instruction based on the comment.

   Next examine the FBQ's for indications of dwindling interest and attention.

The final step is to examine the FBQ's for a problem with teaching strategy and ways in which the instruction might be changed.

If there is a performance deficiency which cannot be explained by the FBQ analysis the problem can be explored during the face-to-face seminars.

This is an evaluation system which identifies problems and suggests solutions. Combined with feedback questionnaires, post-test scores and attitude survey followed by tester interviews, this procedure made it simple to identify problem areas and provided a wealth of information for revision.

CHAPTER 4

Results and Revisions

The following discussion focuses on the results of the data analysis and the subsequent revisions. At the small group field test stage, the data for each lesson was generated by applying the algorithm formulated by Nathenson and Henderson. Each lesson has been evaluated using the following:

- performance on self-assessment questions,
- responses to questions in the end of lesson questionnaires regarding each concept, the associated explanation, example and exercises,
- free comments of the testers,
- performance on the post-test.

1. Expert Review

Results: The expert review yielded the following information: typographical errors, confirmation of the clarity of the content, inconsistencies, verification of the explicitness and relevance of the aims and objectives and content.

Since the expert had previously used PERT for large scale projects, without the assistance of a computer programme, his evaluation of the workbook focused on the adequacy and the practicality of the content. Without a first hand knowledge of the target audience, he felt that he could not adequately address questions related to the relevancy of the examples to the learners' interests and the appropriate level of difficulty.

Revisions: Typographical errors were corrected, explanations were clarified and inconsistencies were corrected.

2. Small Group Field Test

Lesson 1

Results: According to the responses to the End of Lesson Questionnaire, no difficulties were experienced with this lesson. An examination of the workbooks and the post-test showed that the testers were able to correctly construct a network. This task requires the ability to distinguish events from activities and to represent concurrent, non-concurrent and dummy activities.

One tester expressed a desire to have more practice in network construction, so that he might become familiar with the variety of configurations.

Revisions: In response to this request a section was included, explaining the possible configurations of any network.

Lesson 2

Results: Lesson 2 dealt with the concepts of activity time estimates, t_e, variance and standard deviation. The SAQs, FBQs and free comments revealed a problem caused by an oversight during the revision of the materials. In one of the exercises, the terms optimistic and most likely time were switched, causing some confusion. The formula for standard deviation had been incorrectly entered. However, an examination of the related SAQs revealed that testers were able to complete the exercises based on the preceding explanation. The post-test supported this.

In their free commenting and during the debriefing session, some of the learners requested additional information about generating activity time estimates and an explanation of the origin of the formula for t_e.

Revisions: The typographical errors were corrected. A section explaining the formula for t_e was added, as was a section on generating activity time estimates.

Lesson 3

Results: Lesson 3 dealt with the concepts of T_E, T_L, and slack. None of the learners expressed experiencing any difficulty with this lesson. The FBQ's indicated that all the concepts were clearly understood. This was supported by an examination of the accompanying SAQs in the workbook and the subsequent post-test. The majority of learners felt that there were an appropriate number of exercises and that the answers were sufficiently detailed as to address any problems they might have encountered.

The only suggestion was to enlarge the networks if possible, as the testers preferred to write the calculated values on the network rather than in the chart.

Revisions: In response to the testers' request, the networks were enlarged and the charts removed.

Lesson 4

Results: Although there were no major problems in Lesson 4, it was revised as the testers appeared to be somewhat uncomfortable with it. All of the testers stated that the understood the explanation of the probability factor but a few had a problem with the related exercise. An examination of the SAQs and of their comments indicated that the problem lay in the fact it was not sufficiently clear that the denominator of the formula for the probability factor involved the sum of the variances of the activities along the critical path. However, by looking at the answer to the question, they were able to figure this out.

One learner experienced problems with the exercise and stated that it was because the T_L for the end event was not stated. However, it was clearly explained in the previous lesson, that when the T_S is stated then this value becomes the T_L for the event.

In the original version of Lesson 4, there was only one exercise. However, in the End Lesson Questionnaire, three out of five testers said that this was not enough.

Revisions: Changes to this lesson included the clarification of the formula for the probability factor and since they appear in the denominator of the formula, a review and elaboration of the concepts of variance and standard deviation.

Lesson 4 seemed to be the most logical place to deal with the problem of practice. It is in this lesson that all the individual values that have been calculated come together to reveal crucial information about the existing plan. As a result learners are now required to complete two exercises that incorporate everything they have learned. In addition to calculating all the values necessary to determine the probability of achieving a scheduled date, they are required to analyse the existing plan and explain what actions they would take in the light of the situation that presents itself.

An additional section was added explaining how PERT provided timely information for programme evaluation. This dealt specifically with the reporting system.

In response to tester requests, a list of the formulae was also attached.

End of Workbook Questionnaire

This questionnaire focused on the testers' attitudes towards using the workbook. As previously mentioned, the workbook is a learning environment. It is therefore important to know if the testers felt comfortable in that environment and if it was conducive to learning.

Four out of five testers stated that they quite liked using the workbook and the fifth thought the question was irrelevant. In terms of locating information, two testers stated that information was easy to find and three said that it was fairly easy to find.

In terms of the level of difficulty, three thought it was fairly easy and a fourth rated it as average. Three of the testers felt that they were given sufficient practice in using the concepts and two felt that there was not enough. When asked how much they learned, in view of the amount of time spent on each lesson, one tester who was somewhat familiar with the technique felt that he learned a great deal and three felt that they learned a reasonable amount. The questionnaire also sought information about the design of the page. The responses are discussed below.

1. Titles presented in the form of definitions

Results: In keeping with Rowntree's suggestion of using self-explanatory titles, the developer expressed the title to each section in the form of a definition. Four out of the five testers felt that this gave them a general idea of what the section was about, one said that it made it easy to locate information. One of those tester's said that it said that it made a glossary unnecessary.

Revisions: No revisions were made as the titles served their intended function.

2. Page Layout

Results: The page layout varied depending on the strategy used to teach the content. Pages containing the explanations had a three inch left hand margin containing notes. In the case of pages containing examples, the rationale behind the format was to be able to present networks, charts and explanatory text on the same page, wherever possible. This reduces the amount of page turning that the learner will have to do. However, this does reduce the amount of white space that might be available for the learner to make her own notes.

All five testers commented that they felt comfortable with this format. One pointed out that in the case of the examples, there was no need to make notes in the margin. Of the five, two said that it reduced the monotony by adding some visual relief. Two said that it that it gave them an idea of how much work was involved and helped to plan out the time. One said that it was not particularly useful in any way.

Revisions: No changes were made due to the fact that the testers were comfortable with this format and found some benefit in it.

3. Justification of line endings

Results: The pages with the three inch left hand margins had ragged line endings on the righ. hand side. Pages containing examples had one inch margins and were right hand justified. As previously mentioned this was due to a coding error. One of the questions in the debriefing session questionnaire drew the testers' attention to the different line lengths but did not refer to the fact that some were justified and some were not. None of the testers made any reference to justification or stated that they found it disturbing in any way.

Revisions: Since there was no objection to the use of right justification, line endings were right justified throughout the text, as originally intended. The revised workbook was produced using Pagemaker 4. This allowed greater control over the spaces between words.

4. Network diagrams

Results: Most of the exercises in Lessons 3 and 4 involve calculating values and placing them on a network diagram. Each exercise page included a diagram and a chart in which the learner could calculate and write down the values which are then placed on the network. All of the testers would have preferred larger diagrams without charts if they did not have to turn the workbook around to fill in the values.

Revisions: Networks were enlarged and the charts removed.

Debriefing Session Questionnaire

1. Margin notes

Results: All but one of the testers used the margin notes. The tester who said he never uses them in any text, stated that he was able to make his own notes in the margin.

Four testers said that they read them before reading the corresponding paragraphs and one also used them to find information when doing the self-assessment questions. The same 4 people said that they preferred having the notes provided as opposed to making their own and would find them useful later when applying PERT to their own projects. Other uses were as a review and as a checklist. Only one out of the four would have preferred the notes stated in the form of a question.

Revisions: No changes were made since the majority of testers appreciated the presence of the margin notes. There is no evidence to suggest that they interfered to any great extent with the testers' established study strategies.

2. Underlining and bold lettering

Results: While these methods of highlighting information were available to the developer, they were not used for fear of interfering with the learners' own study strategies. However a question was included in order to determine whether or not to include those devices.

Four out of five testers said that they preferred to underline the key words and concepts themselves. One learner would have liked to have seen those concepts in bold.

Revisions: The only change that was made was to use bold lettering to identify the concepts when they were first introduced in the overview. This would make these words easier to locate when using the overview for revision.

3. Location of answers to SAQs

Results: Rowntree suggests that answers to SAQs be placed immediately following the exercise, as opposed to placing them at the end of the book. Only two of the five testers would have preferred to have the answers at the end of the book.

Revisions: Due to the majority's preference, no changes were made. One might draw attention to the fact that in most textbooks containing mathematical exercises, the answers to questions are located at the end of the book. Perhaps the break with tradition made those testers uncomfortable or they may have found themselves more inclined to look at the answer before tackling the exercise.

Log Sheets

The purpose of the Log Sheets was to determine the average time it took to complete each lesson. This information would then be included in the study guide.

The results of the Log Sheet have to be examined in conjunction with responses in the other questionnaires that relate to the amount of practice and the number of exercises in each lesson. Adding more exercises will increase the amount of time required to complete each lesson. This brings up the issue of the amount of time and effort that the learner must invest and how much the learner feels that she has learned in relation to this. However, if there is sufficient evidence that more practice is required in order to facilitate learning, then more exercises should be added.

Results: The log sheets indicated that the learners spent approximately one hour on Lessons 1 and 2 and 90 minutes on Lessons 3 and 4.

The End of Lesson Questionnaire was filled in after completion of each lesson. In Lesson 1 there were three exercises: the first dealt with identifying events and activities, the second with network terminology and logic and the third with network construction. Two of the testers felt that there were enough exercises and two felt that there were too few.

In Lesson 2, there were three exercises. Four of the testers felt that this was enough.

In Lesson 3 there were eight exercise. However, this lesson covered more material.

Three of the learners felt that this was an appropriate number of exercises and two felt there were too many.

In Lesson 4, there was only one exercise. Three out of the five testers felt that this was not enough.

Revisions: No exercises were added to Lesson 1. An examination of the related SAQ and post-test question showed that the testers had no trouble constructing the network. It would have been quite difficult for the developer to produce a project in the field of education that would display all the possible configurations that are likely to occur in a given network. However, as previously mentioned, a section was added explaining the various configurations in any network. In the lessons that follow there are many examples of the variety of configurations. Increasing the number of exercises would also increase the amount of time necessary to complete the lesson.

No exercises were added to Lesson 2 as the majority of the testers felt that there were enough.

While some of the testers felt that there were too many exercises in Lesson 3, none were removed. The learner is likely to do only so many as she feels necessary.

The content of Lesson 4 was altered to include new information and a change of teaching strategy. One of the examples was converted into an exercise, for a total of two exercises. This might increase the time required to complete the lesson, but the additional exercise appears to be warranted, in the light of the testers' request.

Conclusion

The formative evaluation showed that a few alterations were necessary. The data from the various feedback questionnaires supported the inclusion of the various access devices. The End of Lesson Questionnaires and the algorithm developed by Nathenson and Henderson were particularly useful in gathering data and identifying the source of any problems.

The testers were generally pleased with the workbook. There were no difficulties with the teaching strategy and the content was clearly explained. Attitudes towards the access and structuring devices and page design as suggested by Rowntree and Hartley supported their inclusion.

Given that formative evaluation is a test-revise-test cycle, the developer has to set the limit as to the number of cycles that the materials go through. Geis point out that there are two options. The developer can set a specific performance criteria on the post test. Test data is an important indicator of the success of the materials. The other alternative is to continue the cycle until there are fewer complaints about confusion and more comments on liking the materials.

In this formative evaluation the criteria for the post test was that 90% of the learners score 90%. In addition to this, it was intended to continue the cycle until the positive comments outweighed the negative ones. Both criteria were achieved with the small group field test.

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Appendix A

Workbook

Programme Evaluation Review Technique

A self-instructional workbook

prepared by

Chareen Dias

Table of Contents

A WORD TO THE READER

This workbook has been designed specifically for use by those students enrolled in the Educational Systems Analysis (ETEC 653) course in the Educational Technology programme at Concordia University.

No previous knowledge is necessary in order to carry out the exercises in this book. If you are already familiar with the technique you may still want to go through the workbook as a review. While there are computer programmes that will carry out all the computations for you, it is important that you understand the operations that are being performed. When you have completed this workbook, you will be able to read a computer print-out and know what information to look at, in order to make an informed decision about the re-allocation of resources for any given project.

It has been said that an individual trained in the use of a desk calculator can manually process 200 activities in less than one working day. In this workbook you will work with no more than 20 activities. This will give you enough practice to be able to handle larger projects.

USING THE WORKBOOK

Lesson Format

This workbook contains four lessons. On the title page of each lesson, you will be given some introductory information about the objectives of the lesson, the nature of the content along with advice on how to proceed. Each lesson follows the same format. It begins with an explanation of the concept(s), followed by a detailed example. Each example is followed by one or more self-assessment questions or SAQ's. These are exercises that permit you to test your understanding of what you have just read and give you practice in using the concepts.

Materials

You will need a hand calculator that has a square root function. You will notice that the pages of this workbook are printed on one side, permitting you to use the opposite page for notes and calculations.

Time

Each lesson will take between 60 and 120 minutes of uninterrupted work. Please proceed through this workbook at a comfortable pace.

Study guidelines

Before starting each lesson you might find it helpful to read the OVERVIEW in Lesson 1. This will help refresh your memory. Browse through each lesson before starting, so that you will have an idea of how to structure your learning time.

LESSON 1

OBJECTIVE:

Upon completion of this lesson, you will be able to construct a PERT network. The network is a visualisation of your project. It reveals the relationships and dependencies amongst tasks. It is a means of coordinating all the activities that must be accomplished to ensure the timely completion of a project.

Study Guide

This is the simplest lesson in the workbook and should take no more than an hour to complete. All the components of the PERT network are defined and illustrated. We will go step-by-step through the construction of a network for an experimental research project and then you will tackle a network for a video production project. All the information you need to accomplish this task this will be provided.

Time: 1 Hour

Materials: pencil, ruler, eraser, circle template (optional)

Previous knowledge required: none

PERT applications

Many of the projects that you will encounter as an educational technologist will be related to the production of instructional materials, the administration of research projects or the implementation of educational or organisational change. While these projects differ in nature, they all involve a number of tasks that can be performed independently and simultaneously. They may also be one-time-only projects, and as such, many of the tasks may be new to the members of the project team. Fortunately, there is a management technique known as PERT (Programme Evaluation Review Technique) which allows you to plan, organise, control and schedule such complex and large scale projects.

usefulness to the educational technologist

In reference to projects carried out in the field of education and educational technology, PERT can be applied to experimental and historical research, surveys, curriculum planning and materials production.

PERT has been extensively applied to development efforts in the aerospace, defense and construction industries. It has demonstrated its value in projects ranging from the development of the Polaris Weapon System in 1957-58, to the production of a Broadway play. It has been used in book publishing, new product introduction, organisational change and educational planning.

project size and complexity

There is no limit to the size or complexity of the projects to which PERT can be applied. A minimum capacity could be set at a project requiring one or two persons, working on between twenty and twenty-five activities, over a period of two months. While PERT can be introduced at any phase, its full potential is realised when it is implemented at the start, unhampered by previous planning and control techniques.

When deciding whether or not to use PERT for any given project, you might want to ask yourself the following questions:

when to use PERT

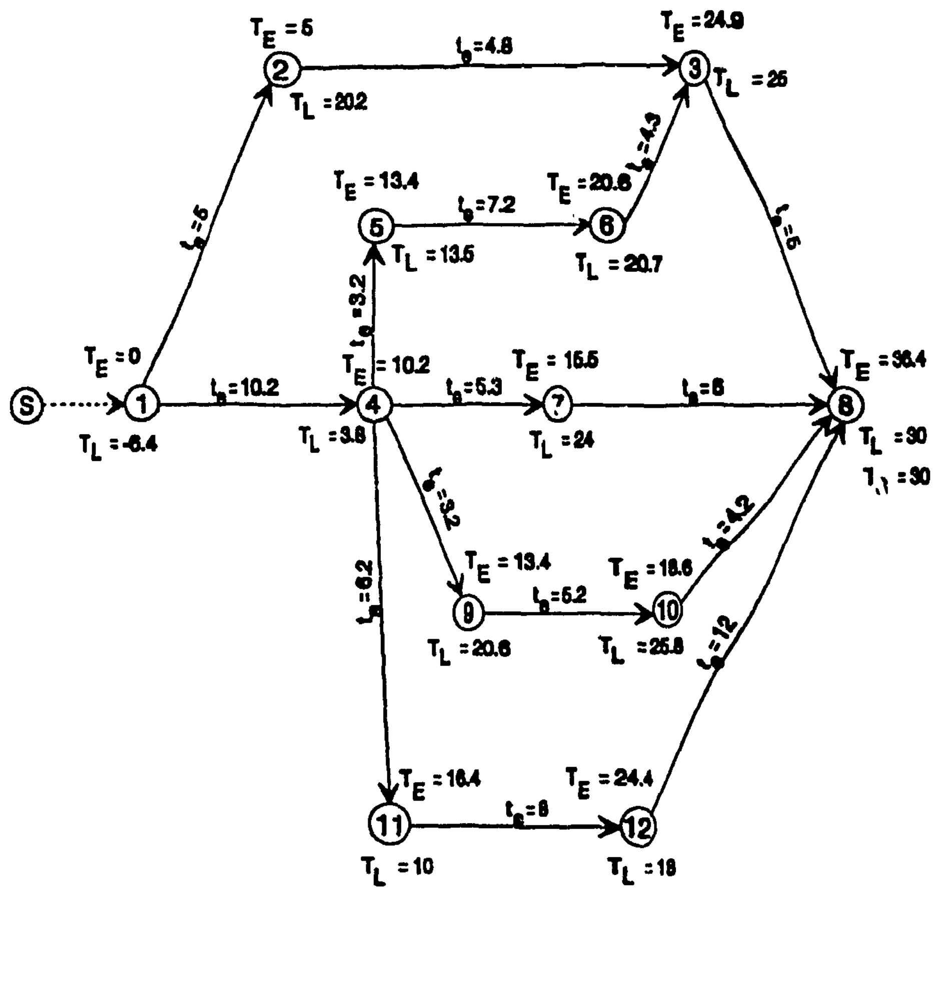
1. Does this project involve the development of a new product or procedure ?
2. Is there a specified end objective which must be accomplished by a given date ?
3. Is the project complex enough to warrant the use of PERT ?
4. Is there a degree of uncertainty as to the definition of some or all of the project elements?

OVERVIEW: components and calculations

Let's begin with an overview of PERT, focusing on the components and calculations involved in applying it to a project. This overview should act as a map, showing you where you are going and how to get there.

list activities and define relationships

In applying PERT, you will work in stages. First you will list the component tasks or activities, clarifying the relationships between and amongst them. Then you will construct a network flow diagram or map of the project, showing the activities and the activity paths that must be followed and the events or milestones that must be reached. Activities are represented by arrows. Events are represented by circles or nodes, as they will be referred to from now on. Here is an example of a network flow diagram.



determine the average time for each activity

Since you want to determine how long it will take to complete the project, the second factor dealt with is time. Continuing with the analogy of the map, time is akin to the distance between two points. As previously mentioned, PERT is best suited to projects that are non-repetitive. In such projects it is difficult to determine exactly how long each activity will take, therefore we use a statistically averaged expected time known as t_e. This is the average time an activity would take if repeated many times. It is based on the optimistic, most likely and pessimistic time estimates for the activity.

determine the uncertainty of time estimates

PERT also allows for the presentation of statistical information regarding the uncertainty associated with the three activity time estimates. A statistical measure of uncertainty known as **variance,** represented by the symbol σ^2, is calculated for each activity. This is normally calculated after calculating the t_e. The greater the variance, the greater the uncertainty.

simulate how increasing or decreasing t_e affects completion date

Another useful statistical measure is the **standard deviation,** referred to as S or by the symbol σ. Calculation of the standard deviation establishes a range, either side of the expected time, within which each activity or the entire project is likely to be completed. Using the standard deviation and the area under the normal curve, you can determine the probability of completing any activity or the entire project within the given range. The advantage of this process is that it allows you to simulate what will happen when you have a predetermined completion date and must plan all your activities according to it. The standard deviation can be calculated after you have calculated the variance, as it is the square root of the variance. The standard deviation and the range are not normally reported on the activity-output slack sort chart, an example of which appears on the following page.

determine project duration

The next major step is to identify the **critical path.** This is the longest path through the network, therefore it determines the duration of the project. In order to identify it, we must calculate three other values.

determine the earliest time an event can be reached

schedule a project completion date

First, for each event we calculate $\mathbf{T_E}$, which is defined as the earliest expected time that an event can be reached. This simple calculation requires summing the t_e's for all the activity paths leading to each event. When you have calculated T_E for the final event, it serves as the scheduled project completion date $\mathbf{T_S}$, if no scheduled date has already been specified. If, on the other hand, the T_E is later than the specified completion date, PERT provides the means for reducing T_S. Looking back at the network, you will see that T_E is placed above the event node.

determine latest completion time for an event

Next we calculate $\mathbf{T_L}$ which is the latest allowable completion time for an event. It is the latest time by which an event must be completed to keep the project on schedule. T_S, T_E and t_e are used in this calculation. The procedure is one of subtraction. This value is placed below the event node on the network.

identify events that will be on, ahead of or behind schedule

Now we must determine the **slack** or excess time associated with each event. To do this, we must subtract the earliest expected time from the latest allowable time. A positive value indicates an ahead of schedule condition, while a negative value indicates a behind schedule condition. A value of zero means that the event is likely to be reached or completed on schedule. The slack value highlights potential trouble spots and points to possible solutions, such as the re-allocation of resources.

The values that you have calculated for T_E, T_L and slack are transferred to an Activity-Output Slack Sort Chart. By consulting the network flow diagram and the slack values on the chart you can determine the critical path. The critical path is also the path through the network which has the greatest sum of t_e values from network beginning to ending event.

determine the probability of meeting a scheduled date

The last calculation is the probability factor **Z**, which allows you to determine the probability, $\mathbf{P_R}$, of meeting a scheduled date. In addition to the final event, there are other events that may have a scheduled completion date. The probability factor allows you to determine the probability of reaching or completing those events on time.

determine possible resource trade-offs

You can now construct the **activity-output slack sort chart**, which is used to manage and control the project. By consulting the slack and variance columns you can determine possible resource trade-offs. This requires a re-examination of time estimates and subsequent re-calculation. The following chart corresponds to the network at the beginning of this section.

