COMPARISON OF CRITICAL CHAIN AND CRITICAL PATH METHODOLOGIES IN CONSTRUCTION MANAGEMENT

by

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ABSTRACT

COMPARISON OF CRITICAL CHAIN AND CRITICAL PATH METHODOLOGIES IN CONSTRUCTION MANAGEMENT

According to Peter Drucker, the fundamental task of management is, to make people capable of joint performance through common goals, common values, the right structure, and the training and development they need to perform and respond to change.

The important issue in this description is to respond to change. As Construction sector become more competitive, the need for improvement embraces every aspect of business. Traditionally, construction had low barriers to entry and cash positive. Change is inevitable and provides extraordinary opportunity. It is being driven by demands from clients, markets and the share holders for greater predictability in project performance in all respects- time, quality and cost. Winners will be the ones able to manage the risk and uncertainity. Although the stakeholders require predictability in time, quality and cost, Projects are late, over budget and mostly change is scope. According to a study by Standish Group, 30 per cent of IT projects cancelled before finished, 75 per cent of completed projects are late, average cost overruns are 189 per cent and average time overruns are 222 percent, and according to a study by USA Ministry of Energy in the last 20 years, 31 of 80 projects was cancelled after spending US$10 billion, 50 per cent of them have time delays, 28 per cent of them cost overruns. In order to overcome these consequences, new methodologies or system thinking has to be adapted to how we manage projects.

This thesis study tries to identify the benefits from an improvement methodology called "Critical Chain" developed through the " Theory of Constraints" by comparing with the former Critical Path Methodology. Theory of Constraints, developed by Dr. Eliyahu Goldratt, uses methodologies to identify and focus specific resources, which restrict organization's ability to improve, which are called "constraints".

ÖZET

İNŞAAT YÖNETİMİNDE KRİTİK ZİNCİR VE KRİTİK YOL METODOLOJİLERİNİN KARŞILAŞTIRILMASI

Peter Drucker'a göre, yönetimin temel görevi, ortak hedeflerle, ortak değerlerle, doğru bir yapı ile ve gerçekleştirmeleri gereken eğitim ve gelişmelerle ile, insanları birlikte hareket etmelerini sağlamak ve değişime cevap verecek hale getirmektir.

Yönetimin bu tanımında en önemli konu değişime cevap verebilmektir. İnşaat sektörü daha fazla rekabetçi olmakta ve her konuda gelişme ihtiyacını ortaya koymaktadır. Geleneksel olarak, İnşaat sektörü giriş için az engele sahiptir ve nakit olarak artıdadır. Değişim kaçınılmaz olup, önemli imkanlar yaratmaktadır. Müşteriler tarafından, proje performansının her konusunda zaman, kalite ve maliyet olarak daha fazla tahmin edilebilirlik talep edilmektedir. Aynı şekilde piyasalar ve ortaklar daha fazla tahmin edilebilirlik talep etmektedirler. Kazananlar risk ve belirsizliği daha iyi yönetenler olacaktır. Proje ortakları zaman, kalite ve süre belirliği talep etselerde, projeler gecikir, bütçelerini aşar ve genellikle kapsamları değişir. Standish Group tarafından yapılan bir çalışmaya göre IT projelerinin yüzde 30'u tamamlanmadan iptal edilmiş, yüzde 75'i geç tamamlanmış, ve ortalama maliyet aşımı yüzde 189 ve zaman aşamı yüzde 222 olmuştur. Amerikan Enerji Bakanlığı tarafından yapılan bir çalışmaya göre son 20 yılda 80 projenin 31'i 10 Milyar US$ harcandıktan sonra iptal edilmiş, projelerin yüzde 50'sinde zaman gecikmesi ve yüzde 28'inde maliyet artışı olmuştur. Projeleri nasıl yönettiğimiz konusunda yeni metodolojiler ve sistem düşüncelerini uygulamaya koymalıyız.

Bu tez çalışması, "Kısıtlar Teorisi"nin "Kritik Zincir" ve "Kritik Yol" Metodolojilerini karşılaştırarak, avantajlarını ortaya koymaya çalışmaktadır. Dr. E. Goldratt tarafından geliştirilen "Kısıtlar Teorisi", organizasyonun ileri gitmesini engelleyen ve "Kısıt" olarak adladırılan bazı kaynakları ortaya çıkarıp, bunlara yoğunlaşmaktadır.