Activities	Actual Date	T_E	T_L	T_s	SLACK	σ^2	P_R
S-1		0	-6.4		-6.4	0	
1-4		10.2	3.8		-6.4	2.3	
4-11		16.4	10		-6.4	1.4	
11-12		24.4	18		-6.4	0.4	
12-8		36.4	30	36.4	-6.4	4	.0139
3-8		29.9	30		0.1	2.8	
4-5		13.4	13.5		0.1	0.7	
5-6		20.6	20.7		0.1	3.4	
6-3		24.9	25		0.1	1	
4-9		13.4	20.6		7.2	0.7	
9-10		18.6	25.8		7.2	0.7	
10-8		22.8	30		7.2	1.4	
4-7		15.5	24		8.5	1.8	
7-8		21.5	30		8.5	1	
1-2		5	20.2		15.2	2.8	
2-3		9.8	25		15.2	1.4	

You should now have a basic idea of how PERT can help you complete your projects on time. It forces you to manage your resources effectively and efficiently. It provides statistical and other information that serves to identify potential problems and possible solutions. So you see, it is a most useful aid to decision-making. By the end of this workbook you will have recreated this chart and will be able to analyse it and make suggestions for the improved management of the project's resources.

NETWORK CONSTRUCTION: terminology

While it is possible that different people will construct different networks for the same project, there are some conventions that should be followed. To be able to construct a network, you must understand the basic terminology. PERT networks are composed of events and the activities that link them.

events defined

Events are significant points or milestones, which can be used as checkpoints to monitor the project. An event is the start or the completion of a task and not the actual performance. A single event can be both the completion of one activity and the start of another. An important point to note is that PERT events do not consume time or resources.

representing events

Events are represented by nodes which contain identifying numbers. The initiating event of the project is often referred to as project start and in this case, the node will contain the letter S. The initiating event can be seen as a decision to start the project or as the the receipt of some resource (financial, material, human or equipment) needed to start the project. It can also be represented by the number 1 when it initiates a time-consuming activity.

sequencing and numbering events

The accomplishment of one event is the start of another. Events are the beginning and end of activities. Later, when you develop your own network, you will see that some events can be reached simultaneously, therefore, ordering all the numbers sequentially is not possible. Events must occur in a logical sequence, as some events depend on others.

The distinction between preceding and succeeding events and terminating and initiating events, depends on whether one is looking at events in relation to each other or in relation to activities.

successor events and predecessor events

As the term suggests, successor events are those events that immediately follow another event, without any intervening events. The event or events that come before another event, without any intervening events, are called predecessors to that event.

initiating and terminating events

Each activity is initiated and terminated by an event. No activity can begin until the initiating event has occurred or end until the terminating event has occurred. An event is not considered as having taken place until all activities leading to it have been accomplished.

network ending event

The network ending event terminates the project. In a PERT network the direction is from left to right, so this event will appear on the right hand side of the network. All activity paths terminate at this event.

activities defined

An activity is the actual performance of a task. Therefore, activities require time, manpower, material, space, facilities and other resources.

representing activities

loops defined

Activities are represented by the numbers of the events that initiate and terminate them. Between any two events there can be only one activity. The activity arrowhead is always to the right of the tail. There can be no loops in the network, as this would result in the repetition of activities. A loop occurs when a successor event has an activity dependency which leads back to a predecessor event.

concurrent and non-concurrent activities

Some activities can be performed independently and simultaneously if desired. Such activities are said to be concurrent or in a series-parallel arrangement. When one activity is dependent on the other, the activities are said to be in a series-connected or non-concurrent arrangement.

dummy activities defined

Dummy activities consume neither time nor resources. They are used to preserve the logical flow of the network, or to restrain one event from happening until a pre-requisite event has occurred. Dummy activities are represented by a broken arrow. They are often used between an end and a start event, where no activity takes place or when the completion of two or more concurrent activities terminate in a single event.

SAQ 1: identifying events and activities

This exercise will give you a chance to see if you can distinguish between activities and events. Place the letter E beside the events and the letter A beside the activities.

___ 1. instructional design started

___ 2. instructional design completed

___ 3. write the proposal

___ 4. proposal submitted

___ 5. interview applicants for instructors' position

___ 6. instructors hired

___ 7. record sound tracks

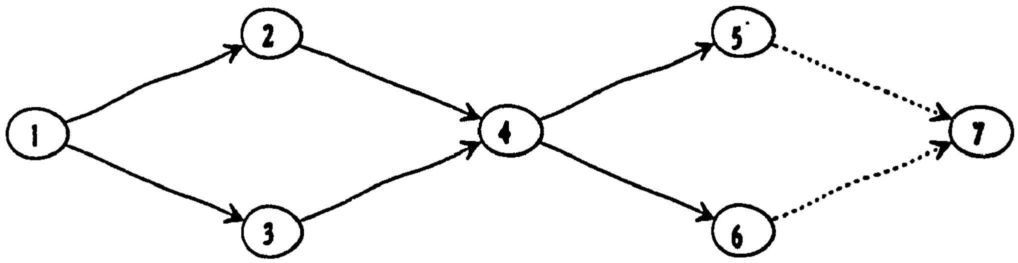
___ 8. sound tracks recorded

___ 9. formative evaluation completed

___ 10. perform formative evaluation

SAQ 1: Answer 1) E. 2) E. 3) A. 4) E. 5) A. 6) E. 7) A. 8) E. 9) E. 10) A.

SAQ 2: network terminology and logic



Here are a few questions to test your understanding of network terminology and logic.

1) Event____ is the network beginning event.
2) Event____ is the network ending event.
3) Identify the concurrent activities in this network ____
4) The predecessor event for Event 3 is Event____.
5) The predecessor events to Event 4 are____________.
6) Event 3 is the predecessor to Event ___________.
7) Activities__________are dummy activities.
8) Event 1 is the predecessor to Events_____________.
9) Event 4 is the successor to Events_______________.
10) Event_____ is a start event and event___ is an end event and events _____ and event ____ is both a start and an end event.

SAQ 2: Answer

1) 1.
2) 7.
3) 1-2 and 1-3, 2-4 and 3-4, 4-5 and 4-6.
4) 1.
5) 2 and 3.
6) Event 4.
7) 5-7 and 6-7.
8) 2 and 3.
9) 2 and 3.
10) 1 is a start event and 5,6,7 are end events and events 2,3,4 are both end and start events

NETWORK CONSTRUCTION: representing activity relationships

The network is the basis of the PERT system. Networks vary in their shape and complexity, depending upon the project and how the activities are related.

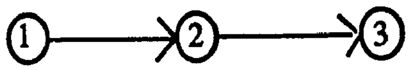
The network reveals the following information:

- the plan established to reach the project objectives
- the inter-relationships and inter-dependencies of activities and events
- the priorities and sequences of activities and events

All networks are based on the following simple constructions.

Series Construction

This construction is used when events follow each other in a linear sequence.



Series Construction with Dummy Activities

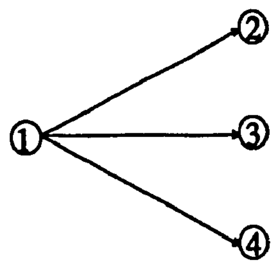
Dummy activities are used when one or several elements must be linked together to preserve the logical flow of the network. Dummy activities consume neither time nor resources. The dummy activity is placed between an end event and a start event or between two start events. If you were to use an S node to start the network, you would place a dummy activity between the S node and the first event of the project, since there is no time consumed between the two events.

In this construction, we see that:

- events 1 and 3 are start or initiating events
- events 2 and 4 are end or terminating events
- activity 1-2 precedes activity 3-4
- activity 2-3 is the dummy activity that joins the two

Burst Construction

A burst construction represents a situation where several succeeding events are constrained by a single preceding event.

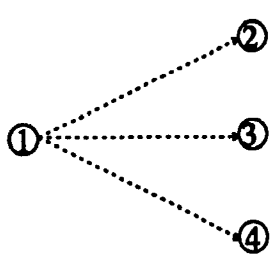


In this case,

- Event 1 initiates activities 1-2, 1-3 and 1-4
- Event 1 must be reached before any of these activities can take place
- Events 2, 3, and 4 as they are shown, are end events

Burst Construction with Dummy Activities

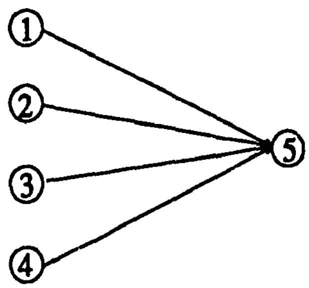
When no time is consumed between a single predecessor event and the several dependent successor events, dummy activities are used to link the predecessor event with the successor events. The successor events in this case are in fact start events, as they do not end any time consuming activities. Rather, they are the starting points for 3 activities which can commence following the completion of event 1.



So, if you were working on an educational research project, event 1 might stand for the completion of the instructional and testing materials and events 2,3 and 4 for the start of treatment administration to be carried out in three different schools.

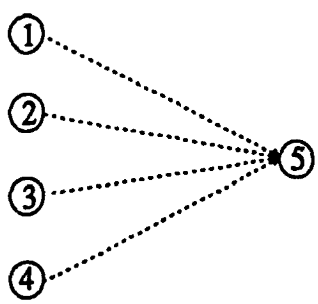
Merge Construction

A merge construction occurs when a single successor event is dependent on the completion of several preceding activities.



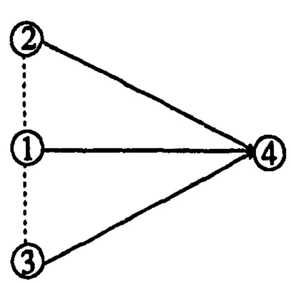
Merge Construction with Dummy Activities

Here we have a case in which a single successor event is dependent on several predecessor events. However, there are no time consuming activities between any of the predecessor events and the successor event. Hence the predecessor events, 1,2,3 and 4 do not start any activities. Assuming that you are being shown part of a network, we can consider those events as terminating previous activities. For example, they may represent chapters of a book written by different authors, that when collected together form the first draft.



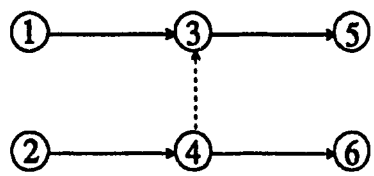
Concurrent Activities

There can be only one activity between any two events. When concurrent activities are performed between common events, dummy activities are used to indicate that the activities are concurrent. Here 1-2 and 2-3 are dummy activities, showing that 1-4, 2-4 and 3-4 occur concurrently.



<u>Concurrent Activities with Different Dependencies</u>

Dummy activities are used to clarify dependencies when concurrent activities are not dependent on a single event or activity. In the network below, activity 3-5 is dependent on the completion of 1-3 and 2-4. Activity 4-6 depends only on the completion of 2-4.



NETWORK CONSTRUCTION

Perhaps the best way to learn how to construct a network is to go through the process of developing a network for an educational research project. Any experimental research project is as different as the skills of the researchers, the nature and scope of the problem, the availability of subjects and the choice of experimental design. All those factors and more can influence the time estimates that are made for the activities. PERT is well-suited to this type of project.

The first few times you tackle network construction, even in the case of a relatively simple network, you might find yourself getting confused. Some people are event-oriented and others activity-oriented in their approach. Some of us are half and half. The first step is to list all the major tasks that must be completed. Your list may be expressed as either events or activities, depending on what makes most sense to you. Many of those individual tasks can be further broken down to create smaller sub-networks. However, I have kept this example simple.

I find it easier to start with a list such as the following one, specifying as single events, the initiating and terminating events for each activity. Next, applying some order to the list, I identify those events that are prerequisites to others and those that can be carried out concurrently. I use different coloured highlighter pens for this. It is up to you whether you work backwards or forwards in developing the list, although the former is often suggested.

Next I develop a refined list based on the fact that a single event can represent the start of one activity and the beginning of the next. That is, a single event terminates one activity and initiates another. Had I not refined the list, I would have ended up with an unnecessarily large network resulting from a need to use dummy activities to link up the start and end events.

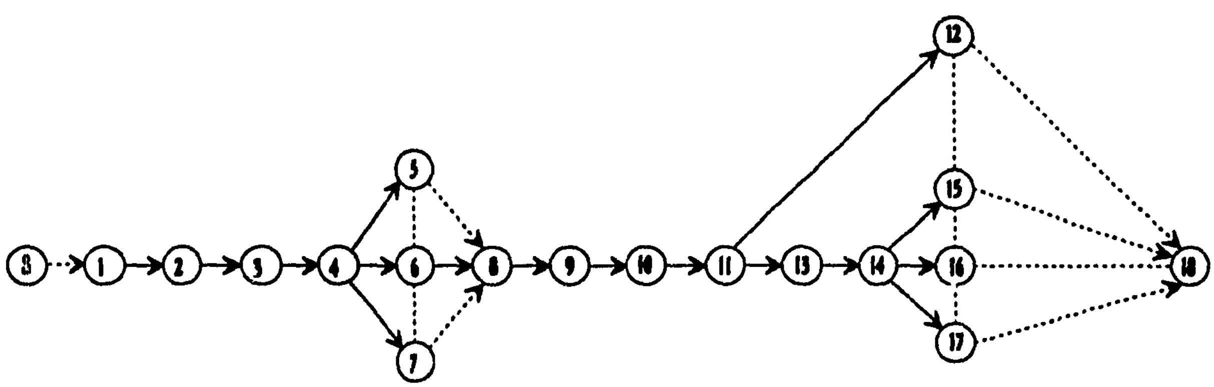
NETWORK CONSTRUCTION: an example

Preliminary event list for an experimental research project:

project start
preliminary reading started
preliminary reading finished
literature review started
literature review finished
writing literature review started
writing literature review finished
sampling started
sampling finished
instructional and testing materials started
instructional and testing materials finished
assignment of subjects to treatment groups started
assignment of subjects to treatment groups finished
pre-testing started
pre-testing finished
treatment started
treatment finished
post-test started
post-test finished
data coding started
data coding finished
Methods section started
Methods section finished
analysis started
analysis finished
Results, Discussion, Conclusion, Bibliography started
Results, Discussion, Conclusion, Bibliography finished
Graphs and tables started
Graphs and tables finished
Study completed

The refined version of the event list shown below is based on the fact that an event can be both the end of one activity and the beginning of another. Some events such as 5, 6 and 7 are end events only. All three events have to be achieved before Event 8 can be started, but the activities leading to them can be carried out concurrently. By naming Event 8 as a start event, we are avoiding the inclusion of a specific single terminating event. If we had done this we would have needed to included a dummy activity followed by a start pre-testing node, followed by a real activity arrow, and an end pre-testing node.

Event S:	project start
Event 1:	preliminary reading started
Event 2:	preliminary reading finished / literature review started
Event 3:	literature review finished / writing literature review started
Event 4:	writing finished / sampling started
	writing finished / instructional and testing materials started
	writing finished / assignment to treatment groups started
Event 5:	sampling finished
Event 6:	instructional and testing materials designed
Event 7.	subjects assigned to treatment groups
Event 8:	pre-testing started
Event 9:	pre-test finished / treatment started
Event 10:	treatment finished / post-test started
Event 11:	post-test finished / data coding started
Event 12:	post-test finished / Methods section written
Event 13:	coding finished / analysis started
Event 14:	analysis finished / Bibliography started
	analysis finished / Results section started
	analysis finished / graphs and tables started
Event 15:	Bibliography finished
Event 16:	Results section finished
Event 17:	Graphs and tables finished
Event 18:	Study completed



The following activity list explains the network flow diagram.

non-concurrent activities:

S-1 project start - a dummy activity (no time consumed)
1-2 preliminary reading
2-3 conducting literature review
3-4 writing literature review

Concurrent activities connected to Event 8 by dummies:

4-5 carrying out sampling procedures
4-6 designing instructional and testing materials
4-7 assignment of subjects to treatment groups
5-8 and 6-8 and 7-8 are dummy activities

Non-concurrent activities:

8-9 pre-testing
9-10 administering treatment
10-11 post-testing

Concurrent activities:

11-12 writing Methods section
11-13 coding and entering data

Non concurrent activity:

13-14 data analysis logically follows 11-13

Non-concurrent activities connected to the final event by dummies:

14-15 write up Results, Discussion, Conclusion sections
14-16 produce graphs and tables
14-17 write up Bibliography
12-18 and 15-18 and 16-18 and 17-18 are dummy activities

SAQ 3: network construction.

Now let's see if you can construct a network.

Suppose you have received a request to produce an instructional video for teachers and guidance counsellors that will improve recognition of adolescent depression and suicidal behaviour. First, you will conduct a needs assessment in order to determine the problem(s), the target audience, the type of information to be presented, the desired results and what can be done within the specified budget. Based on this you will develop the instructional objectives which will define the content.

Let's assume that a dramatisation of several case studies, followed by commentary and discussion, has been selected as the best approach. First the rehearsal script is written. It contains full details regarding the location, dialogue and action in each scene, along with a breakdown showing the shooting order together with details of topics, scene durations, shooting arrangements and a cast list. Next, the camera script is developed. This consists of the rehearsal script plus information about the full production treatment, specifying the type of camera shot (viewpoint and camera movements), supplementary picture information (added titles and video effects) supplementary sound information (details of effects and music) and directions for transitions from one scene to another (cut or dissolve). It also contains a list of facilities and equipment that will be used. This serves as the guideline for all the video and audio components and for identifying the number of actors, locations props and equipment required.

Since there are 3 cameras and all 3 types of footage are independent of each other, you will be able to shoot them concurrently. Since there is only one edit controller, all the footage will be logged at the same time. The takes will be numbered and the best ones selected, then they will be edited together.

According to the camera script there will be music, live sound and narration. The music and narration are to be pre-recorded on audio tape and transferred to the video during the editing process.

Pre-production

These are non-concurrent activities and occur in this order:

Conduct needs assessment
Identify instructional objectives
Develop rehearsal script
Develop camera script
Conduct remote survey (details of location)
Hire talent (audition and selection)
Carry out preliminary administrative functions.
(obtaining permits for taping people and releases for copyrighted materials, arranging insurance coverage and scheduling shooting sessions, etc.)

Production

These activities are concurrent and take place once all permits, contracts and insurance are confirmed.

Record soundtrack
Record location footage (case studies)
Record studio footage

Titles, captions, artwork must be prepared before they can be recorded on video but these two activities while occurring in sequence are carried out concurrently with the others.

Prepare titles, captions, artwork
Record titles, captions, artwork

Post-production

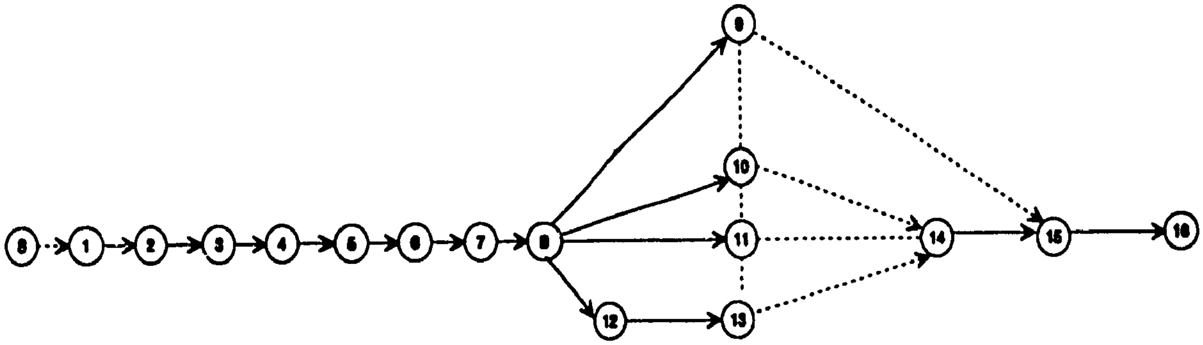
These activities are non-concurrent:

Log footage
Edit video

Now, draw the network on the opposite page.

SAQ 3 : Answer

The network should resemble this one.



LESSON 2

OBJECTIVE:

Upon completion of this lesson you will be able to calculate the following values:

- t_e, the average time an activity would consume if it were repeated many times
- Variance, a statistical measure of uncertainty about the time estimates
- Standard deviation, a means of estimating the range of time within which an activity can probably be completed

These values provide statistical information that will allow the project manager to schedule or re-schedule the project and make decisions about the re-allocation of resources. By examining the variance the manager can determine whether or not the time estimates are accurate.

Study Guide

This lesson requires that you perform some rather simple statistical procedures. All the information you need is provided in the text. The answers have been worked out in detail so that you will not waste time trying to find simple calculation errors. It is not necessary to understand the origin of the formula for t_e but for those who do not wish to accept the formula on faith, an explanation has been provided. Don't be too concerned if you do not understand the explanation. It is only there as background information and not necessary for calculating t_e. The same applies to the explanations of the origin of the formulae for variance and standard deviation.

Time: 35 to 60 minutes

Previous knowledge required: Lesson 1

Factors to consider when making activity time estimates

Once you have developed a network representation of your project, you are ready to assign time durations to the constituent activities. As you will recall, PERT is most useful when applied to non-recurring projects, where the project team may be uncertain about estimating times for unfamiliar activities. This may lead to considerable uncertainty about the completion time of the project.

a way to reduce uncertainty

To reduce this uncertainty, PERT uses three time estimates which are condensed into a statistically averaged expected time, t_e. These estimates are best submitted by individuals who are familiar with the activities and responsible for carrying them out. If they are not familiar with the activity, then they must consult others who are. Another source of information about activity times is any documentation from previous projects involving the same activity or activities.

generating time estimates

Some of the factors involved in generating time estimates for an activity are:

- the available financial resources
- the number of people required
- the skills of those people
- equipment and facilities

When generating time estimates, one assumes that the financial and human resources, facilities and equipment will be available on a normal basis or as requested in the project proposal.

It is important that the time estimates be accompanied by an explanation of the circumstances and conditions under which they would occur. This is an important source of information that can be used much later, when and if activity times have to be altered.

The existence of a calendar schedule date may inhibit clear thinking about the numerous factors to be considered in forming estimates. This can be avoided by taking the following measures:

how to avoid biased estimates

- collecting time estimates before the scheduled or contractual date is announced

- breaking down the larger network into sub-networks and obtaining separate estimates for the sub-networks

- making estimates for individual activities in a random manner, to avoid biasing the time estimates of an activity by that of the previous activity.

t_e: a statistically averaged expected activity time

t_e defined

t_e is the average expected time an activity would take if repeated many times.

The calculation of t_e is based on this simple formula, where;

formula

$$t_e = \frac{a + 4m + b}{6}$$

- a is the optimistic time
- m is the most likely time
- b is the pessimistic time

optimistic time

The three time estimates on which t_e is based are the optimistic time, the most likely time and the pessimistic time. The optimistic time, is the shortest possible period in which the activity can be accomplished. It is the time required for completion, if all proceeded better than normally expected.

most likely time

The most likely time, is the most re[illegible] estimate of the time required to complete the activity. This is the estimate one would submit if only one estimate was originally requested.

pessimistic time

The pessimistic time is the longest possible time that it would take to accomplish the activity. This is the time it would take if everything, other than major catastrophes, went wrong.

Origin of the formula for t_e

The t_e of an activity is based on three estimates of elapsed activity time: the optimistic time, the most likely time and the pessimistic time. By obtaining three estimates rather than one, certain assumptions enable us to translate these estimates into the characteristics of a probability distribution of activity performance times. With three estimates, the time required to accomplish a task can be expressed in terms of likelihood rather than positive assurance. In turn, likelihood can be expressed in terms of statistical probability and distribution curves.

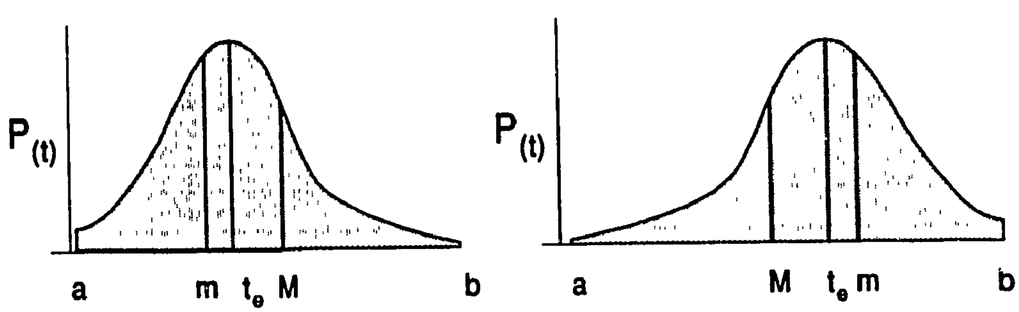
The conversion of a, m and b into an estimate of expected value, t_e, is based on the assumption that the probability distribution of the time required for an activity is a beta distribution, where:

- a is the optimistic time and the upper bound of the distribution
- m is the most likely time and the mode or highest point of the distribution
- b is the pessimistic time and the lower bound of the distribution

Since m should occur most often, it is assumed that it is the mode of a probability distribution. a and b should occur the least often.

t_e is located between the mode (most likely time) and the median, M, (mid point) of the distribution. The distance between t_e and m, is one third of the total distance between m and M. t_e represents the 50% probability of the distribution as it divides the area under the normal curve into two equal portions. The position of m between a and b can vary, that is, it can be closer to one than the other.

Beta distribution



As a result of the approximation and analysis of the beta distribution

$$t_e = 1/3\ (2m + M)$$

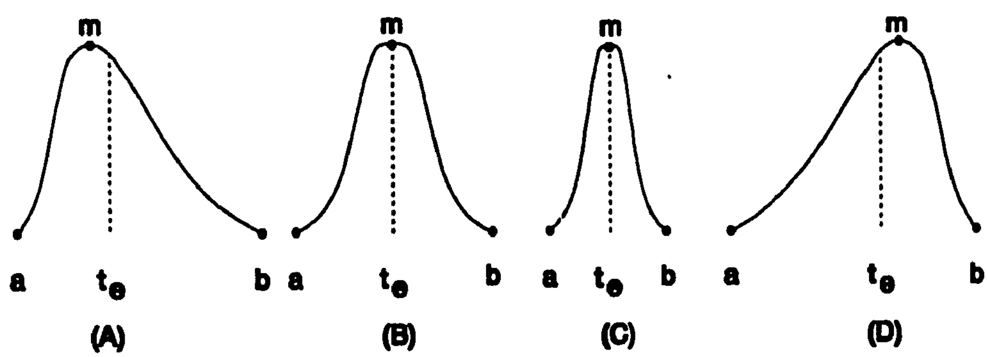
$$= \frac{1}{3}\left[2m + \frac{(a + b)}{2}\right]$$

$$= \frac{a + 4m + b}{6}$$

According to the first equation, t_e is interpreted as the weighted mean of m (most likely time) and M (median) estimates with weights of 2 and 1 respectively. The most likely time carries two thirds of the entire weight.

The assumption of the beta distribution has provided a reasonable way of locating t_e with respect to a, m and b.

The three time estimates for any activity will establish a distribution curve similar to one of those below. The relative positions of a, m and b on the distribution curves depends on the numerical values the estimator has assigned to them.



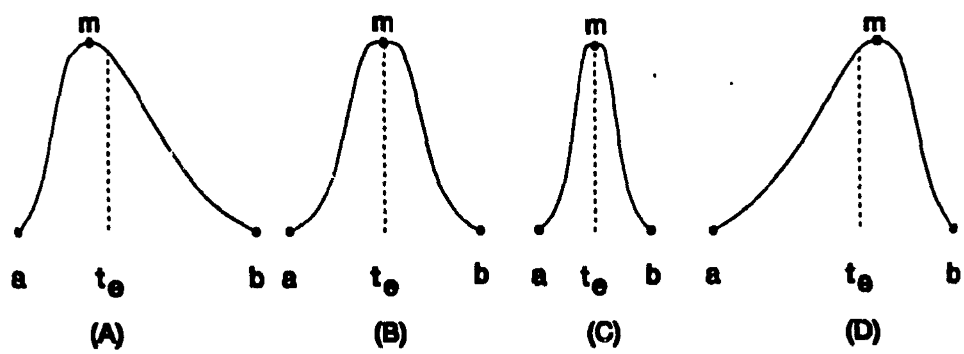
The curve represents the frequency of occurrence of the various times which it is assumed would occur if the activity were performed many times. The curve is assumed to have only one peak, the most likely time. There is relatively little chance of the a and b estimates. Small probabilities of approximately 1 in 100 are associated with a and b. No assumption is made regarding the position of m. It may take any position between a and b, depending on the estimator's judgement.

Distribution curves: an example

Perhaps looking at an example will make this clearer.

	a	m	b	t_e
activity 1	6	7	10	7.33
activity 2	3	6	9	6
activity 3	5	6	7	6
activity 4	2	5	6	4.67

The following curves represent the variety of forms which the distribution may take.



Activity 1 corresponds to distribution A where m is closer to a than to b and t_e is greater than m.

Activity 2 corresponds to distribution B, where m is equidistant from a and b and t_e has the same value as m.

Activity 3 corresponds to distribution C. Notice that t_e is only one point away from either a or b and is equal to m. In contrast to distribution B the distance between a and b is narrower.

Activity 4 corresponds to distribution D. Notice m is closer to b than to a and t_e is less than m.

SAQ 1: calculating t_e and determining the distribution curve

The following exercise will give you a chance to calculate t_e and to establish the appropriate distribution curve.

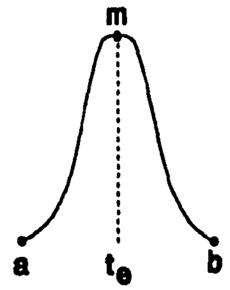
1. a = 30 days, m = 45 days, b = 60 days

2. a = 14 days, m = 17 days b = 25 days

3. a = 32 days, m = 54 days, b = 71 days

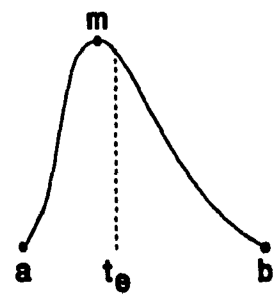
SAQ 1: Answer

1. a = 30 days, m = 45 days, b = 60 days, t_e = 45



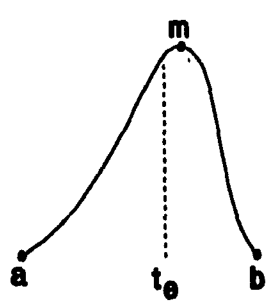
(B)

2. a = 14 days, m = 17 days b = 25 days, t_e =17.8



(A)

3. a = 32 days, m = 54 days, b = 71 days, t_e = 53.2



(D)

VARIANCE: a measure of uncertainty about time estimates

function of variance

Once we have calculated the t_e for each activity, we must determine the accuracy of this estimate. Therefore, we calculate variance, which is a measure of uncertainty, in this case, about time estimates. Ultimately, the variance data for the entire network will make it possible to determine the probability of meeting a scheduled date and to make decisions about the re-allocation of resources. We will see how variance is used for this purpose, later on, when we will be required to determine which time estimates should be revised.

a measure of the gap between optimistic and pessimistic times

When estimating activity times, it is best to seek the advice of someone who is familiar with the activities in question. A large variance may be the result of an excess or lack of information, or a desire to leave plenty of leeway for anticipated problems. More often than not, the more information available about the activity, the narrower the gap between optimistic and pessimistic time estimates. The greater the gap between the optimistic and the pessimistic times the greater the variance. The smaller the variance, the more precise the estimate.

Variance is calculated using this formula:

formula for variance

$$\sigma^2 = \left[\frac{1}{6}(b-a)\right]^2$$

$$= \left(\frac{b-a}{6}\right)^2$$

where,

σ^2 = variance
a = optimistic time
b = pessismistic time

The formula for variance is based on the same assumptions as those for t_e.

SAQ 2: calculating variance

In the following example, whose time estimates are likely to be the most accurate?

	optimistic	most likely	pessimistic
Smith	12	8	26
Jones	12	8	16

The formula

SAQ 2: Answer

Using the formula we calculate the variance for each:

Smith: $\left(\frac{a - b}{6}\right)^2 = \left(\frac{26 - 12}{6}\right)^2 = 5.4$

Jones: $\left(\frac{a - b}{6}\right)^2 = \left(\frac{16 - 12}{6}\right)^2 = .44$

The greater the variance the more uncertain the estimates, therefore we would use Jones' estimates.

STANDARD DEVIATION: a means of estimating the range of time within which an activity can probably be completed

a measure of deviation from the mean

Once you have calculated the t_e for an activity, it is also useful to know within what range of this average time, the activity can probably be completed. That is, how many minutes or days more or less than the expected time, is it likely to take. This value is known as the standard deviation. The standard deviation is a measure of variability; a numerical index that indicates an average dispersion or spread of scores around the mean. Quoting the standard deviation of a distribution is a way of indicating a kind of average amount by which all the values deviate from the mean. Here our mean is the t_e.

The calculation of the standard deviation is quite simple. Remember, it must be calculated for each activity.

the formula

The formula is:

$$\sigma = \sqrt{\left(\frac{b - a}{6}\right)^2} = \frac{b - a}{6}$$

where

σ = standard deviation
b = pessimistic time
a = optimistic time

the formula explained

The standard deviation is also the square root of the variance and equals 1/6 of the range of reasonably possible time requirements. The rationale for this assumption is that the tail of many probability distributions, such as the normal distribution, are considered to lie about 3SD (standard deviations) from the mean, a span of 6SD between the tails.

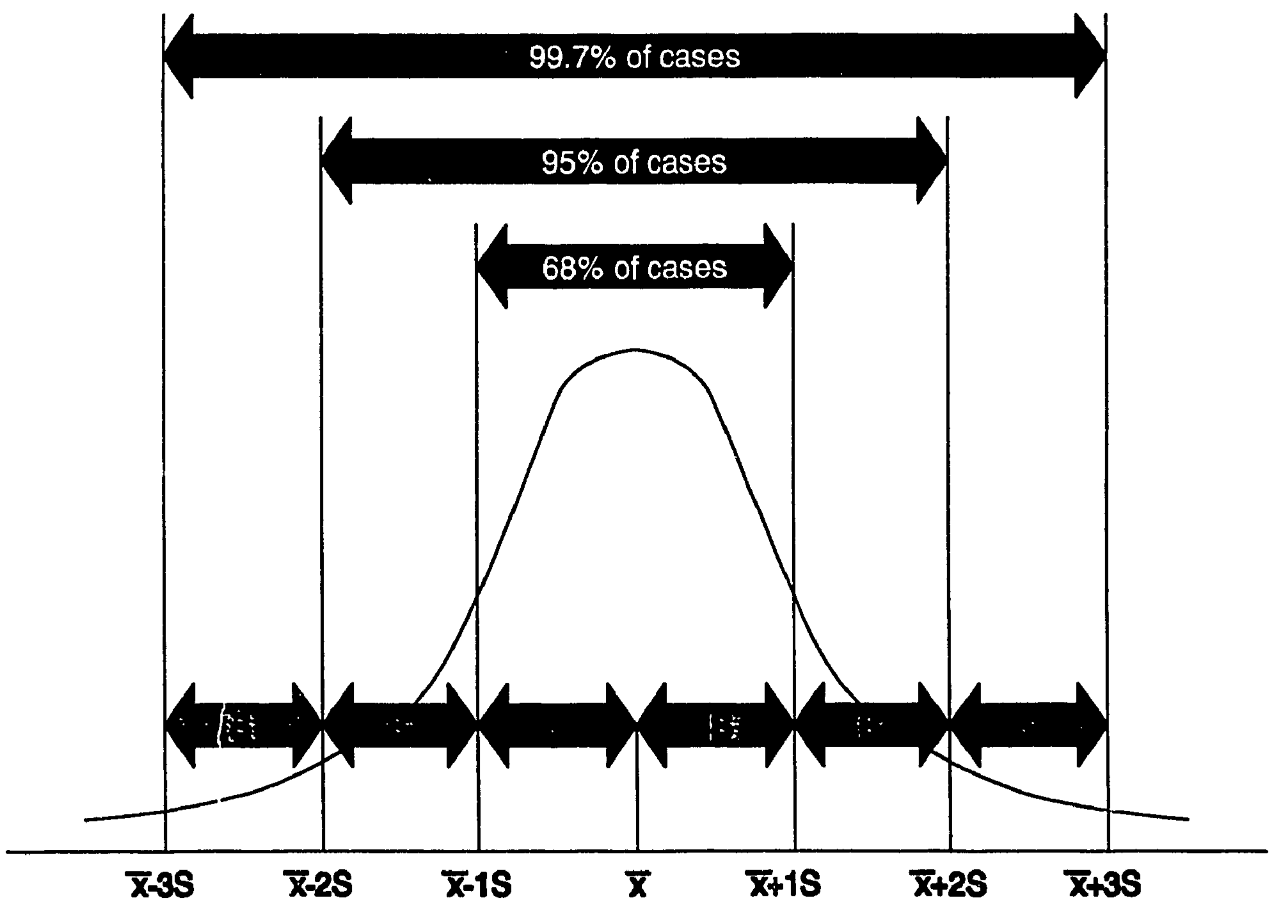
The Standard Deviation and Normal Distribution

We can consider task performance as describing a normal distribution. The normal curve is a theoretical distribution which, because of its precise mathematical qualities, can be used to transform data and to calculate many statistics. It is derived from a set of scores that when plotted in a frequency distribution, result in a bell-shaped curve, where the mean (arithmetical average of scores), median (midpoint of the distribution) and the mode (most frequently occurring score) are all the same.

The area under the normal curve is divided up into proportions or percentages. About 68% of all the scores in a normal distribution lie within 1 standard deviation either side of the mean. This range is known as 'mean plus or minus one SD', or M ±1 SD

Approximately 95% of the scores lie within 2 standard deviations either side of the mean and approximately 99.7% of the observations lie within 3 standard deviations either side of the mean.

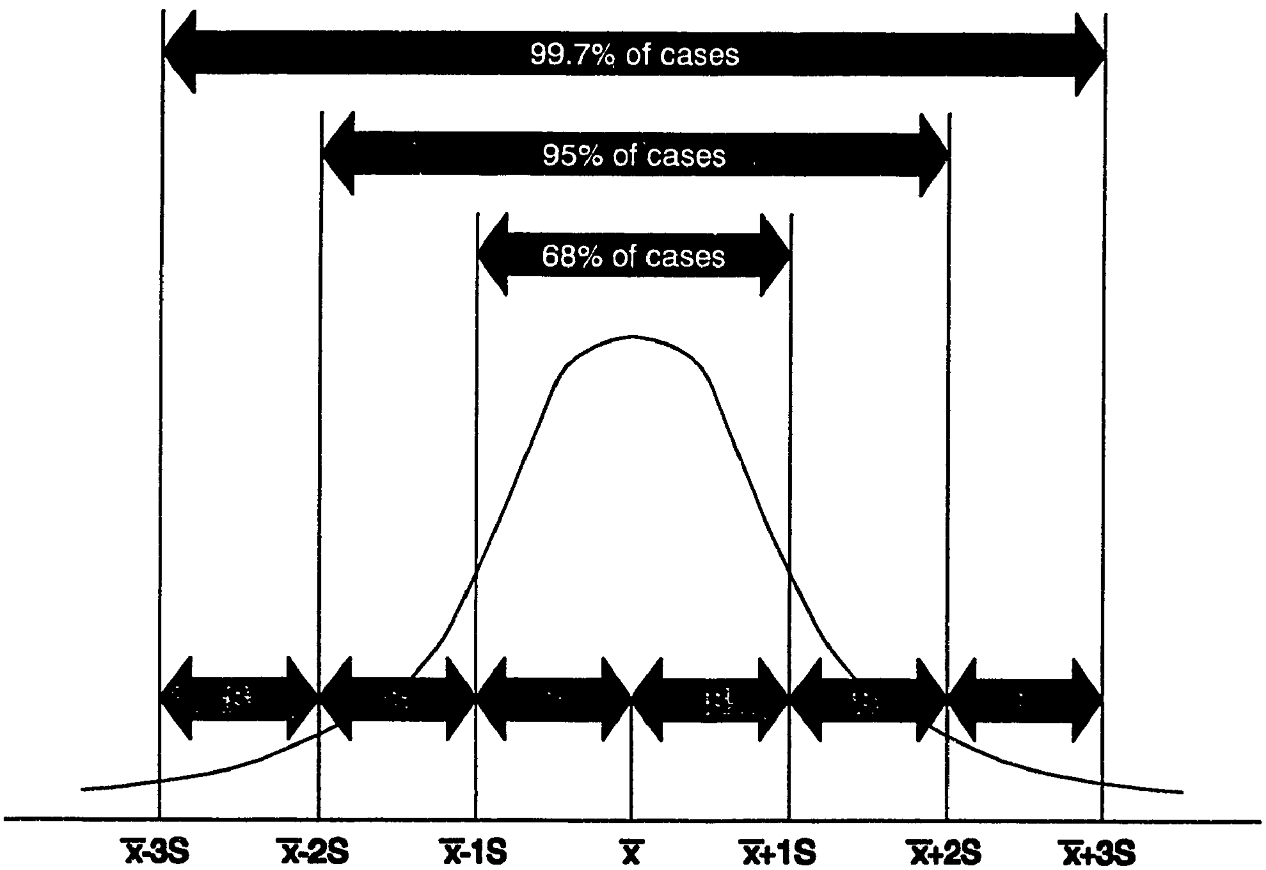
The standard deviation and the normal distribution



Suppose we want to know the percentage of observations in the normal distribution that will have values greater than 1 SD above the mean. Since ±1SD accounts for 68% of the observations then we must subtract this value from all the observations, hence (100 - 68) or 32% lie outside this range. The distribution is symmetrical, therefore half or 16% will lie below -1 SD and 16% will lie above +1 SD.

SAQ 3: standard deviation and the area under the normal curve

The following questions will test your understanding of the standard deviation and the area under the normal curve.



Approximately what percentage of the observations will be:

a) at least 1 but less than 2 SD below the mean.

b) more than 2 SD away from the mean

c) lie within 3 SD of the mean

SAQ 3: Answer

a) We are looking for an area that is at least equal to -1 SD but less than -2 SD. Remember, 95% of the observations lie within 2 SD of either side of the mean. We are interested in only those observations below the mean. Therefore, half of this is 47.5%. From the mean to -2 SD we have 47.5, but we only want part of this, the area that is between -1 and -2 SD. Therefore we subtract the area from 0 to - 1, (47.5 - 34) and get 13.5%.

b) Here we are looking for an area which corresponds to a percentage of the observations that are greater than ±2 SD from the mean. You will remember that 95% of scores lie within 2 SD either side of the mean. Since we are considering the areas above and below the mean, this is (100 - 95) or 5%.

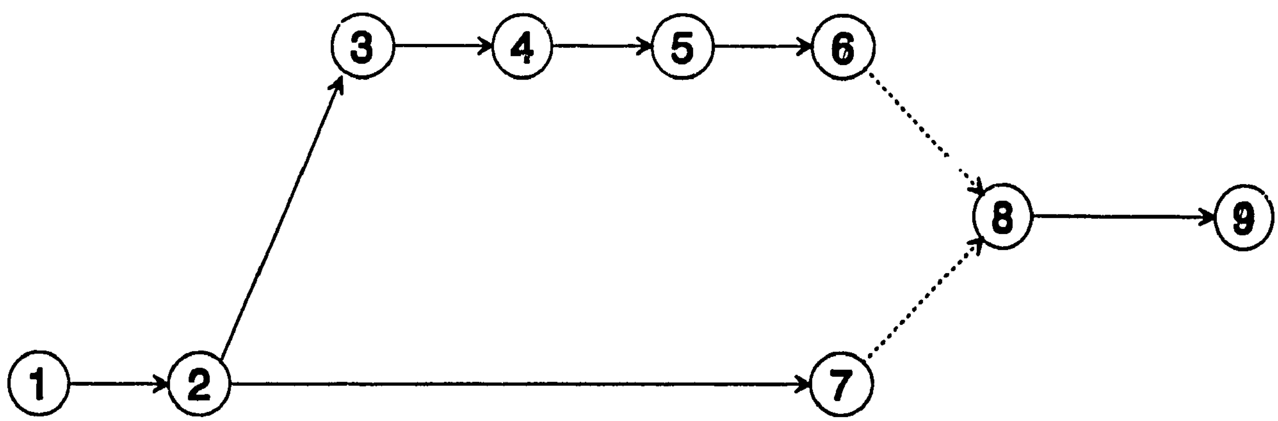
c) We are looking at an area that lies within ±3 SD of the mean. Notice that this is almost the all of the area under the curve, which is actually 99.7%.

Using the standard deviation: an example

The instructional designer could use PERT to plan, organize and schedule the teaching-learning times for a course. The teaching-learning of the objectives would be the activities. Estimating an appropriate optimistic, pessimistic and most likely time for the teaching-learning of an objective requires the input of individuals with considerable experience in teaching the content to students of high, average and low ability, using different teaching strategies.

Let's say that you are designing an industrial safety course for supervisors and shop floor workers in a manufacturing plant. The course is to be delivered in the following manner. Supervisors and shop floor workers must take the introductory session together. Then the shop floor workers will complete a different four units of instruction: personal protectiv equipment, tools, equipment and procedures. While they are doing this, the supervisors are attending a specially designed unit on the management of industrial safety programmes. Both groups must follow the final course unit on orderliness.

This can be represented as a network flow diagram.



Time will be expressed in minutes. We will use the standard deviation and the area under the normal curve to determine:

a) the range around the expected time (t_e)

b) the probability of completing the activities within this range

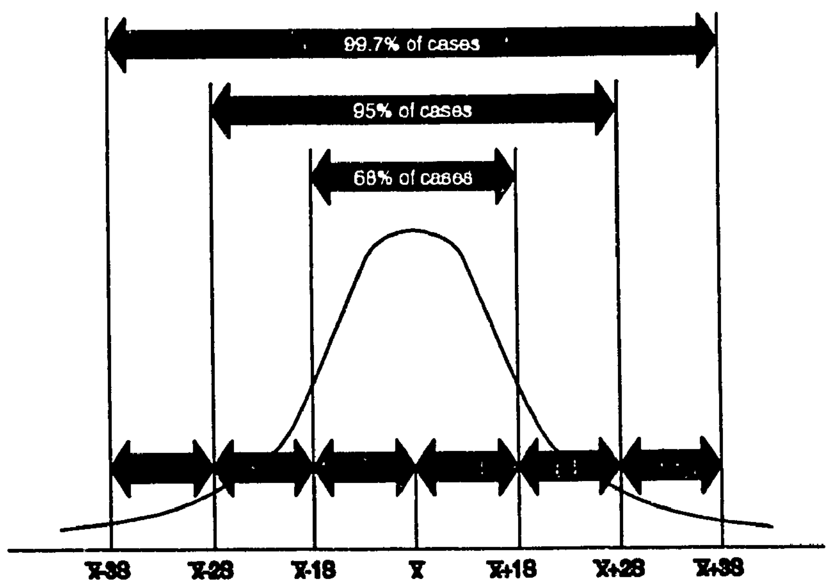
c) the probability of completing the teaching within a scheduled time

To obtain the range, the standard deviation is added to and subtracted from the t_e. Remember, each activity time has a different standard deviation. Two paths merge at event 8, so the longest path is selected.

Range of allowable time for 68% probability of completion

Activity	t_e	1 SD	Range from	to
1-2	66.6	6.7	59.9	73.3
1-7	178.3	3.7	174.6	182.0
2-3	40.0	6.7	33.3	46.7
3-4	66.6	6.7	59.9	73.3
4-5	120.0	6.7	113.3	126.7
5-6	116.0	6.7	109.3	122.7
8-9	70.0	3.3	66.7	73.3
Total	412.6		382.5	442.7

Moving 1 SD either side of the t_e establishes a range that falls within the 68% level or chance of completing the activity within that range. There is a 68% chance that the total sequence will be between 382.5 and 442.7 minutes or within a total of 30.1 minutes either side of the expected time.



Suppose there is a pre-determined schedule of 5 days of one 90 minute class per day, a total of 450 minutes. At the 68% level, the total range for the activity sequence was from 382.5 to 442.7 minutes or 60.2 minutes. If the teaching was completed in 382.5 minutes, it would be 68 minutes early. If completed within 442.7 minutes it would be only 7.3 minutes early. If completed by the expected time, it would be 38 minutes early.

Increasing the standard deviation increases the range and moves you into the 95% probability of completion.

Range of
allowable time for 95% probability of completion

Activity	t_e	2 SD	Range from	to
1-2	66.6	13.4	53.2	80.0
1-7	178.3	7.4	170.9	185.7
2-3	40.0	13.4	26.6	53.4
3-4	66.6	13.4	53.2	80.0
4-5	120.0	13.4	106.6	133.4
5-6	116.0	13.4	102.6	129.4
8-9	70.0	6.6	63.4	76.6
Total	412.6		352.4	472.8

We can conclude that there is a 95% chance that each of the objectives will be taught-learned within the range of times indicated. There is also a 95% chance that the length of time required for the total sequence will be between 352.4 and 472.8 minutes There is a 95% chance of completion within a total of 60.2 minutes either side of the expected time.

Suppose there is a predetermined schedule, such as 5 days of one 90 minute class per day, giving a total of 450 minutes. At the 95% level, we have a range of 120.4 minutes, from 352.4 to 472.8 . Should the teaching be completed at the low end of the range, it will be 97.6 minutes early. At the expected time would be 37.4 minutes early but at the high end of the range, 22.2 minutes late.

From this example you can see that the danger of allowing a wider range of time in which to complete the teaching, is that you run the risk of having too much spare time or not enough time. One of the advantages of calculating the standard deviation is that it allows you to simulate what will happen when you have a predetermined completion time and must fit your teaching in to it.

The standard deviation, as you will see later, does not appear on the activity-output slack sort chart. However, you can see that it can be useful with reference to selecting your activity times.

LESSON 3

OBJECTIVE:

Upon completion of this lesson, you will be able to to calculate the following values which lead to the identification of the critical path.

- T_E, the earliest expected completion time for an event
- T_L, the latest allowable completion time for an event
- Slack, a measure of the excess time available in reaching an event

This lesson is about determining where you are going to have problems associated with the time allotted to carry out activities. Analyzing the PERT charts for areas of critical slack focuses the manager's attention on latent problems that require decisions and solutions.

Study Guide

The calculations involved in this lesson are simply a matter of addition or subtraction. The exercises will give you practice in reading the network and determining these values.

Time: 1 hour

Previous knowledge required: Lessons 1 and 2

T_E: the earliest expected time for an event

T_E defined

Once you have calculated the t_e, the average value of the time estimates for each activity, the next step is to establish the earliest possible time that an event can be reached or said to be completed. A point to note is that capital letters are used in reference to events, while lower case are used for activities.

calculating T_E

select highest value

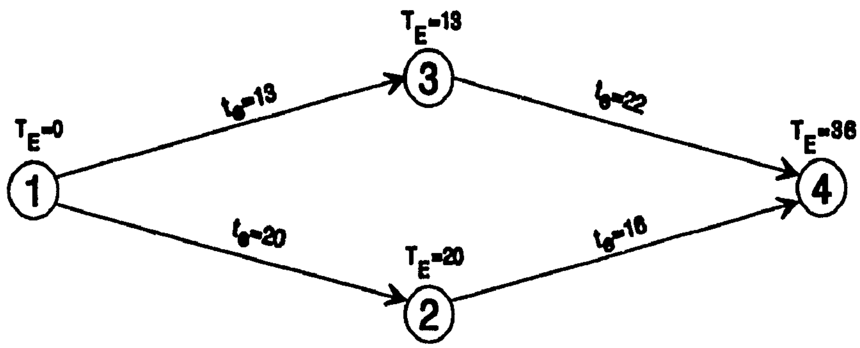
The T_E for an event is computed by starting at the network beginning event, which always has a T_E of zero and summing the t_e's of the activity paths leading to each event in the network. To get to an event, all the activities leading to it must be completed. When there is more than one path we select the longest, the one with the highest T_E value. Do not add in the t_e values that appear in the network after the event in question.

appears above event node

When you fill in the T_E value, place it above the circled event number as in the network on the following page. The highest T_E value in any network will always be associated with the network ending event.

Calculating T_E: an example

Now, let's work through this network together.



1. Event 1 starts the project. No activity precedes event 1, so no time is consumed in reaching it. The T_E for Event 1 is 0.

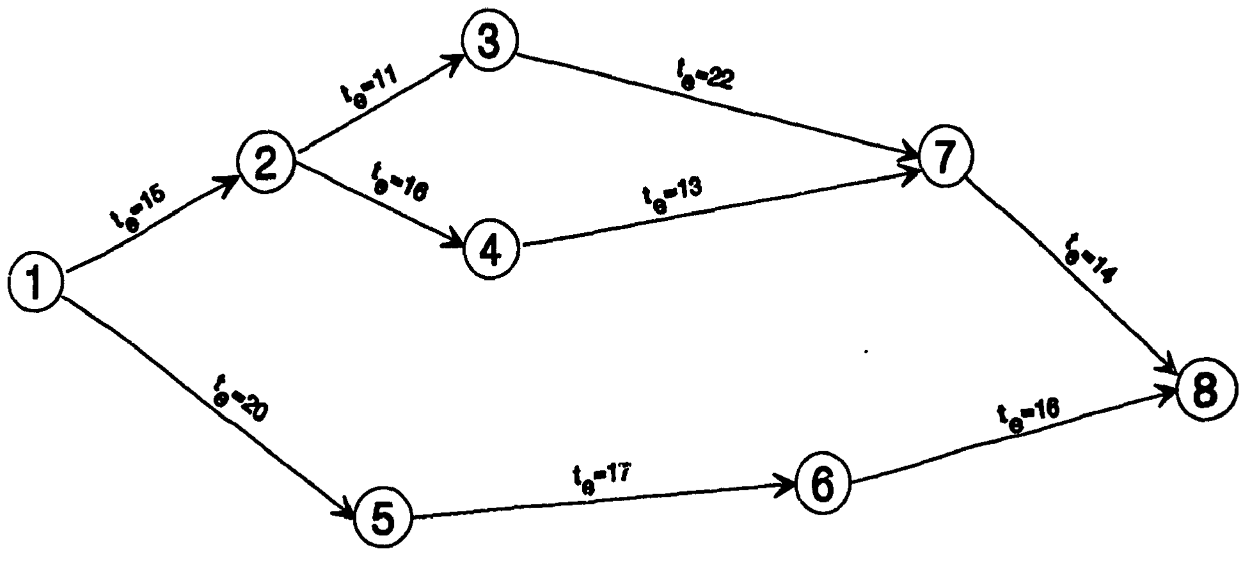
2. Event 1 and Event 2 are connected by an activity with a t_e of 20 days. You can expect to reach Event 2, 20 days after starting the project. Therefore, the T_E for Event 2 is 20 days.

3. The activity connecting Events 1 and 3 has a t_e of 13 days. Event 3 has a T_E of 13 days.

4. The network shows that all activities must be completed before Event 4 can be reached. Two paths lead to Event 4. The short path, 1-3-4 takes 35 days. The long path, 1-2-4 takes 36 days. The most time-consuming path represents the earliest possible time you can expect to reach an event. The T_E for Event 4 is 36, the sum of 20+16. This T_E value is placed above the event, as shown on the network.

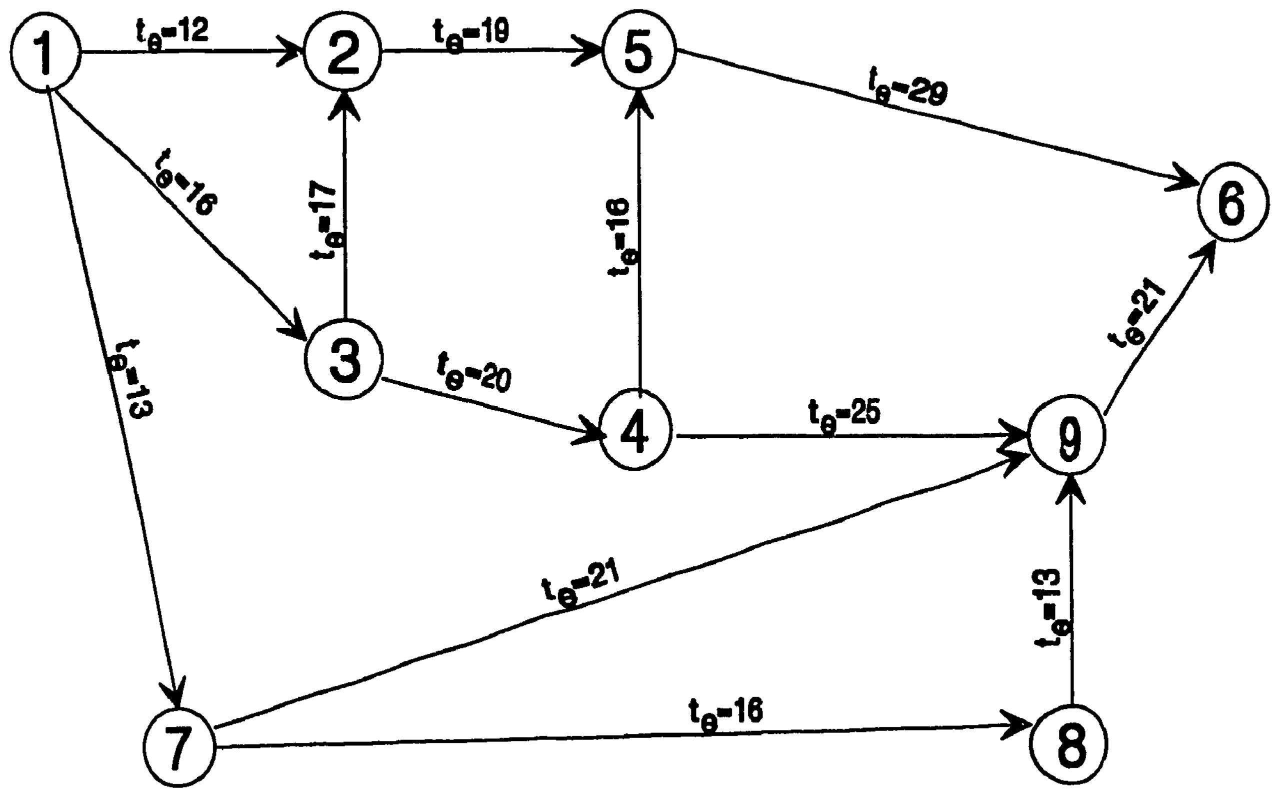
SAQ 1: calculating T_E

Based on what you have just read, calculate the T_E for each event in this network, and place it in the appropriate location.



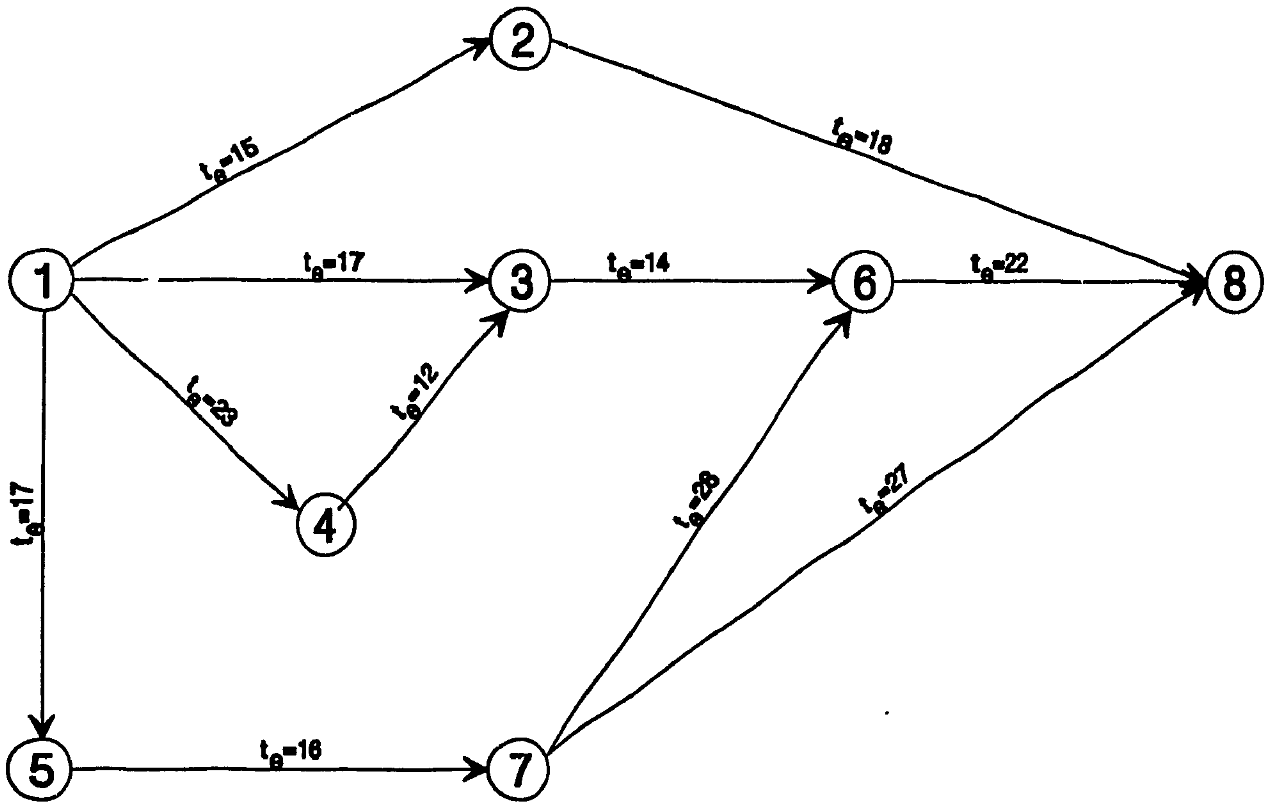
SAQ 2: calculating T_E

Calculate the T_E for each event and place it in the appropriate location on the network. This network is a little more complex.



SAQ 3: calculating T_E

If you feel that you require additional practice in calculating T_E or more complex networks, do this exercise.



SAQ 1, 2, 3: Answers

SAQ 1:

EVENT	T_E	Sum of t_e's
1	0	0
2	15	15
3	26	15+11
4	31	15+16
5	20	20
6	37	20+17
7	48	15+11+22
8	62	15+11+22+14

SAQ 2:

1	0	0
2	33	16+17
3	16	16
4	36	16+20
5	52	16+20+16 or 16+17+19
6	82	16+20+25+21
7	13	13
8	29	13+16
9	61	16+20+25

SAQ 3:

1	0	0
2	15	15
3	35	23+12
4	23	23
5	17	17
6	61	17+16+28
7	33	17+16
8	83	17+16+28+22

T_E should be placed above each event.

REVIEW

Before going on, let's take a moment to review what you have just learned. This will help you build up a mental picture of the process and how the calculations feed into each other.

The first step is to provide optimistic, most likely and pessimistic time estimates for all the activities in the network.

The first value to be calculated is t_e. This is a weighted average based on the three time estimates of how long it will take to complete an activity. This value is calculated for all the activities in the network.

You may at this point or later on, calculate the variance associated with each activity, so that you can evaluate the accuracy of the estimate.

Calculating the standard deviation will allow you to simulate what will happen given the existing t_e values, with or without a pre-determined scheduled date.

Once you have t_e, the next step is to determine the earliest expected time for the completion of an event, that is, T_E. The performance of activities leads to the accomplishment or reaching of events. Since the completion of the project involves the accomplishment of a number of events, the T_E of an event is calculated by summing the t_e's of the activities leading to that event.

T_L: the latest allowable time for the completion of an event

T_L is the latest time by which an event must occur, without causing delay in the accomplishment of the final event.

when $T_S = T_L = T_E$ for network ending event

In working through the previous networks, you have calculated T_E (the earliest expected completion date), for each event. When the T_E date for the final event is accepted by the project team, as the actual number of days required to complete the project, it becomes known as T_S or the scheduled date. This scheduled date then becomes the T_L for the project, or the latest allowable time for project completion. Therefore, T_S, T_E and T_L of the network ending event have the same value. The T_E value appears above the final event node and the T_S and the T_L below it.

when T_S and T_L differ

There are occasions when the scheduled date for the completion of the project has been previously established and will differ from the T_L. When the scheduled date is earlier than the T_L, it is obvious that the project will be behind schedule. This will be dealt with in more detail, later on in the lesson.

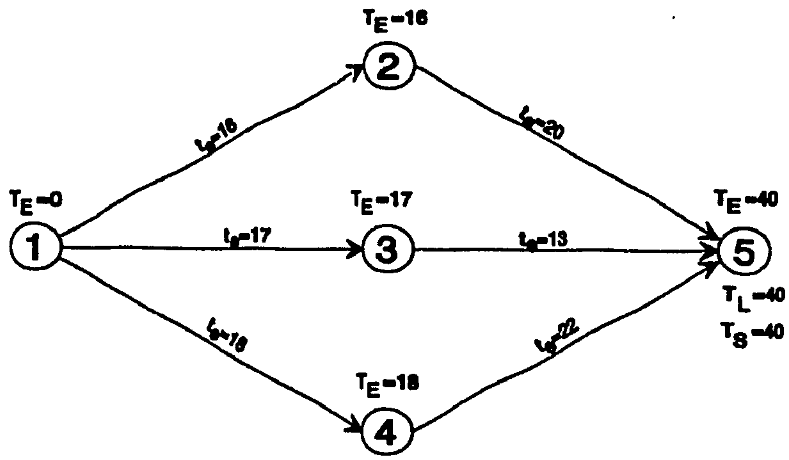
calculating T_L

select lowest value

The calculation of T_L is the reverse of the calculation of T_E. Determine the T_L for the network ending event. It will be either the T_E for this event or the pre-established scheduled date. Start with the network ending event and work backwards. Subtract the t_e of the activity terminating at the network ending event from the T_L of the terminating event of that activity. When a single event has several activity arrows leading from it, the T_L must be calculated from each successor event. The lowest T_L value is selected for the event in question.

Calculating T_L: an example

Now let's work through this network step by step. Complete the network as you read.



Event 5 is the network ending event. The T_L is 40; it is the same as the T_E. Remember that when there is no predetermined scheduled date, the T_E for the network ending event becomes accepted as the T_L, the latest allowable time for completing the project.

Let's start with Event 2. The t_e of the activity 2-5 is 20. Event 5, the terminating event for activity 2-5, has a T_E of 40. The T_L for Event 2 is calculated by subtracting the t_e of 20 from the T_L of 40. The result is 20.

The T_L for Event 3 is 27 days. Event 5 is the terminating event for activity 3-5. Event 5 has a T_L of 40 days and activity 3-5 has a t_e of 13 days and 40-13=27 days.

The T_L for Event 4 is 18 days. Event 5 is the terminating event for activity 4-5. Event 5 has a T_L of 40 days and activity 4-5 has a t_e of 22 days and 40-22=18 days.

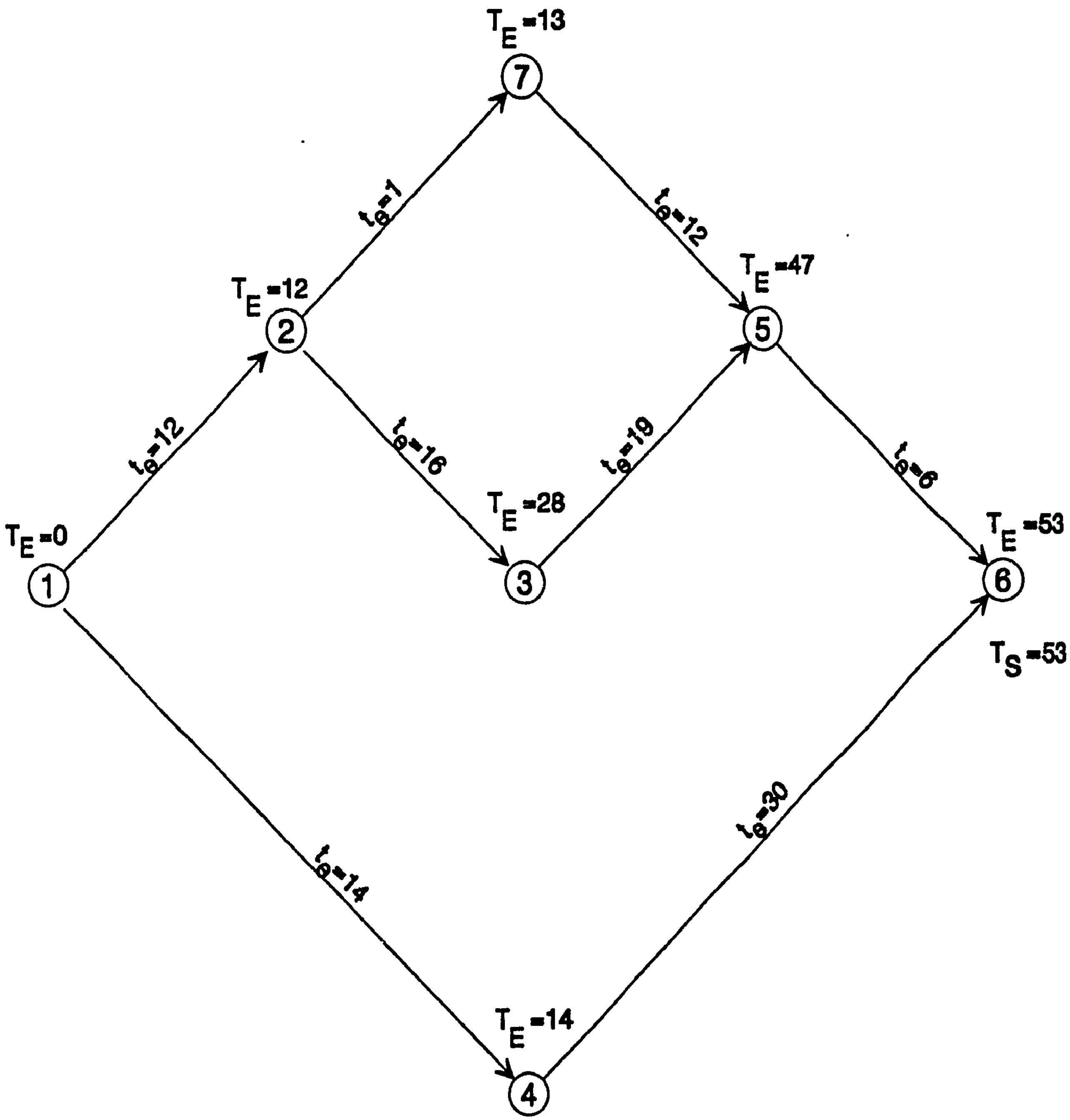
Calculating the T_L for event 1 is a little more complicated. Events 2, 3, 4, succeed Event 1. The T_L for Event 1 is computed for three different paths and the smallest value is selected. There can only be one T_L for an event.

The T_L of event 2 is 20. The t_e of activity 1-2 is 16, resulting in a T_L of 4.
The T_L of event 3 is 27. The t_e of activity 1-3 is 17, resulting in a T_L of 10.
The T_L of event 4 is 18. The t_e of activity 1-4 is 18, resulting in a T_L of 0.

Here, 0 is selected as the T_L for event 1. In other words, if you found out today that the project had to be completed in 40 days, you would have to start immediately.

SAQ 4: calculating T_L

Calculate all the T_L's for the following PERT network and place them in the appropriate place.



SAQ 4: Answer

$(T_L)6 = 53$

$(T_L)5 = 53 - 6 = 47$

$(T_L)4 = 53 - 30 = 23$

$(T_L)3 = 47 - 19 = 28$

$(T_L)7 = 47 - 12 = 35$

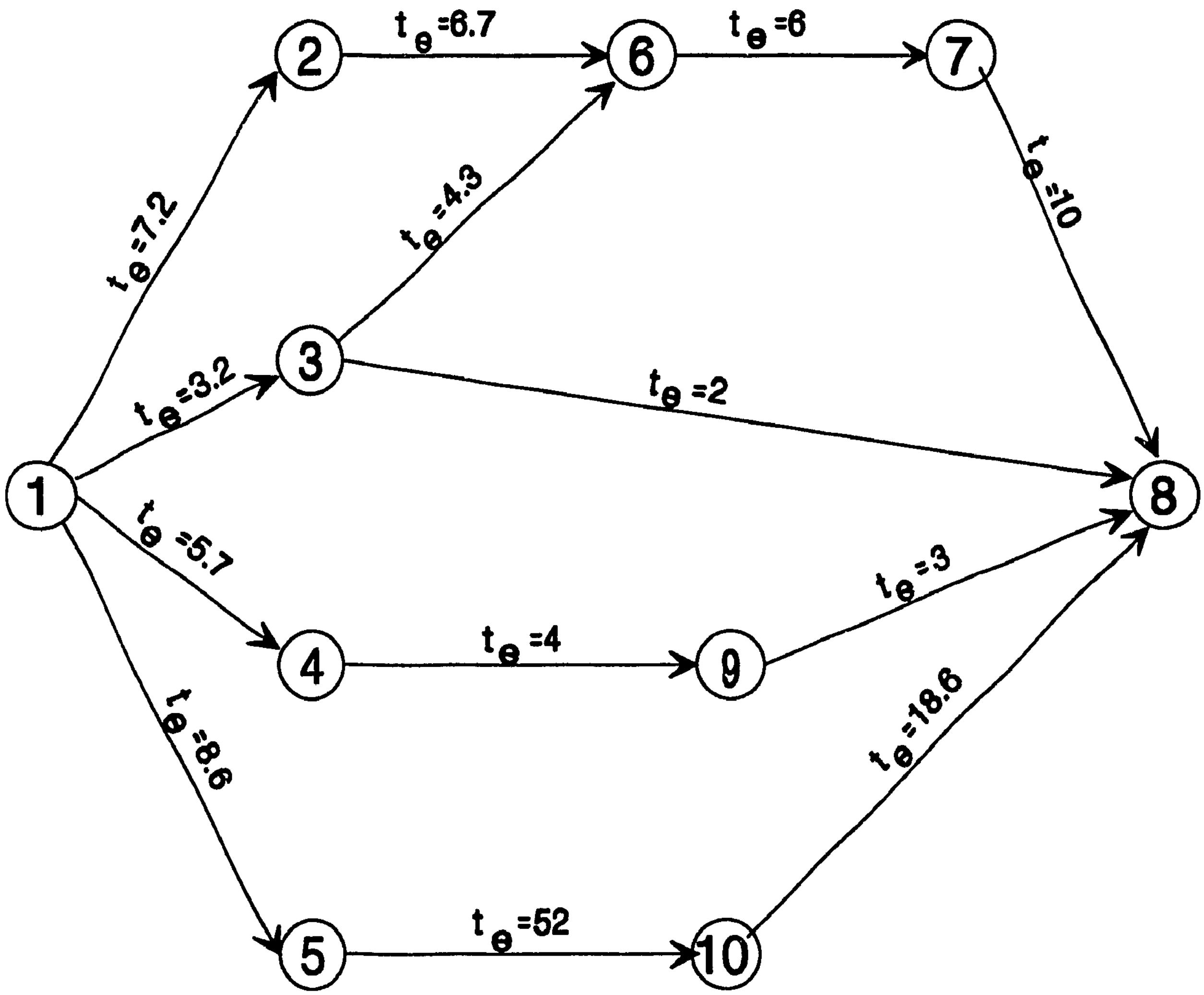
$(T_L)2 = 28 - 16 = 12$

$(T_L)1 = 12 - 12 = 0$

Remember, T_L is placed below the event.

SAQ 5: calculating T_E and T_L

Do this exercise as a review in calculating T_E and T_L. Place these values in the appropriate position on the network.



SAQ 5: Answer

$(T_E)1 = 0$

$(T_E)2 = 7.2$

$(T_E)3 = 3.2$

$(T_E)4 = 5.7$

$(T_E)5 = 8.6$

$(T_E)6 = 7.2 + 6.7 = 13.9$

$(T_E)7 = 7.2 + 6.7 + 6 = 19.9$

$(T_E)8 = 8.6 + 52 + 18.6 = 79.2$

$(T_E)9 = 5.7 + 4.0 = 9.7$

$(T_E)10 = 8.6 + 52 = 60.6$

$(T_L)8 = 79.2$

$(T_L)9 = 79.2 - 3 = 76.2$

$(T_L)10 = 79.2 - 18.6 = 60.6$

$(T_L)7 = 79.2 - 10 = 69.2$

$(T_L)6 = 69.2 - 6 = 63.2$

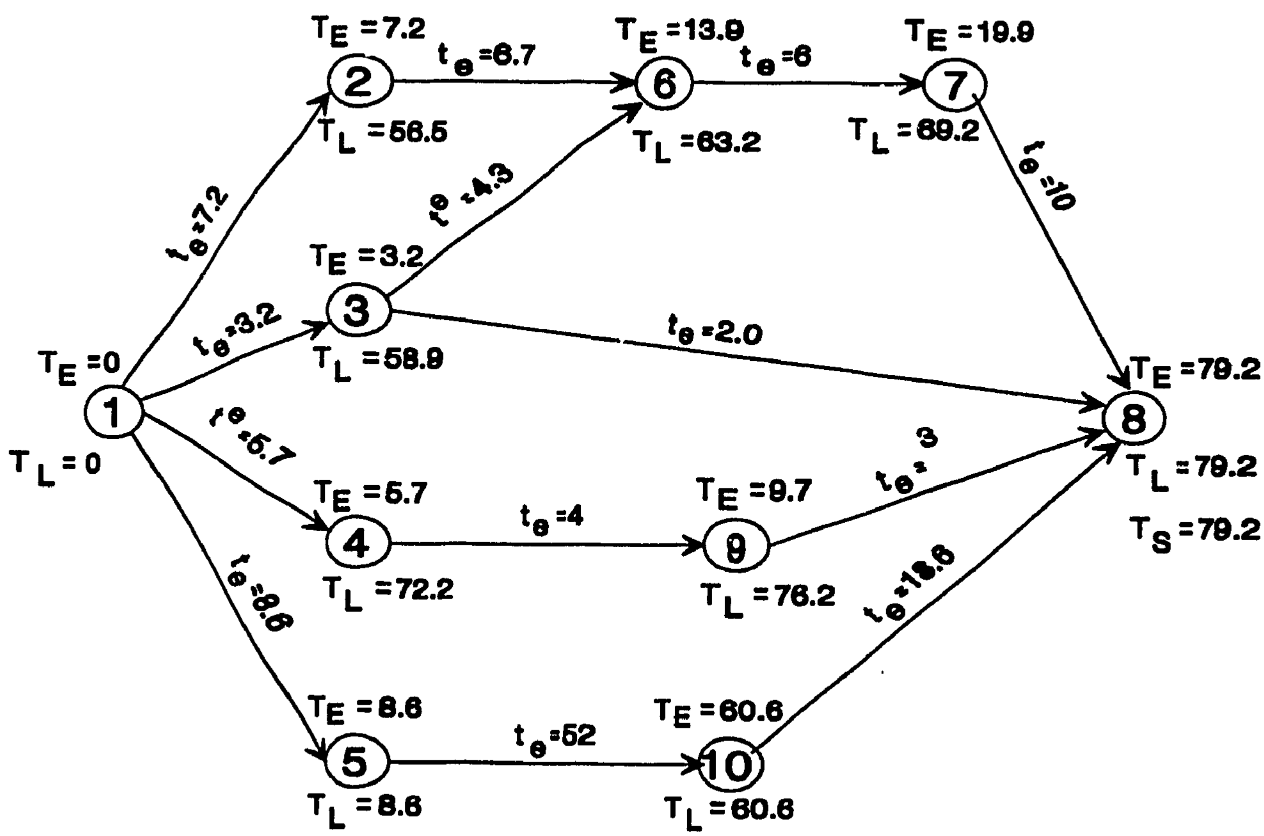
$(T_L)2 = 63.2 - 6.7 = 56.5$

$(T_L)3 = 63.2 - 4.3 = 58.9$

$(T_L)4 = 76.2 - 4 = 72.2$

$(T_L)5 = 60.6 - 52 = 8.6$

$(T_L)1 = 8.6 - 8.6 = 0$



Slack: a measure of the excess time available in reaching an event

excess resources associated with an event

If you are given 10 weeks to complete a project and you can actually complete it in 8 weeks, you have a 2 week period of grace. This period of excess time is what is referred to as slack. The slack value of an event is a measure of the excess time (resources) available in reaching that event.

The slack value of an event reveals those activities which have adequate or inadequate resources and those activities having excess resources, from which trade-offs can be arranged.

Depending on the relationship between T_L and T_E, the value of slack can be either positive, negative or zero.

what slack reveals about the existing plan

Positive slack indicates an ahead of schedule condition or excess resources associated with reaching the event.

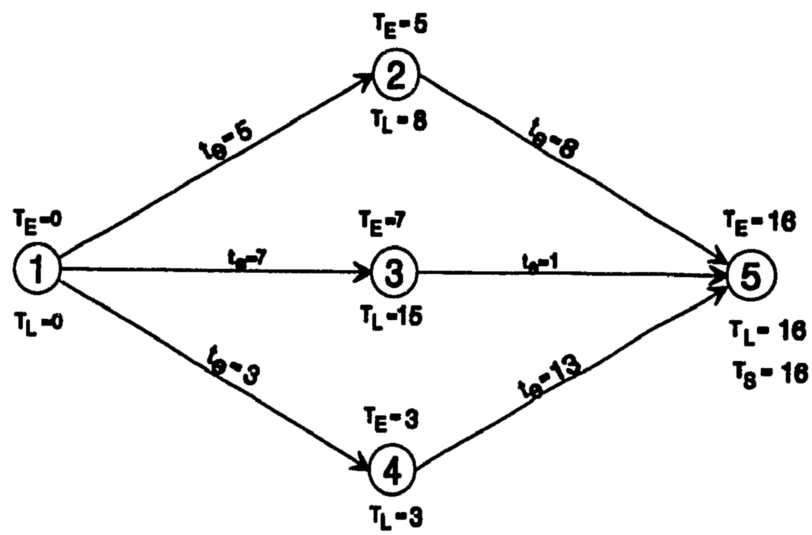
Negative slack is an indication of behind schedule condition or lack of resources. When we encounter negative slack we look to those events displaying a positive slack as a source of resources.

Zero slack is an indication of an on schedule condition or adequate resources.

As you gain experience in calculating slack, you will notice that the slack time of the terminal event will always be the same as the T_L for the start event.

Calculating slack: an example

Let's work through this simple example together.



EVENT	$T_L - T_E$	SLACK
1	0 - 0	0
2	8 - 5	3
3	15 - 7	8
4	3 - 3	0
5	16 - 16	0

Events 1,4,5, have 0 slack and are the critical events in this network. They will be completed exactly on schedule if there are no delays. Any delay in activities between them could lead to a corresponding delay in the completion of Event 5.

The greater the slack the less critical the event. Event 2 has 3 weeks slack. Event 3 has 8. These events will be completed ahead of schedule. The activities connecting either of these events could be delayed by the slack value without affecting the completion time of Event 5.

Event 1 must start exactly on schedule. The network also shows that the resources of activities 1-2 and 1-3, in this case time, can be shifted to activities 1-4 and 4-5.

Critical path: the path of minimum slack

critical events

The slack value associated with an event determines how critical that event may become. The less slack, the more critical the event. The critical path is the path of minimum slack. By calculating the slack value for each event and consulting the network flow diagram, you can identify the critical path.

features of the critical path

Another way to determine the critical path is to sum the t_e values of all the paths leading to the network ending event. In a project, one or more of the many paths leading from the initial to the final event usually stands out as being more critic ıl than any of the others. The critical path is the path of activities which extends from the network beginning to the network ending event, which has the greatest sum of the t_e values between those two events. That is, it is the path which yields the greater T_E value. There can be more than one critical path, as two or more paths may have the same T_E value. The critical path does not pass through all the events in the network. It requires the most time to get from the initial event to the final event.

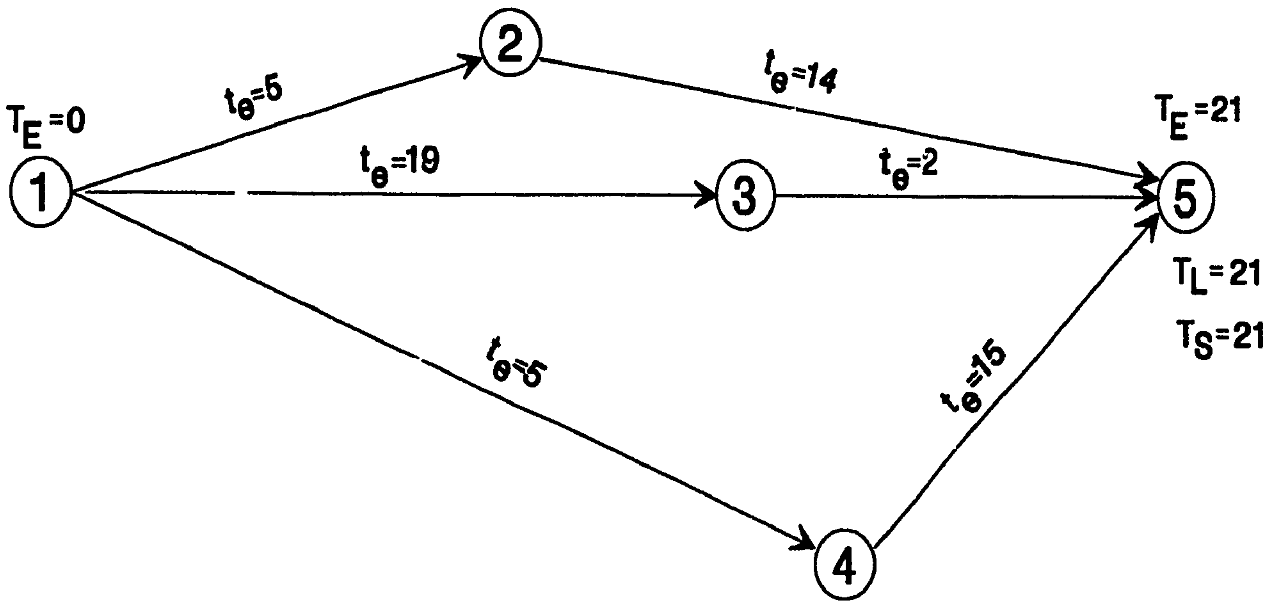
a rigid time constraint

can change as project progresses

If any event on the critical path slips in time, the final event will slip in time by the same amount. The critical path provides the most rigid time constraint on the project, so it must be the focus of the project manager's attention. As the project itself progresses, the network must be updated to reflect this progress. It is likely that the critical path will change in terms of the activities and events through which it passes. Continuous updating ensures that everyone is aware of those changes. This can be quite a cumbersome activity, preferably handled by a computer.

Finding the critical path : an example

Let's start with a simple network.

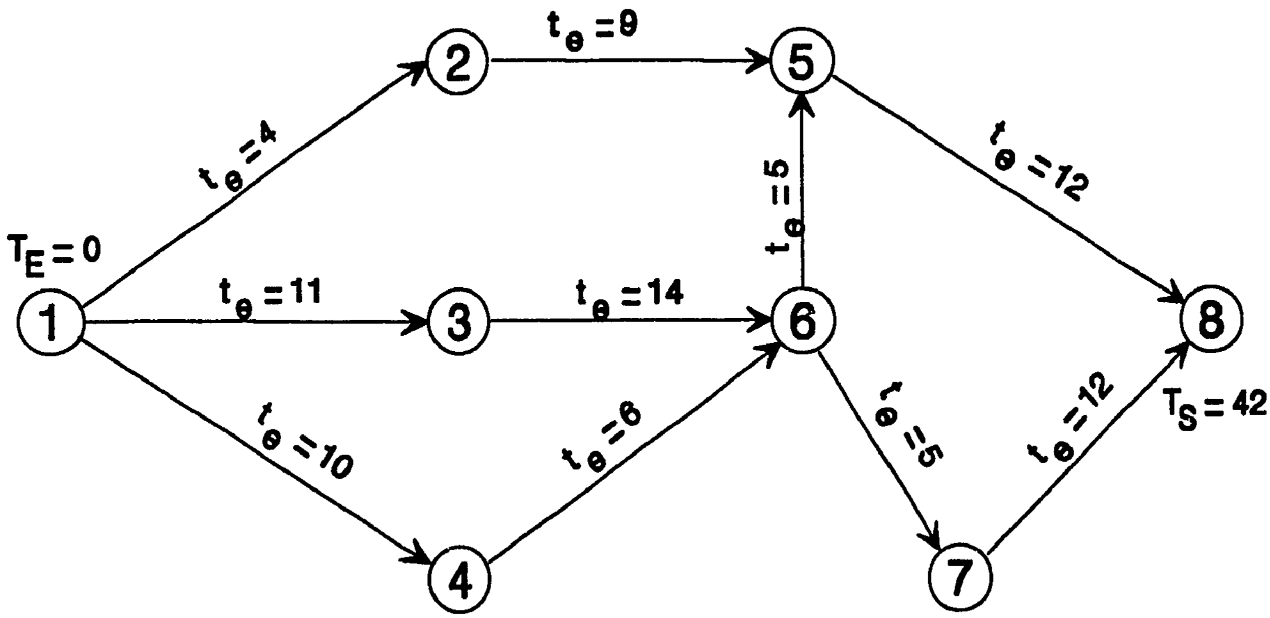


EVENT #	T_E	T_L	SLACK
1	0	0	0
2	5	7	2
3	19	19	0
4	5	6	1
5	21	21	0

All the values have been calculated for you. All we need to do is to look at the slack values and at the network. Events 1 to 3 to 5 are the critical path, as they all have 0 slack. This is the path of minimum slack. It is also the longest path through the network, it has a total T_E of 21.

SAQ 6: determining the critical path

Identify and outline the critical path in this network.

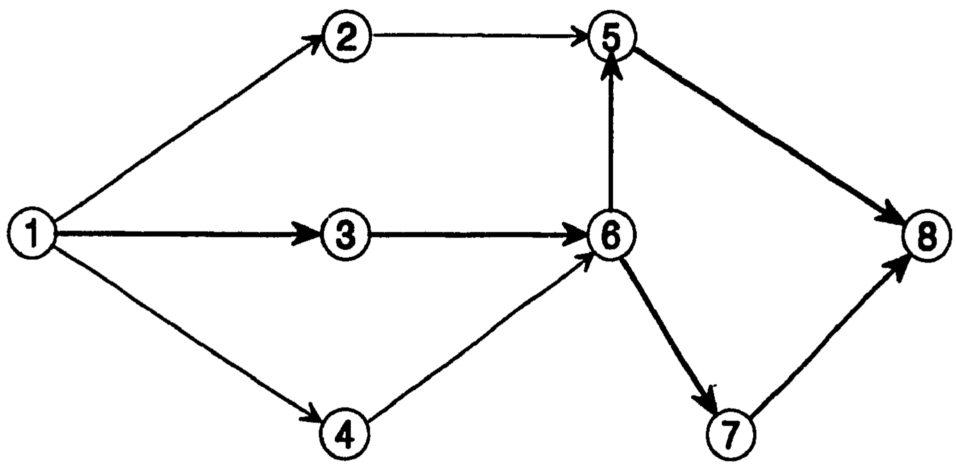


EVENT #	T_E	T_L	SLACK
1			
2			
3			
4			
5			
6			
7			
8			

SAQ 6: Answer

Look at the slack values in the chart. You see that Events 1, 3, 5, 6, 7 and 8 all have a slack value of 0. However, these events do not lie along a single path. You cannot go from Event 3 to Event 5. So, to incorporate all the Events that have a slack of zero, there must be two paths.

The critical paths are; 1 to 3 to 6 to 5 to 8 and 1 to 3 to 6 to 7 to 8.

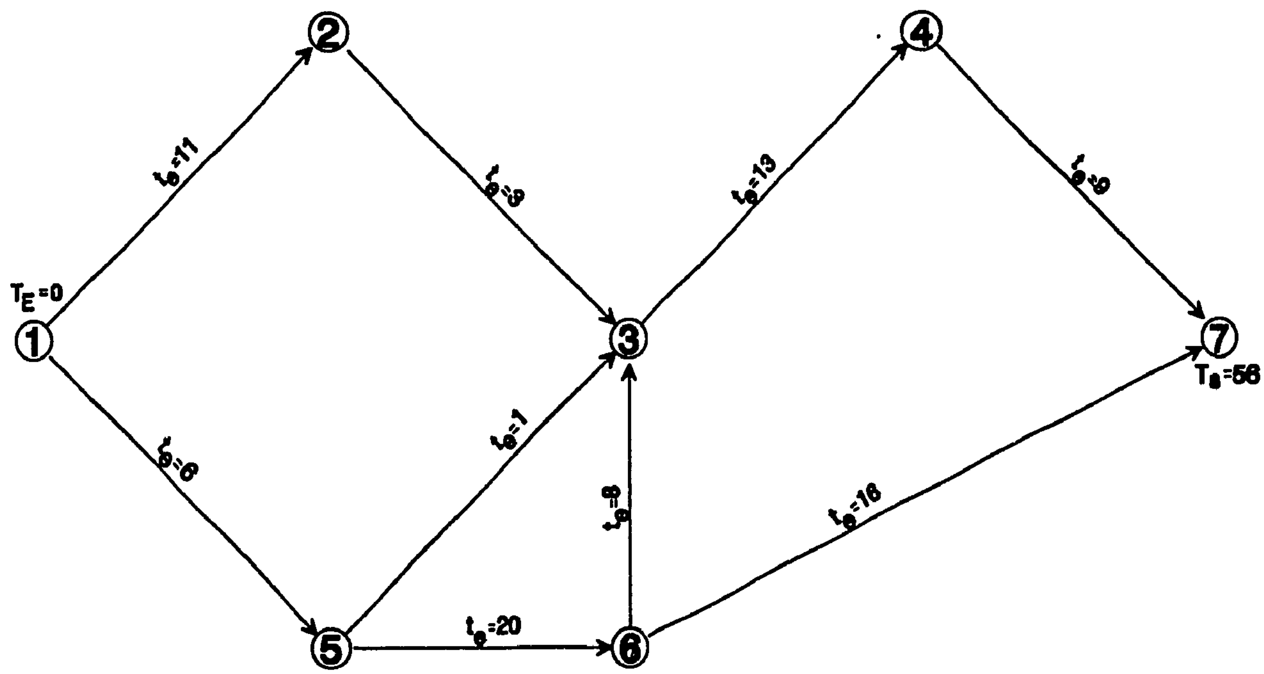


EVENT	T_E	T_L	SLACK
1	0	0	0
2	4	21	17
3	11	11	0
4	10	19	9
5	30	30	0
6	25	25	0
7	30	30	0
8	42	42	0

If you did not get these values, re-check your calculations of T_E and T_L.

SAQ 7: determining the critical path

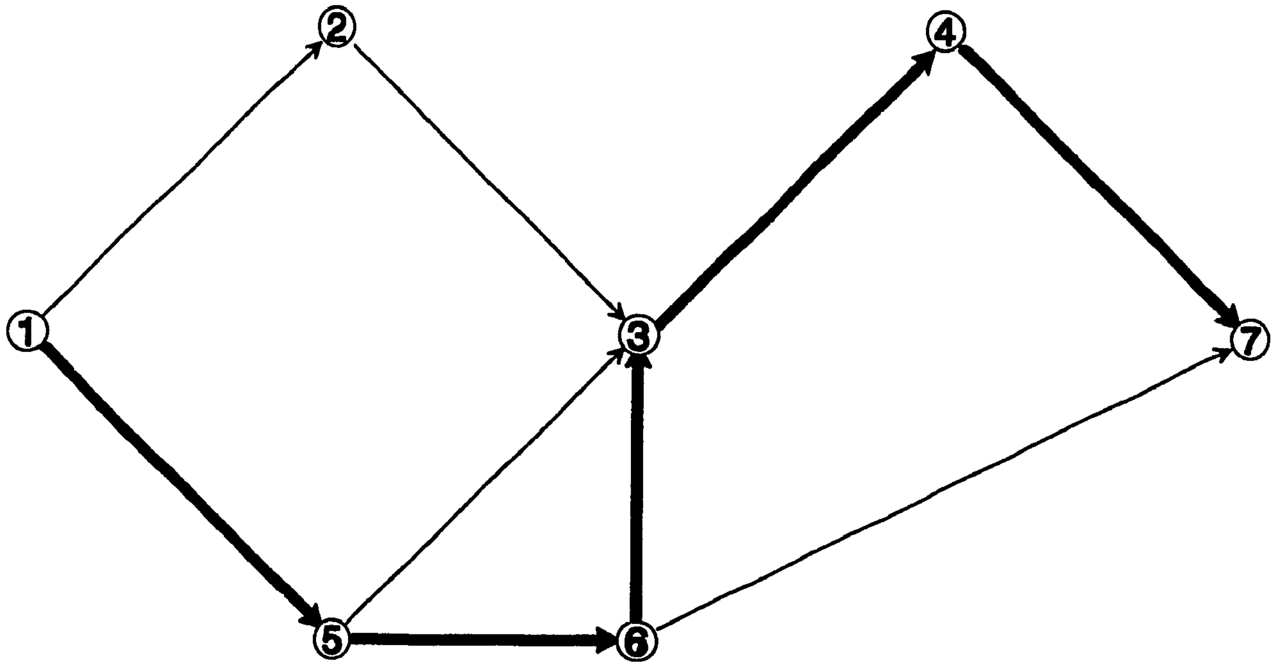
Identify and outline the critical path in the following network.



EVENT #	T_E	T_L	SLACK
1			
2			
3			
4			
5			
6			
7			

SAQ 7: Answer

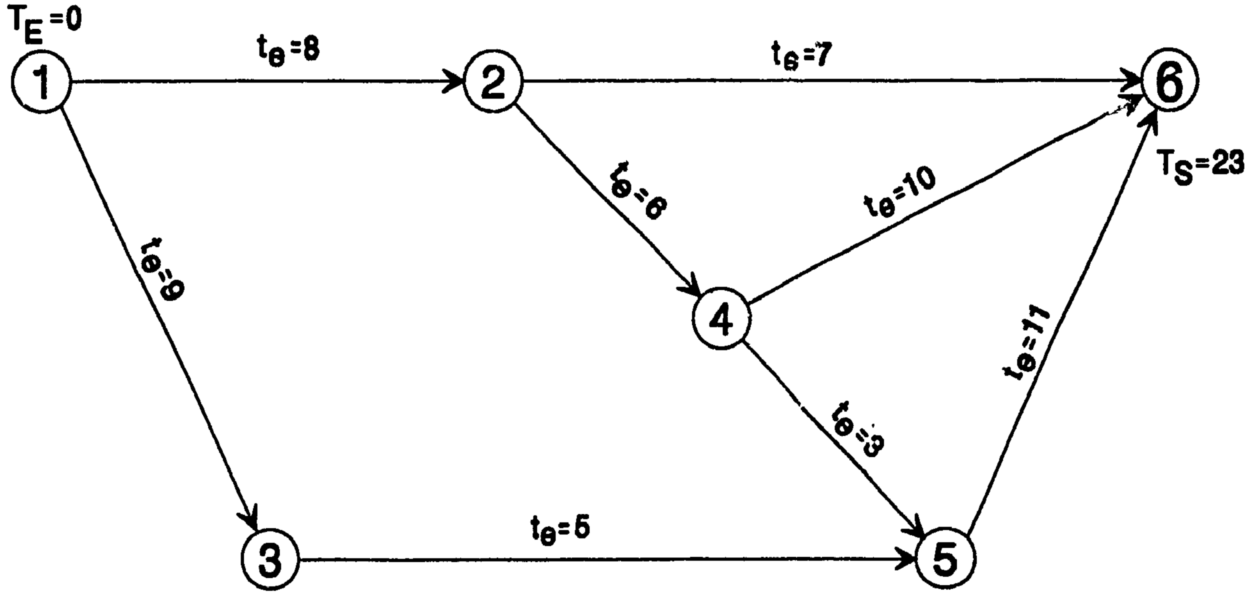
The critical path is Events 1 to 5 to 6 to 3 to 4 to 7. With a 0 slack you have an on schedule condition for those events and for the critical path. For Event 2 you are likely to be 20 days ahead of schedule.



EVENT	T_E	T_L	SLACK
1	0	0	0
2	11	31	20
3	34	34	0
4	47	47	0
5	6	6	0
6	26	26	0
7	56	56	0

SAQ 8: determining the critical path

In the previous networks, the scheduled date was the same as the expected time for the network ending event. Do this exercise to see what happens when the scheduled date is earlier than the expected time for the network ending event.



SAQ 8: Answer

EVENT	T_E	T_L	SLACK
1	0	-5	-5
2	8	3	-5
3	9	7	-2
4	14	9	-5
5	17	12	-5
6	28	23	-5

The critical path is 1 to 2 to 4 to 5 to 6. These events have the least slack time. An event with a slack of -5 is more critical than an event with a slack of -2.

The situation as described occurs very often. The original estimates of resources must be adjusted to achieve the established completion date.

The project manager has two choices to resolve the difference of 5 days between the T_E and the T_S.

1. Get the client to accept a new scheduled date of 28 days, assuming that the original estimates were reasonable.

2. Add more resources to the activities to achieve a critical path with a of T_E equal to 23.

LESSON 4

OBJECTIVE:

In this lesson you will learn how to calculate the probability, P_R, of meeting a scheduled date, in addition to learning how to use the activity-output slack sort chart as a decision-making tool.

This is the final lesson in the workbook. It is here that all the calculations come together to provide you with all the information about the existing plan that will permit you to evaluate it and determine where changes are necessary.

Study Guide

Before starting this chapter you might want to go back and read the OVERVIEW on pages 6-8, to refresh your memory. The exercises in this lesson are long, in comparison to those you have encountered previously. This is because you will be required to use all that you have learned so far. I suggest that you try both exercises as they will help you determine whether or not you have really understood the material. If you are going to take a break during this lesson, I suggest that you complete all the calculations for the first exercise before doing so.

Time: This lesson may take up to 2 hours depending on your speed and accuracy using the calculator.

Previous knowledge required: Lessons 1, 2 and 3

PROBABILITY FACTOR: the probability of meeting a scheduled date

risk

When we refer to the probability of meeting a scheduled date, we are talking about the risk associated with completing any given activity, any portion of a project or the entire project, by a given date. The penalties of late performance must be evaluated in terms of cost and with regard to other penalties associated with a failure to meet contractual obligations.

function of the probability factor

A statistical procedure exists for determining the probability of meeting the scheduled date for a strategic event. It involves computing the probability factor, Z, and consulting the Table of Values for the Standard Normal Distribution. The probability, P_R, lets you know whether or not you have to adjust your plan in order to achieve the scheduled date with an appropriate level of risk.

underlying assumptions

The probability of completing a project on schedule is based on 3 assumptions:

1. Activity times are statistically independent.

2. The critical path (in terms of expected times) always requires longer than the total elapsed time of any other path. This implies that the t_e and variance are just the sum of the times of the activities along the critical path.

3. Project time has a normal distribution. The rationale behind this assumption is that project time is the sum of many independent random variables. In the theory of probability there is a Central Limit Theorem which states that such a sum is approximately normal under a wide range of conditions.

range of acceptable probabilities

The range of probabilities, P_R, which is acceptable in PERT is from .35 to .64. A probability of less than .25 indicates that there is considerable risk in proceeding with the existing plan. This means that you will want to make some revisions to the existing plan. A probability of .50 indicates good planning and that the scheduled date is likely to be met, but the project will have to be monitored closely. If the probability is around .64 you will have to monitor the project but not as closely as with a .50 probability. A probability, of greater than .64 indicates that too many resources are being used. A probability approaching 1.0 means that you have to revise your plan, examining the activity times and the associated descriptions to determine where you have too many resources in use.

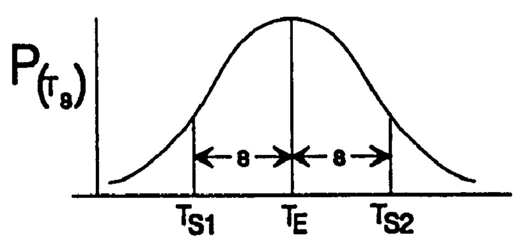
Origin of the Probability Factor

In Lesson 2, we took a brief look at variance and standard deviation. You saw how variance can be used to evaluate the accuracy of time estimates. Then we looked at how one could use the standard devation and the area under the normal curve to determine the liklihood of meeting a scheduled completion date. The standard deviation allowed you to simulate what would happen if you allowed a wider range of times for each activity. The variance and the standard deviation are also found in the denominator of the formula for the probability factor Z , therefore I shall take a moment to review and elaborate on them.

When the observed values of a quantity variable are arranged in order, it is called a distribution. Some values are greater than the mean and some are less. Therefore, the deviations can be positive or negative. To overcome this difficulty, these deviations are squared and summed and their mean is found. Variance is the mean of the squared deviations. However, variance is expressed in terms of squared units. This is an impractical value, as the original values in the distribution were in units. In order to get the dispersion back into the original units, we take the square root of the variance, which is the standard deviation.

On the basis of the Central Limit Theorem, the probability distribution of times of a job, consisting of a number of activities, may be approximated by the normal distribution. Therefore, we may define a curve which represents the probability of meeting an established scheduled date, T_S.

Probability of Meeting an Established End Date



where;

T_{S1} represents a scheduled time earlier than T_E
T_{S2} represents a scheduled time later than T_E

The probability of meeting T_S, given T_E and the variance of a chain of activities, is the ratio of the area under the normal curve to the left of T_S, to the area under the entire curve.

$$Z = \frac{T_S - T_E}{\sqrt{\Sigma \sigma^2_{T_E}}}$$

The value that results from the formula for the probability factor is expressed in terms of standard deviation. It will yield a value for the probability, P_R, of accomplishing T_S, by use of the Table of Values of the Standard Normal Distribution on page 69.

Calculating the probability factor

The formula for probability factor Z is

$$Z = \frac{T_S - T_E}{\sqrt{\Sigma \sigma^2_{T_E}}}$$

where:

Z is the probability factor

T_S is the scheduled date for the event

T_E is the expected completion date for the event

$\sqrt{\ }$ (radical) is the square root

Σ (sigma) is the sum of

σ^2 is variance (of the activities along the critical path to the event)

a) To obtain the numerator, subtract the expected time T_E of the event from T_S, the scheduled date.

b) To obtain the denominator, sum all the variances of the same activities that were used in calculating the T_E for the event and take the square root of this sum. This is the standard deviation for the event.

Z can be either positive or negative, depending on the relationship of T_S to T_E.

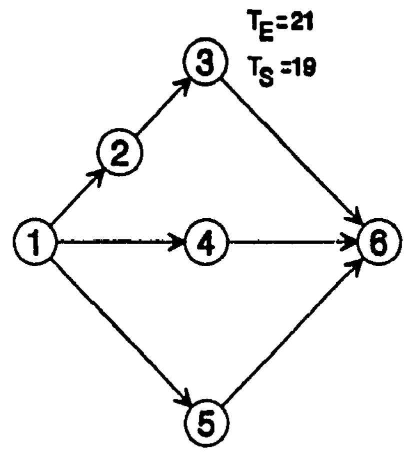
If T_S is later than T_E, then Z will be positive.

If T_S is earlier than T_E, then Z will be negative.

Determining the probability of meeting a scheduled date: an example

Event 3 is scheduled to be completed 19 days after the start of the project. To determine the probability of meeting this scheduled date we must compute Z for Event 3.

ACTIVITY	a	m	b.	t_e	σ^2
1 - 2	12	14	16	14	0.4
2 - 3	6	7	8	7	0.1
3 - 6	4	8	12	8	1.8
1 - 4	9	14	20	14.2	3.4
4 - 6	3	6	9	6	1.0
1 - 5	12	13	14	13	0.1
5 - 6	3	9	18	9.5	6.3



Only one path leads to Event 3, activities 1-2 and 2-3. The t_e for each activity appears on the chart. Remember, we use the t_e to compute the T_E, (the longest time consuming path and the earliest expected time you can expect to reach an event). If more than one path leads to the event in question, select the one with the largest T_E value. As you can see, T_E for the event appears in the numerator of the formula for the probability factor. T_S for Event 3, is 19 days, the T_E is 21 (14 +7).

In the formula for Z we use the variances of the activities along the critical path to the scheduled event. The variance for each activity has been calculated using this formula.

$$\left(\frac{b - a}{6}\right)^2$$

Remember the value of Z can be either positive or negative.

$$Z = \frac{T_S - T_E}{\sqrt{\Sigma \sigma^2_{T_E}}} = \frac{19 - 21}{\sqrt{.4 + .1}} = \frac{-2}{\sqrt{.5}} = \frac{-2}{.71} = -2.8$$

Now, take the computed value of Z and look it up in the Table of Values of the Standard Normal Distribution on the following page. Locate this value and select the probability value that appears in the O column to the right of the Z. Here the P_R=.0026 or .26%. That is, the probability of reaching the scheduled date of 21 days is .26%. As previously mentioned, the range of probabilities which is acceptable in PERT is between .35 and .64. Such a low probability necessitates a major revision of the existing plan.

TABLE OF VALUES OF THE STANDARD NORMAL DISTRIBUTION

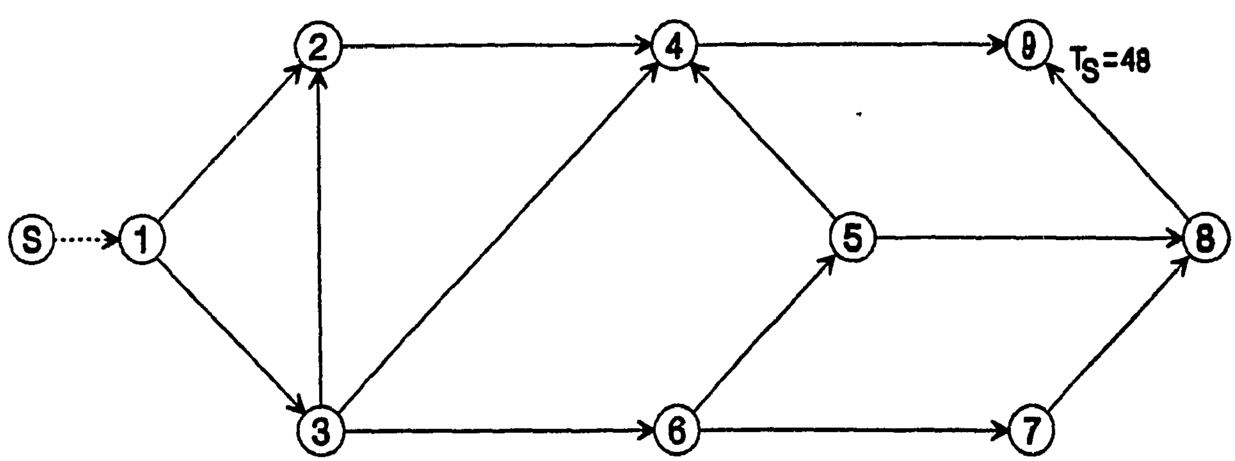
Z	0	Z	0
.0	.5000	-3	.0013
.1	.5398	-2.9	.0019
.2	.5793	-2.8	.0026
.3	.6179	-2.7	.0035
.4	.6554	-2.6	.0047
.5	.6915	-2.5	.0062
.6	.7257	-2.4	.0082
.7	.7580	-2.3	.0107
.8	.7881	-2.2	.0139
.9	.8159	-2.1	.0179
1.0	.8413	-2.0	.0228
1.1	.8643	-1.9	.0287
1.2	.8849	-1.8	.0359
1.3	.9032	-1.7	.0446
1.4	.9192	-1.6	.0548
1.5	.9332	-1.5	.0668
1.6	.9452	-1.4	.0808
1.7	.9554	-1.3	.0968
1.8	.9641	-1.2	.1151
1.9	.9713	-1.1	.1357
2.0	.9772	-1.0	.1587
2.1	.9821	-0.9	.1841
2.2	.9861	-0.8	.2119
2.3	.9893	-0.7	.2420
2.4	.9918	-0.6	.2743
2.5	.9938	-0.5	.3085
2.6	.9953	-0.4	.3446
2.7	.9965	-0.3	.3821
2.8	.9974	-0.2	.4207
2.9	.9981	-0.1	.4602
		-0.0	.5000
3.0	.9987		

SAQ 1 : calculating the probability of meeting a scheduled date

It is important that you complete this exercise as it will give you practice in calculating the probability of meeting a scheduled date. To do this, you will have to use just about everything you have learned so far.

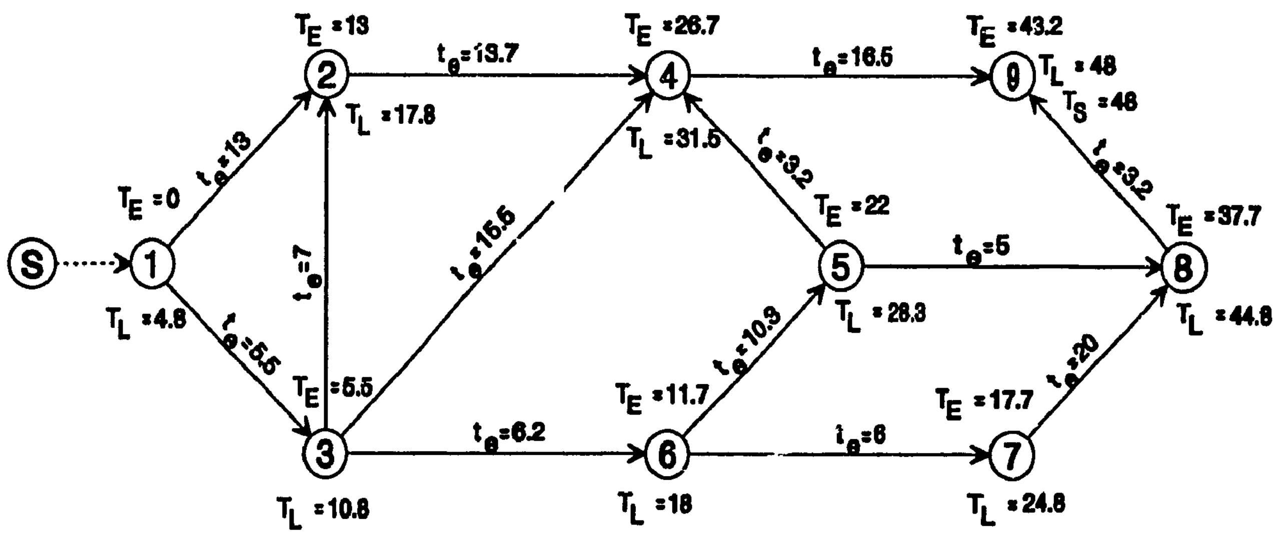
In the network below Event 9 ends the project. What is the probability of meeting its scheduled date? Indicate and outline the critical path.

ACTIVITY	a	m	b	t_e	σ^2	T_E	T_L	Slack	P_R
1-2	6	12	24						
1-3	3	5	10						
3-2	4	7	10						
3-4	9	15	24						
3-6	4	6	9						
6-5	6	10	16						
6-7	3	6	9						
4-9	12	17	19						
5-4	1	3	6						
5-8	3	5	7						
7-8	10	20	30						
8-9	2	3	5						
2-4	9	14	17						



SAQ 1: Answer

ACTIVITY	a	m	b	t_e	σ^2	T_E	T_L	SLACK	P_R
S-1	0	0	0	0	0	0	4.8	4.8	
1-2	6	12	24	13	9	13	17.8	4.8	
2-4	9	14	17	13.7	1.8	26.7	31.5	4.8	
4-9	12	17	19	16.5	1.4	43.2	48	4.8	.9192
1-3	3	5	10	5.5	1.4	5.5	10.8	5.3	
3-2	4	7	10	7	1	12.5	17.8	5.3	
5-4	1	3	6	3.2	0.7	25.2	31.5	6.3	
6-5	6	10	16	10.3	2.8	22	28.3	6.3	
3-6	4	6	9	6.2	0.7	11.7	18	6.3	
6-7	3	6	9	6	1	17.7	24.8	7.1	
7-8	10	20	30	20	11	37.7	44.8	7.1	
8-9	2	3	5	3.2	0.3	40.9	48	7.1	
3-4	9	15	24	15.5	6.3	21	31.5	10.5	
5-8	3	5	7	5	0.4	27	44.8	17.8	



In this problem, we are determining the probability of meeting the scheduled date for the network ending event. Remember, the critical path is the path of activities which extends from the network beginning to the network ending event, and has the greatest sum of t_e values. It yields the greatest T_E value.

The critical path is 1 - 2 - 4 - 9 and it heads the list on the chart.
The T_E for Event 9 is 43.2. The T_S is 48.

We use the variances of the activities along the critical path, that were used in the calculation of T_E. Now we substitute the appropriate values into the formula.

$$Z = \frac{T_S - T_E}{\sqrt{\Sigma \sigma^2_{T_E}}} = \frac{48 - 43.2}{\sqrt{9 + 1.8 + 1.4}} = \frac{4.8}{\sqrt{12.2}} = \frac{4.8}{3.5} = 1.37 \text{ or } 1.4$$

Looking up P_R on the table, we get .9192 or 92%. This is very close to 1.0, indicating that too many resources are being used. An acceptable probability range for PERT is between .35 and .64.

In this case, we have an ahead of schedule condition, due to a large positive slack associated with all of the events. The critical path, which is the path of minimum slack, has a slack value of 4.8.

This will be discussed further in the following pages.

THE ACTIVITY-OUTPUT SLACK SORT CHART: an aid to decision-making

All the values that have been calculated in the previous exercise and placed on the network, have been transferred to an Activity-Output Slack Sort Chart.

ACTIVITY	Actual Date	T_E	T_L	T_S	SLACK	σ^2	P_R
S-1		0	4.8		4.8	0	
1-2		13	17.8		4.8	9	
2-4		26.7	31.5		4.8	1.8	
4-9		43.2	48	48	4.8	1.4	.9192
1-3		5.5	10.8		5.3	1.4	
3-2		12.5	17.8		5.3	1	
5-4		25.2	31.5		6.3	0.7	
6-5		22	28.3		6.3	2.8	
3-6		11.7	18		6.3	0.7	
6-7		17.7	24.8		7.1	1	
7-8		37.7	44.8		7.1	11	
8-9		40.9	48		7.1	0.3	
3-4		21	31.5		10.5	6.3	
5-8		27	44.8		17.8	0.4	

Looking at this chart you will notice that the events are listed from minimum to maximum slack. The critical path, the longest path from network beginning to network ending event, heads the list.

You will also note that every activity in the network has been accounted for. As a result there will be T_E values that do not appear on the network. Take for example, the activity paths that lead to event 8; 5-8 and 7-8. To determine the T_E for event 8, you will calculate the longest path to event 8. It is 7-8 and in this case the T_E is 37.7. The shorter path is 5-8; the T_E for event 8 is 27. The T_L for an event always remains the same since when you calculate the T_L, you always use the shortest path back to the event.

The probability of .9192 is placed alongside activity 4-9 which is on the the critical path. Looking back at the network, you will see that this corresponds to the T_E of 43.2 and the T_L of 44.8.

A probability of less than .25 indicates that there is a considerable amount of risk in proceeding with the existing plan. A probability of .50 indicates good planning and that the scheduled date is likely to be met. A probability of greater than .60 indicates that too many resources are being used. The problem facing the project manager is one of an excess of resources being used. The probability is .92.

The actual date column is filled in as the project progresses.

The purpose of this workbook has been to teach you how to develop a network representation of a project and to perform all the calculations necessary to allow you to determine the probability of meeting a scheduled date. The activity-output slack sort chart is the result of all those calculations. It presents all the information in a logical order and provides a frame of reference for discussing the existing plan and proposed changes. Activities that have a large variance and events that have a large slack will have to be re-evaluated.

The objective is to reduce the slack to 0 while maintaining a .5 probability of meeting a scheduled date. The goal of the manager is the effective and efficient management of resources and the completion of the project on or ahead of schedule. Whether the project is to come in ahead of or on time is a matter for discussion. All the consequences have to be considered. Any project carried out by an organisation is part of a larger system of on-going projects and daily operations. People, money, time, equipment and facilities have to be deployed in an effective and efficient manner within the organisation as a whole.

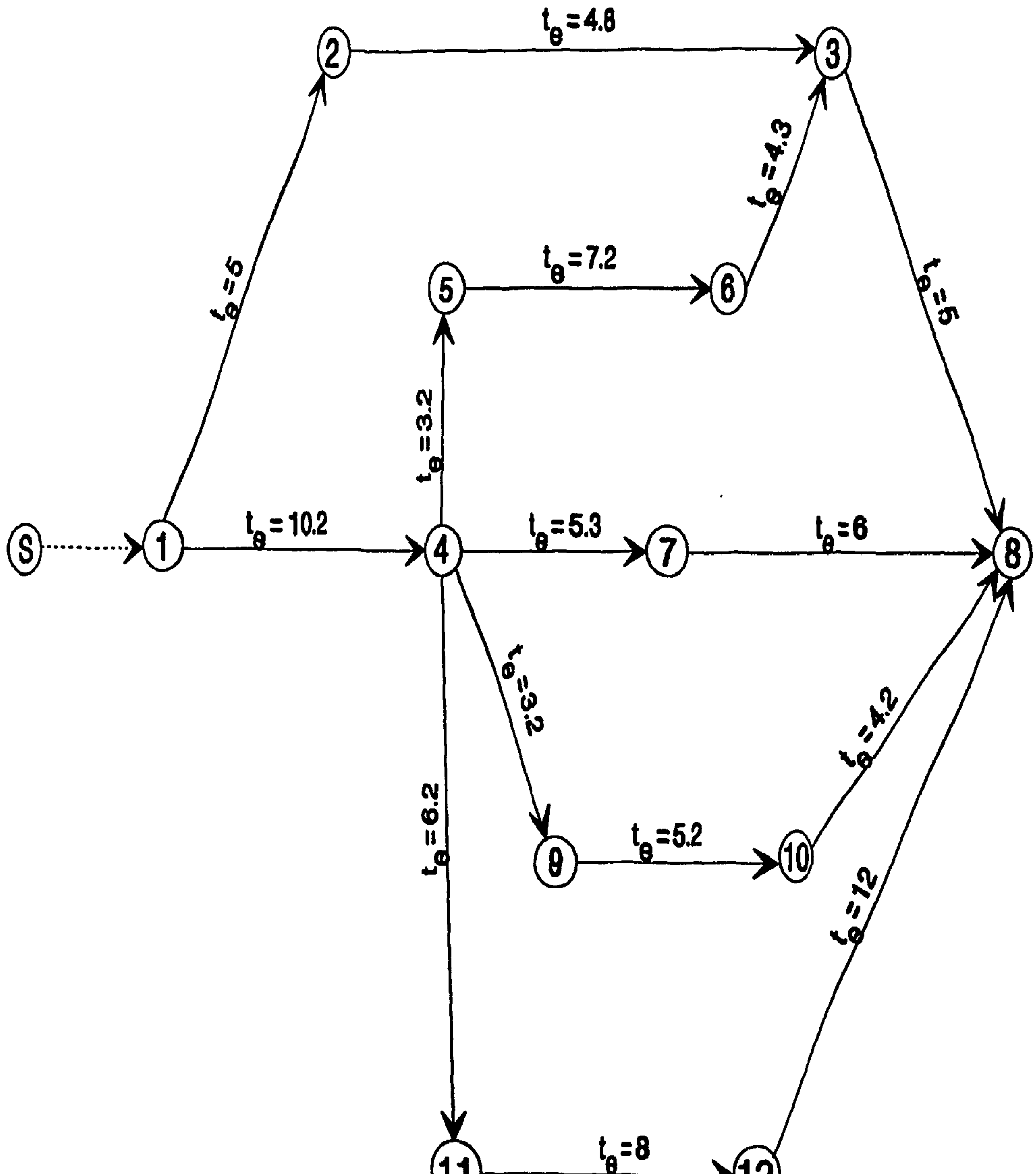
It is at this point that a computer programme is most useful. It can run through the same procedures with different sets of data, until it comes up with an acceptable alternative to the existing plan.

SAQ 2: calculating the probability of meeting a scheduled date

Calculate the probability of meeting the scheduled date for the network on the next page. Indicate and outline the critical path. Explain what you might do upon receiving the results of the existing plan.

Activity	a	m	b	t_e
s-1	0	0	0	0
1-4	6	10	15	10.2
4-9	1	3	6	3.2
10-8	1	4	8	4.2
6-3	2	4	8	4.3
3-8	2	4	12	5
4-5	1	3	6	3.2
5-6	4	6	15	7.2
12-8	6	12	18	12
4-11	3	6	10	6.2
9-10	3	5	8	5.2
11-12	6	8	10	8
4-7	2	5	10	5.3
7-8	3	6	9	6
1-2	2	4	12	5
2-3	1	5	8	4.8

Activity	Actual Date	T_E	T_L	T_S	Slack	σ^2	P_R


S
1
2
3
4
5
6
7
8
9
10
11
12
$t_e=5$
$t_e=4.8$
$t_e=4.3$
$t_e=7.2$
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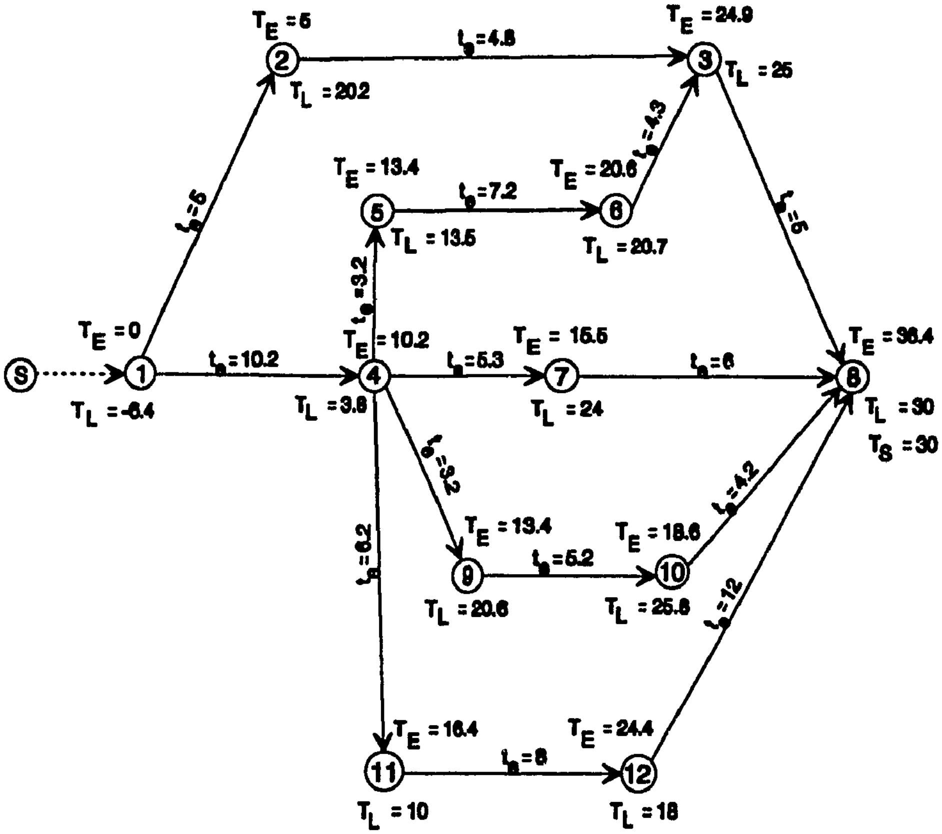
$t_e=6$
$t_e=3.2$
$t_e=6.2$
$t_e=5.2$
$t_e=4.2$
$t_e=12$
$t_e=8$

SAQ 2: Answer



Activities	Actual Date	T_E	T_L	T_S	SLACK	σ^2	P_R
S-1		0	-6.4		-6.4	0	
1-4		10.2	3.8		-6.4	2.3	
4-11		16.4	10		-6.4	1.4	
11-12		24.4	18		-6.4	0.4	
12-8		36.4	30	36.4	-6.4	4	.0139
3-8		29.9	30		0.1	2.8	
4-5		13.4	13.5		0.1	0.7	
5-6		20.6	20.7		0.1	3.4	
6-3		24.9	25		0.1	1	
4-9		13.4	20.6		7.2	0.7	
9-10		18.6	25.8		7.2	0.7	
10-8		22.8	30		7.2	1.4	
4-7		15.5	24		8.5	1.8	
7-8		21.5	30		8.5	1	
1-2		5	20.2		15.1	2.8	
2-3		9.8	25		15.2	1.4	

The critical path is 1 - 4 - 11 - 12 - 8

$T_S = 36.4, T_E = 30$

The variances for the activities along the critical path are 2.3, 1.4, .4 and 4. These values are substituted into the formula.

$$Z = \frac{T_S - T_E}{\sqrt{\Sigma \sigma^2_{T_E}}} = \frac{30 - 36.4}{\sqrt{2.3 + 1.4 + .4 + 4}} = \frac{-6}{2.9} = -2.1$$

On the table, -2.1 corresponds to a P_R of .0179

Here we have a situation where there is very little likelihood of completing the project on time. Considering that the project has to be completed in 30 days, a negative slack of 6.4 days is quite high.

There are two options; the first is to ask the client to accept a later scheduled date, the second is to re-examine the activity times and the slack. However, in this case it does not make sense to ask the client to accept a delay, as it obvious that resources are being mismanaged. The logical step is to re-evaluate the existing plan.

You would first look at the activities which have a highest variance; 1-2, 3-8, 1-4, 5-6, and 12-8. It is these activities that you would want to examine first. While a large variance may be due to an inability on the part of the estimator to provide an accurate estimate, it may also be that she is over-cautious when estimating the pessimistic time and over-optimistic when estimating the optimistic time. Remember, variance is a measure of the gap between those two times. A large gap is acceptable if it can be fully justified. So, in the cases where we know that the activity times should not be altered, we leave them as they are. When it is clear, upon re-examination of the time estimates and the corresponding conditions that they account for, that they are not acceptable, they must be re-worked.

The next step is to look at the activities that have a high positive slack. This means that they are ahead of schedule and have resources to spare, that at the most correspond to the amount of slack. A slack of 15.2 days means that the various excess resources from that event, be they financial, human, facilities or equipment, can be re-distributed to those events on the critical path that have a negative slack.

As previously mentioned, finding the optimum allocation of resources and an acceptable level of risk is an appropriate task for the computer.

Analysis of the data should start early in the project. There should be a continuous evaluation of the original plans, in the light of current operating conditions. Again, with a computer programme, one can easily simulate what will happen when alternative conditions with an acceptable risk are considered.

Once you have established a plan that has an acceptable level of risk, you can go ahead with the project. As the project progresses, there will be changes. The actual slack time may in fact differ from the calculated slack time and in the resulting calculations, the critical path may change. PERT is a mechanism that allows you to develop a plan, monitor that plan, anticipate and respond immediately to any change in the system.

How PERT provides timely information for programme evaluation

During the execution of the project, periodic requests for information will be received from the various departments involved. These request will be related to the more critical paths and the audit or examination of specific events. Essentially they will be for more accurate data on tight areas. This auditing results in improved accuracy of the network as the project develops. The audit is likely to focus on small groups of activities and will differ from month to month. Eventually the entire network will have been audited. The effectiveness of this part of PERT depends on the speed of recognising problems and making adjustments.

In order to keep everyone informed as to the progress of the project, reports are issued on a bi-weekly, monthly and quarterly schedule. This procedure of issuing reports ensures that everyone involved is kept up-to-date on the progress of the project and provides all the necessary information for discussion and re-evaluation.

Bi-weekly reports indicate anticipated changes, problem areas and provide the necessary data for proposed corrective action. Monthly reports focus on those activities that are currently most critical and not the majority of events. Quarterly reports go through the same procedure used to set up the original network diagramme and chart. All events and activity times are re-examined and revised as necessary. The results provide management with all the information required to evaluate the project and make a new prognosis.

SUMMARY

You have gone through all the procedures involved in applying PERT, without using a computer. Well done! Now let me summarise this procedure for you.

The construction of a network flow diagramme provides a visual representation of the project. This is followed by a number of calculations related to the time component. By calculating t_e and variance, we can determine the average expected time for each activity and the accuracy of this estimate. When we have calculated T_E and T_L we have determined the earliest time we can expect to reach an event and the latest allowable time to reach an event. With these values we can calculate slack, the measure of the resources associated with each event. Using the slack value we can determine the critical path, the longest path through the network. This path determines the duration of the project. Our final calculation is the probability of meeting a scheduled date, given the existing plan.

Next we construct an activity-output slack sort chart, listing events in order of minimum to maximum slack, so that the critical path heads the list. This chart provides us with all the information we need to evaluate the existing plan. If there is a low probability of meeting the scheduled date, we can consult the chart to find out where the problem is and how we might solve it. Events with a negative slack are likely to be behind schedule.Next we look for activities that have a high variance and events that have a large positive slack value. This tells us that the activity estimates may be inaccurate and that too many resources are being used to accomplish some of the events.

In the light of all this information, we either go ahead with the project according to the existing plan or we make revisions so that we have a zero slack on the critical path and a probability of .5 of meeting the scheduled date without needlessly consuming resources.

The final component of PERT is the communication system established through the issuing of bi-weekly, monthly and quarterly reports. This ensures the continual analysis of the system which is your project.

FORMULAE

t_e expected time for an activity.

$$\frac{a + 4m + b}{6}$$

σ^2 variance is a measure of the gap between optimistic and pessimistic times

$$\left(\frac{b - a}{6}\right)^2$$

σ or S standard deviation is used to establish a range either side of the expected time

$$\frac{b - a}{6}$$

T_E the earliest expected time for an event. It is the sum of the t_e's to an event. Always select the longest path.

$$t_e + t_e \ldots\ldots\ldots$$

T_L the latest allowable time for an event. Start with the network ending event and work backwards, subtracting the t_e on the activity arrow from the T_L of the event at the head of the activity arrow. When there is more than one arrow, select the shortest path.

$$T_L - t_e$$

Slack is the measure of excess resources associated with an event. Positive slack means that the event is ahead of schedule, negative slack means that it is behind schedule and 0 slack means that it is right on time.

$$T_L - T_E$$

Z the probability factor is calculated using this formula.

$$Z = \frac{T_S - T_E}{\sqrt{\Sigma \sigma^2_{T_E}}}$$

This is the average time an activity would take if repeated many times. The resulting value, when located in the Table of Values of the Standard Normal Distribution, will give you the probability of meeting the scheduled date.

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Appendix B

Instructional Objectives

Terminal Performance Objective

Given a list of activities, specifying their dependencies and relationships, and the values for the optimistic, most likely and pessimistic times the learner will be able to

a) construct a network
b) calculate t_e
c) calculate variance
d) calculate T_E
e) calculate T_L
f) calculate slack
g) identify the critical path
h) determine the probability of meeting the scheduled date
i) explain the acceptable range of probabilities
j) explain the situation that has presented itself with reference to slack
k) use variance to identify estimates that might be inaccurate
l) use slack to identify those events that could give up some of their associated resources

Enabling Objectives

Upon completion of Lesson 1, the learners will be able to:

1.0 construct a network
1.1 define and represent an event
1.2 define and represent successor and predecessor events
1.3 define and identify initiating and terminating events
1.4 define and represent an activity
1.5 distinguish between concurrent and non-concurrent activities and represent them in a network
1.6 define dummy activities and use them correctly in a network
1.7 define and represent concurrent and non-concurrent activities

Upon completion of Lesson 2, the learner will be able to:

2.0 explain the connection between t_e, variance and standard deviation

2.1 explain the difference between optimistic, most likely and pessimistic times

2.2 explain the concept of t_e and calculate it correctly given the optimistic, most likely and pessimistic times

2.3 define and calculate variance given the optimistic, most likely and pessimistic times

2.4 define and calculate standard deviation given the optimistic, and pessimistic times or the variance

Upon completion of Lesson 3, the learner will be able to:

3.0 define and identify the critical path

3.1 define and calculate T_E

3.2 define and calculate T_L

3.3 define and calculate slack

3.4 explain the difference between positive, negative and zero slack

3.5 define a critical event

Upon completion of Lesson 4, the learner will be able to:

4.0 Use the probability value to determine what action should be taken given the existing plan

4.1 explain and calculate the probability factor

4.2 identify the range of acceptable probabilities and how they relate to the management of the project

4.3 identify the components that must be examined before any decisions can be made as to whether or not to proceed with the existing plan

Appendix C

Post Test, Criterion Checklist, Results, Sample Answer

Final Exam: Question 1.

The following activities are involved in the production and evaluation of a distance learning course in the basics of music. Construct the network.

These activities are non-concurrent and are performed in this order:

- project start
- prepare draft 1
- revise draft 1
- revise draft 2

and are followed by these concurrent activities

- develop feedback questionnaires
- record aural training cassette
- record illustrative music cassette
- assemble home kit

which terminate at a single event, signifying the completion of the instructional materials and the beginning of the next activity,

- develop tutor training manual

This is followed by two concurrent activities:

- conduct tutor training
- distribute learning materials to testers

When these activities have been completed, the next step is to

- conduct developmental testing

followed by these non concurrent activities

- carry out data analysis
- conduct tester interviews
- make revisions

Question 2.

1. Using the following activity time estimates, calculate all the values necessary to set up an activity-output slack sort chart. These values must be calculated under the following conditions.

   a) T_E, T_L and T_S for the final event have the same value.

   b) The T_S for the final event is 100 days. Calculate the probability of meeting the scheduled date.

   You may modify the presentation of the material on the chart in order to display both sets of values.

2. Identify the critical path.

3. Discuss your findings with regards to the differing scheduled dates. In your discussion, identify what actions the project manager might take in either case. Cite the pertinent items of information that can be used in making this decision.

Good Luck!

ACTIVITY	a	m	b	t_e
prepare draft 1	28	45	60	44.7
revise draft 1	1	2	3	2
revise draft 2	1	2	3	2
develop FBQ's	1	2	3	2
record aural training cassette	3	5	8	5.2
record illustrative music cassette	3	5	8	5.2
assemble home kit	8	10	15	10.5
develop tutor training manual	12	14	20	14.7
conduct tutor training	4	6	8	6
distribute learning material	3	5	8	5.2
conduct developmental testing	12	14	16	14
perform data analysis	3	4	7	4.3
conduct tester interviews	3	5	6	4.8
make revisions	7	12	14	11.5

Criterion Checklist for Post-Test Answer

The ideal answer to this post-test should include:

1. a correctly constructed network representing concurrent, non-concurrent and dummy activities.
2. the correct method for calculating variance.
3. the correct method for calculating T_E and T_L
4. the correct method for calculating slack.
5. the correct identification of the critical path.
6. the correct method for calculating the Probability Factor.
7. the correct construction of an activity-output slack sort chart
8. An analysis and discussion of the two situations confronting them, making reference to the following information

. identify an activity that has a particularly high variance and suggest that the activity time should be re-evaluated

. specify the acceptable range of probabilities in PERT

. explain what the P_R value means in terms of meeting the scheduled completion date

. explain what slack means in terms of the likelihood of an event being on time, ahead of time or behind schedule

. indicate that events with a large positive slack can give up some of their excess resources to events that have a negative slack

Results of Post Test

1. All 5 testers provided a correctly constructed network representing concurrent, non-concurrent and dummy activities.

2. All 5 testers used the correct method for calculating variance.

3. All 5 testers used the correct method for calculating TE and T_L.

4. All 5 testers used the correct method for calculating slack.

5. All 5 testers correctly identified the critical path.

6. All 5 testers used the correct method for calculating the Probability Factor.

7. Only 4 testers constructed the activity-output slack sort chart correctly. The other tester handed in a hastily done and untidy answer and neglected to completely construct the chart.

8. In the discussion of the results
   . 3 out of the 5 testers specified the acceptable range of probabilities and pointed out that in both examples, the probabilities fell outside this range
   . 2 out of the 5 testers stated that the probability level was unacceptable without making specific reference to the acceptable range
   . 5 testers specified the re-allocation of resources from those activities with a high positive slack to those with a negative slack
   . 3 out of 5 testers made reference to a specific activity that should be evaluated but only 2 mentioned that it was because of the high variance
   . 2 out of 5 learners made general remarks about evaluating the activity time estimates

ETEC653
Educational Systems Analysis
Prof. P. David Mitchell

Angelo de Moura Guimarães

Final Exam
Part I

Question I

Network (see Appendix 1)

Question 2

Activity-output slack sort chart

a) Te, TL and TS for the final event have the same value

ACTIVITY	code	type	te	TE	TL	Slack	Critical Path	Proba-bility
Start project	S-0	dummy	0	0	0	0	✓	
Prepare draft	0-1	real	44.7	44.7	44.7	0	✓	
Revise draft I	1-2	real	2	46.7	46.7	0	✓	
Revise Draft II	2-3	real	2	48.7	48.7	0	✓	
Develop FBQ's	3-4	real	2	50.7	59.2	8.5		
Record aural training cassette	3-5	real	5.2	53.9	59.2	5.3		
Record illustrative music cassette	3-6	real	5.2	53.9	59.2	5.3		
Assemble Home Kit	3-7	real	10.5	59.2	59.2	0	✓	
	4-8	dummy	0	59.2	59.2	0	✓	
	5-8	dummy	0	59.2	59.2	0	✓	
	6-8	dummy	0	59.2	59.2	0	✓	
	7-8	dummy	0	59.2	59.2	0	✓	
Develop tutor training manual	8-9	real	14.7	73.9	73.9	0	✓	
Conduct tutor training	9-10	real	6	79.9	79.9	0		
Distribute learning material	9-11	real	5.2	79.1	79.9	0.8		
	10-12	dummy	0	79.9	79.9	0	✓	
	11-12	dummy	0	79.9	79.9	0	✓	
Conduct developmental test	12-13	real	14	93.9	93.9	0	✓	
Perform data analysis	13-14	real	4.3	98.2	98.2	0	✓	
Conduct tester interviews	14-15	real	4.8	103	103	0	✓	
make revisions	15-16	real	11.5	114.5	114.5	0	✓	
	16-F	dummy	0	114.5	114.5	0	✓	0.500

The probability of meeting the schedule date is .50. This means that if this project is conducted with this plan 100 different times it could meet the scheduled date in 50 times.

b) The Ts for the final event is 100 days.

ACTIVITY	code	type	a	b	te	σ^2_{te}	TL	Slack	Critical path	σ^2_{TE}	Probability
Start project	S-0	dummy	0	0	0	0	-14.5	-14.5	✓	0	
Prepare draft	0-1	real	28	60	44.7	28.4	30.2	-14.5	✓	28.44	
Revise draft I	1-2	real	1	3	2	0.11	32.2	-14.5	✓	0.11	
Revise Draft II	2-3	real	1	3	2	0.11	34.2	-14.5	✓	0.11	
Develop FBQ's	3-4	real	1	3	2	0.11	44.7	-6		0	
Record aural training cassette	3-5	real	3	8	5.2	0.69	44.7	-9.2		0	
Record illustrative music cassette	3-6	real	3	8	5.2	0.69	44.7	-9.2		0	
Assemble Home Kit	3-7	real	8	15	10.5	1.36	44.7	-14.5	✓	1.36	
	4-8	dummy	0	0	0	0	44.7	-14.5	✓	0	
	5-8	dummy	0	0	0	0	44.7	-14.5	✓	0	
	6-8	dummy	0	0	0	0	44.7	-14.5	✓	0	
	7-8	dummy	0	0	0	0	44.7	-14.5	✓	0	
Develop tutor training manual	8-9	real	12	20	14.7	1.78	59.4	-14.5	✓	1.78	
Conduct tutor training	9-10	real	4	8	6	0.44	65.4	-14.5	✓	0.44	
Distribute learning material	9-11	real	3	8	5.2	0.69	65.4	-13.7		0	
	10-12	dummy	0	0	0	0	65.4	-14.5	✓	0	
	11-12	dummy	0	0	0	0	65.4	-14.5	✓	0	
Conduct developmental test	12-13	real	12	16	14	0.44	79.4	-14.5	✓	0.44	
Perform data analysis	13-14	real	3	7	4.3	0.44	83.7	-14.5	✓	0.44	
Conduct tester interviews	14-15	real	3	6	4.8	0.25	88.5	-14.5	✓	0.25	
make revisions	15-16	real	7	14	11.5	1.36	100	-14.5	✓	1.36	
	16-F	dummy	0	0	0	0	100	-14.5	✓	0	0.0062

$\Sigma\sigma^2_{TE}$ = 34.73

$\sqrt{\Sigma\sigma^2_{TE})}$ = 5.893

z = -2.5

c) Discussion

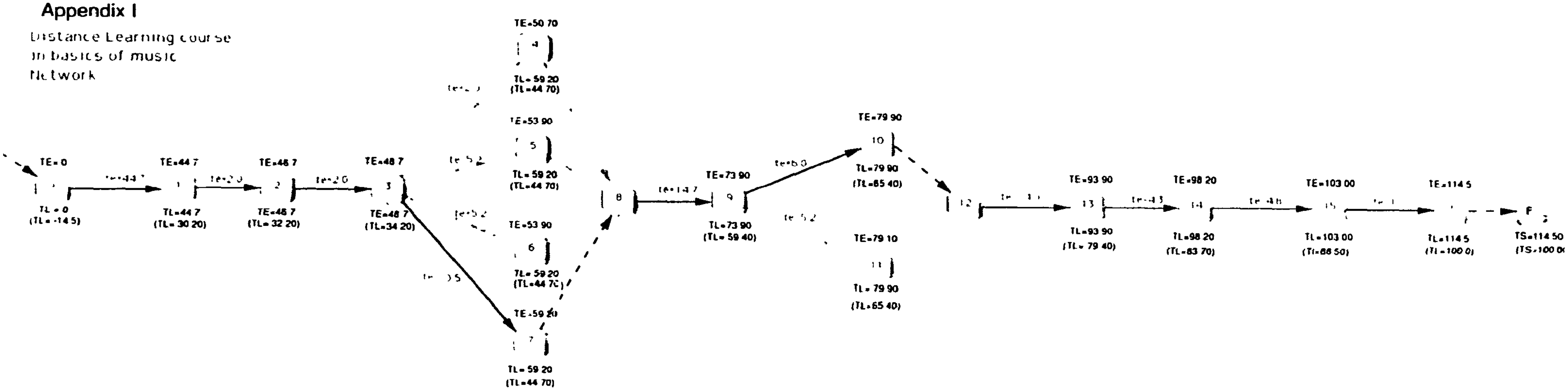
The probability of meeting the schedule date is .0062. This means that if this project is conducted with this plan 100 different times it could meet the scheduled date in less than 1 time. We can say that with 100 days is unviable to conduct this project maintaining this network of activities.

Analysis of the network and the critical path shows that the majority of activities are executed linearly in time. Few activities are executed in parallel. In one case, when activities are executed concurrently, "Assemble home kit" has a disproportional time comparing with the others. The project manager might take the following actions:

- Reanalyze all the activities with high variance in the estimates and try to divide then for a closer examination. It can conduct to better estimation and low variance.
- Reanalyze the activities with high te (For example, the first activity "prepare draft I").
- Try to divide some activities into sub-activities that can be developed concurrently.
- Reanalyze the concurrent activities in order to avoid a disproportional relationship of time.

Appendix I

Distance Learning course
in basics of music
Network



Appendix D

Tester Instructions and Log Sheet

Formative Evaluation

Thank you for participating in this formative evaluation. Your answers to the questions in the following pages will be used as a guideline for improving this self-instructional workbook.

Instructions

1. **Tester's Log Sheet**

   The purpose of this Log Sheet is to determine how long it takes to complete the workbook, therefore it is very important that you remember to fill it out at the start and finish of each lesson.

2. **End of Lesson Questionnaire**

   This questionnaire should be filled out either at the end of each lesson or while you are working through the lesson.

3. **End of Workbook Questionnaire**

   This is to be completed once you have finished all 4 lessons.

Name________________________

Tester's Log Sheet

Lesson 1:

Time Started:

Time Finished:

Did you work through this lesson without interruption ?

Actual time spent on lesson

Comments

Appendix E

End of Lesson Questionnaires and Results

END OF LESSON QUESTIONNAIRE: LESSON 1

1. Did you find that the overview

   ___ made sense to you

   ___ reduced your anxiety towards learning the technique

   ___ increased your anxiety towards learning the technique

   ___ convinced you that PERT would be useful to you

2. The explanation of network terminology was ___ clear ___ confusing.

   a. What did you find confusing ? Please state page number.______

   ____

   ____

   b. What would have helped you? ______________________________

   ____

   ____

3. The explanation of network construction was ___ clear ___ confusing.

   a. What did you find confusing ? Please state page number.______

   ____

   ____

   b. What would have helped you ?______________________________

   ____

4. Did you have problems completing the network construction exercise?

   ___ yes ___ no

5. If you found the network construction exercise difficult please elaborate. What would have made it easier?____

____

____

6. There were

______ not enough exercises in this lesson

______ enough exercises

OTHER COMMENTS:

END OF LESSON QUESTIONNAIRE: LESSON 2

1. Did you understand the explanation of the three time estimates and the calculation of t_e? ____ yes ____ no

   a. What did you find confusing ? Please state page number.________

   ____

   ____

   b. What would have helped you ?______________________________

   ____

   ____

   ____

   c. Was the exercise helpful in clarifying this concept? ____ yes ____no

   d. Was one exercise sufficient? ____ yes ____ no

   e. If you had any problem in completing this exercise please explain.

   ____

   ____

2. Was the concept of variance clearly explained ? ____yes ____no

   a. What did you find confusing ? Please state page number.________

   ____

   ____

   b. What would have helped you? ______________________________

   ____

____

c Was one exercise sufficient practice in calculating and using this value ? ____ yes _____no

d. Did you have any problem in completing this exercise?
___ yes ___ no

e. Was the answer provided of sufficient detail to be of help to you?
___ yes ___ no

3. Was the explanation of standard deviation clear? ___ yes ___ no

a. What did you find confusing ? Please state page number.________

____

____

b. What would have helped you?______________________________

____

4. Did you understand the explanation about the area under the normal curve ?
___ yes ___ no

a. What did you find confusing ? Please state page number.________

____

____

b. What would have helped you?______________________________

____

____

c. Were the examples and exercises useful in explaining the concepts of standard deviation and the normal curve ? ___ yes ___ no

d. Did you have any problem completing the exercise? ___ yes ___ no

e. Was the answer provided of sufficient detail to be of help to you?
___ yes ___ no

5. Were you already familiar with the concepts of

variance ___ yes ___ no
standard deviation ___ yes ___ no
normal curve ___ yes ___ no

a. If you answered yes to any of the above did you find this to be a useful review? ___ yes ___ no

b. If you were already familiar with any of these concepts did you find the explanations _____ good _____ fair _____ poor.

OTHER COMMENTS

END OF LESSON QUESTIONNAIRE: LESSON 3

1. This lesson began with a review of what you had just learned. Did you find the review useful? ____ yes ____ no

2. What was the time gap between the completion of Lesson 2 and the start of Lesson 3 ? ________________________________

3. Was the concept of T_E clearly explained ? ____ yes ____ no

   a. What did you find confusing ? Please state page number. ______

   ____

   ____

   b. What would have helped you ?________________________________

   ____

   ____

   c. Would you have done all three exercises if given the choice?

   ____ yes ____ no

   d. Were there____ too many _____ too few or _____ the right number of exercises ?

   e. Did you have any problem in completing the exercises?

   ____ yes ____ no

   f. Was the answer provided of sufficient detail to be of help to you?

   ____ yes ____ no

4. Was the concept of T_L clearly explained ? ____ yes ____ no

a. What did you find confusing ? Please state page number.______

____

____

b. What would have helped you?______________________________

____

____

c. There were two exercises following this explanation. Was this

_____ too many _____ too few or _____ the right number ?

e. Did you have any problem in completing the exercises?

_____ yes _____ no

f. Was the answer provided of sufficient detail to be of help to you?

_____ yes ____ no

5. Was the concept of slack clearly explained ? ___ yes ___ no

a. What did you find confusing ? Please state page numbers. _____

____

____

b. What would have helped you ?______________________________

____

____

6. Did you understand the explanation of the critical path?

_____ yes ____ no

a. What did you find confusing ? Please state page numbers. _____

____

____

b. What would have helped you ?__________________________________

____

____

c. Three exercises followed this explanation. Was this ____ too many

______ too few ______ the right amount.

d. Did you have any problem in completing the exercises?

_____ yes ____ no

e. Was the answer provided of sufficient detail to be of help to you?

_____ yes ____ no

OTHER COMMENTS

END OF LESSON QUESTIONNAIRE: LESSON 4

1. Did you understand the explanation of the probability factor?

   ___ yes ____ no

   a. What did you find confusing ? Please state page numbers. ______

   ____

   ____

   b. What would have helped you ?________________________

   ____

   ____

   c. Only one exercise followed this explanation. Was this sufficient practice ?

   ____yes ____ no

   e. Did you have any problem in completing the exercise?

   _____ yes _____ no

   f. Was the answer provided of sufficient detail to be of help to you?

   _____ yes _____ no

2. Did you understand the explanation of the activity-output slack sort chart ?

   _____ yes _____ no.

   a. What did you find confusing ? Please state page numbers. _____

   ____

   ____

   b. What would have helped you ?________________________

OTHER COMMENTS

RESULTS OF END OF LESSON QUESTIONNAIRES

Lesson 1

<u>Overview</u>

4 made sense

1 reduced anxiety

1 convinced learner that PERT was useful

<u>Explanation of *network terminology*</u>

4 clear

1 slightly confusing

<u>Explanation of *network construction*</u>

5 clear

<u>Problems with construction exercise</u>

5 no

<u>Number of exercises</u>

2 enough

2 too few

1 no answer

Lesson 2

<u>Explanation of t_e</u>

5 clear

<u>Helpfulness of exercise</u>

4 was helpful

1 no answer

<u>Explanation of *variance*</u>

4 clear

1 no answer

<u>Number of exercises</u>

4 enough

1 too few

<u>Problems with exercise</u>

1 yes

4 no

<u>Sufficiency of answer</u>

2 sufficient

3 no answer

<u>Familiarity with concept of variance</u>

5 yes

<u>Usefulness of explanation as a review</u>

5 yes

<u>Explanation of *standard deviation*</u>

2 clear

1 confusing

2 no answer

<u>Explanation of the *area under the normal curve*</u>

4 clear

1 no answer

<u>Usefulness of examples/exercises</u>

4 useful

1 no answer

<u>Problems with exercise</u>

3 no

1 yes

1 no answer

<u>Sufficiency of answer</u>

3 sufficient

1 insufficient

1 no answer

<u>Familiarity with standard deviation</u>

5 yes

<u>Familiarity with normal curve</u>

5 yes

<u>Usefulness of explanation as a review</u>

5 yes

<u>Quality of explanations</u>

2 good

2 fair

Lesson 3

Review

5 useful

Explanation of T_E

4 clear

1 no answer

Would you have done all 3 exercises if given the choice?

3 yes

1 no

1 no answer

Number of exercises

3 the right number

2 too many

Problems with exercises

3 no

1 yes

1 no answer

Sufficiency of answers

5 no answer

Explanation of T_I

4 clear

1 confusing

Number of exercises

3 right number

2 too many

Problems with exercises

3 no

1 yes

1 no answer

Sufficiency of answer

5 no answer

Explanation of *Slack*

4 clear

1 no answer

Explanation of *critical path*

5 clear

Number of exercises (3)

3 right number

1 too many

1 no answer

Problems with exercises

3 no

1 yes

1 no answer

<u>Sufficiency of answer</u>

3 yes

1 no

1 no answer

Lesson 4

<u>Explanation of *Probability Factor*</u>

5 clear

<u>Number of exercises (1)</u>

1 the right number

3 too few

1 no answer

<u>Problems with exercises</u>

4 yes

1 no answer

<u>Sufficiency of answer</u>

2 yes

1 no

1 no answer

<u>Explanation of *activity-output slack sort chart*</u>

3 clear

1 confusing

1 no answer

Appendix F

End of Workbook Questionnaire and Results

END OF WORKBOOK QUESTIONNAIRE

Your answers to the following questions will be used to determine whether or not there will be any changes to the format and content of this workbook.

1. To what extent did you enjoy working through this workbook ?

____ very much

____ quite liked it

____ indifferent

____ rather disliked it

____ disliked it very much

2. How difficult did you find it?

____ very difficult

____ fairly difficult

____ average

____ fairly easy

____ very easy

3. Do you think that you were given enough practice in using the ideas?

____ too much

____ sufficient

____ too little

4. In view of the amount of time spent on each lesson do you feel you learned

____ a great deal.

____ as much from it as you expected

____ a reasonable amount.

____ too little.

5. How easy was it to find the information you needed

____ very easy

____ fairly easy

____ fairly difficult

____ very difficult

The following questions refer to the page design. Please place a check mark beside the comments that most closely resemble your opinion. There may be more than one response.

1. The use of definitions as page headings and titles

___ made it easy to locate such information

___ gave you a general idea of what the information was about

___ made a glossary unnecessary

___ was not useful as a glossary

2. The page format was different for explanations of concepts (margin notes and short lines) and the examples illustrating those concepts (longer lines, no notes). Did this change in format

___ help you plan out your schedule for working through the lesson

___ give you an idea of the amount of work involved in the lesson

___ reduce the monotony by providing some visual relief

___ was not particularly useful in any way

Comment:____

____

3. In the pages that contained exampies, the rationale behind the layout was to be able to present networks, charts and explanatory text on the same page. This reduces the amount of page turning you will have to do as you read the explanation. However, it does reduce the amount of white space available for your own notes. How do you feel about this?

RESULTS OF END OF WORKBOOK QUESTIONNAIRE

Your answers to the following questions will be used to determine whether or not there will be any changes to the format and content of this workbook.

1. To what extent did you enjoy working through this workbook ?

4 quite liked it

1 indifferent

2. How difficult did you find it?

3 average

1 fairly easy

3. Do you think that you were given enough practice in using the ideas?

3 sufficient

2 too little

4. In view of the amount of time spent on each lesson do you feel you learned

1 a great deal.

2 a reasonable amount.

5. How easy was it to find the information you needed

2 very easy

3 fairly easy

The following questions refer to the page design. Please place a check mark beside the comments that most closely resemble your opinion. There may be more than one response.

1. The use of definitions as page headings and titles

1 made it easy to locate such information

4 gave you a general idea of what the information was about

1 made a glossary unnecessary

2. The page format was different for explanations of concepts (margin notes and short lines) and the examples illustrating those concepts (longer lines, no notes). Did this change in format

1 help you plan out your schedule for working through the lesson

1 give you an idea of the amount of work involved in the lesson

2 reduce the monotony by providing some visual relief

2 was not particularly useful in any way

Comment: *the short lines and margin notes are useful but they are not needed in the examples or explanations. The change of format does not have any of the above effects.*

3. In the pages that contained examples, the rationale behind the layout was to be able to present networks, charts and explanatory text on the same page. This reduces the amount of page turning you will have to do as you read the explanation. However, it does reduce the amount of white space available for your own notes. How do you feel about this?

. *no problem, particularly since left hand page is blank*

. *a reasonable format*

. *comfortable with the approach*

. *good layout*

. *useful*

Appendix G

Debriefing Session Questionnaire and Results

DEBRIEFING SESSION QUESTIONNAIRE

1. Did you use the notes in the margins ?

   __ yes __ no

2. If you did use them, did you

   __ read them before you read the corresponding paragraphs

   __ read them after you read the corresponding paragraphs

   __ use them to find information as you were doing the exercises

3. If you used these notes in any other way, please comment_________

   ____

4. Whether or not you used the margin notes, would you have preferred to make your own notes in the margin?

   __ yes __ no

5. Would you have preferred to have those notes stated in the form of a question ?

   ___ yes __ no

6. Whether or not you used the margin notes, do you think they would be useful to you when using this workbook as a reference guide to develop your own PERT networks and calculations.

   __ yes __ no

7. Most of you underlined key words and phrases as you worked through the text. Would you have preferred to have these words and phrases in bold lettering or to underline them yourself?

   __ bold lettering __ underline them myself

8. When calculating the various values that appear on the networks, would you have preferred larger networks and no chart as opposed to the existing format? this would mean that the networks would appear horizontally on the page and you would have to turn the book around for each exercise.

__ yes __ no

9. In all of the exercises the answers appeared either at the bottom of the page or on the following page. Would you have preferred to have the answers at the back of the book ?

___ yes __ no

RESULTS OF DEBRIEFING SESSION QUESTIONNAIRE

1. Did you use the notes in the margins ?

   4 yes 1 no

2. If you did use them, did you

   4 read them before you read the corresponding paragraphs

   1 use them to find information as you were doing the exercises

3. If you used these notes in any other way, please comment.

   As a review and as a checklist

4. Whether or not you used the margin notes, would you have preferred to make your own notes in the margin?

   1 yes 4 no

5. Would you have preferred to have those notes stated in the form of a question ?

   1 yes 4 no

6. Whether or not you used the margin notes, do you think they would be useful to you when using this workbook as a reference guide to develop your own PERT networks and calculations.

   4 yes 1 no

7. Most of you underlined key words and phrases as you worked through the text. Would you have preferred to have these words and phrases in bold lettering or to underline them yourself?

   1 bold lettering 4 underline them myself

8. When calculating the various values that appear on the networks, would you have preferred larger networks and no chart as opposed to the existing format? this would mean that the networks would appear horizontally on the page and you would have to turn the book around for each exercise.

   1 yes 4 no

9. In all of the exercises the answers appeared either at the bottom of the page or on the following page. Would you have preferred to have the answers at the back of the book ?

   2 yes 3 no

Appendix H

Production Time and Costs

Production Time and Costs

The text of the initial workbook was prepared on an IBM Displaywriter. Due to a printer breakdown it was decided to convert the diskette to WordPerfect 5.1. It was then converted to Pagemaker 4.0 which permitted the use of Micrografx to construct and improve the networks. This gave the document a more professional appearance. An outsider had to be engaged to do the work in Pagemaker and Micrografx. This additional cost is represented under the heading of Desk Top Publishing and would not have been incurred had the developer been familiar with the software and had used it at the outset.

Time

Researching and writing draft 1	40 days
Constructing Questionnaires and Post-Test	7 days
Expert Review (2)	20 days
Small Group Field Test	21 days
Data Analysis	2 days
Revisions	3 days
Desk Top Publishing	12 days
TOTAL	105 days

Cost

Direct Costs: $1,230

Paper	10.00
Photocopying and Binding	220.00
Desk Top Publishing	1000.00

Indirect Costs: $5,000

Developer's time including supervision of desk top publishing (60 days) assuming a yearly salary of $30,000.