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LIST OF SYMBOLS AND ABBREVIATIONS

AACE	American Association of Cost Engineers
ADM	Arrow diagramming method
CC	Critical Chain
CCPM	Critical Chain Project Management
CPM	Critical Path Method
IPMA	International Project Management Association
EVM	Earned value management
PERT	Program Evaluation and Research Technique
PDM	Precedence diagramming method
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institution
ROI	Return on Investment
TOC	Theory of Constraints
TQM	Total Quality Management
WBS	Work Breakdown Structure

1. INTRODUCTION

1.1. Construction Projects

Project can be defined in terms of its distinctive characteristics, a temporary endeavor undertaken to create a unique product or a service [1]. Construction Projects are a group of special unrepetitive activities, which has to be completed with specific resources within a specified time. Construction requires specific engineering applications and it is a contract or a work schedule, with a subject of structures like building, highway, bridge, dam, harbor, power plant, petrochemical plant or steel construction etc., aiming to satisfy the demand or a specific consumer or a user. This definition defines the construction as a process. We can also define construction as a result. Construction can be defined as products, which are built over an area by using material, manpower and equipment. In developing countries, construction industry is an important factor of progress and technology. We cannot think a life style or a part of life without dependence on construction. Management of construction projects are specific events, as each of them is a unique set of coordinated activities, undertaken by an individual or an organization within a defined schedule, cost and performance parameters [2].

1.1.1. Specifications of Construction Projects

Construction projects can cover anything from a 2-day engineering effort to resolve a minor technical problem to a present-day super project such as GAP project. Cost engineering has application regardless of project size. The principles of cost engineering as the same regardless of industry and size and can be applied to most situations [3].

Construction project has a defined aim like building a specified size of specific plant in a specific area. It has a defined start and a finish time [2]. It has a concrete finish time when the target, which is aimed, is achieved. Generally construction project is unique and unrepetetive. It is a set of activities, which requires time and monetarial resources, to establish a specific product. These construction activities can be parallel or successive.

It requires a different organizational structure and different functional requirements. It is dependant on land or an area. It is constructed to stay on the same area for the lifetime. It is heavy and has a big volume and it is complex. It requires an extensive effort. It is expensive and has a long life.

There is a multitude of reasons that a corporation or a company decides to build a project. The decision could be the result of a favorable analysis of the marketing situation that shows future increased product demand or the research department may develop new products with high sale potential, or new government or social requirements may dictate the need for new facilities, especially in the area of environmental protection. Regardless of which of the above-mentioned reasons for building a project apply, the ultimate reason in virtually every case is economic.

The main aim is to make the maximum return that can be made for the money invested. In making this extremely important decision, management asks and needs the answer to many questions. How many products should I make? Where should the plant be built? How competitive will a new product be? If diversification is desirable, where and what?

To answer most of these questions raised requires economic studies. Economic studies cannot be made without investments, which in turn requires an estimate and that in turn requires a Cost Engineer [3].

Not only is the Cost Engineer needed during the very early evaluation stage, but also similar management type decisions must be made throughout the life if a project. We need cost control during all phases of the projects and we have the need for cost control services throughout a project life cycle in order to achieve favorable results. Essential part of any project is estimating or predicting what something will cost and then controlling the cost of doing that something within the limits of the estimate.

Estimate is a prediction of manner in which project will be executed. The estimate basis should reflect a plan of how the project people feel or predict the job will be done.

In case of a design, a flow plan and equipment list is made which predicts the final design will look like when completed. The estimator develops a plan and a schedule, which translates the flow plan and equipment list into cost values and purchase dates and costs by by applying unit costs to the material quantities.

1.1.2. Stages of Construction Projects

Construction projects can be divided into 4 phases; Evaluation and Planning, Conceptual Engineering, Detailed Engineering and Construction [3]. The stages are successive but they can be intersecting. In Figure 1.1 historical project phases, types of estimate at every phase and time period are shown.

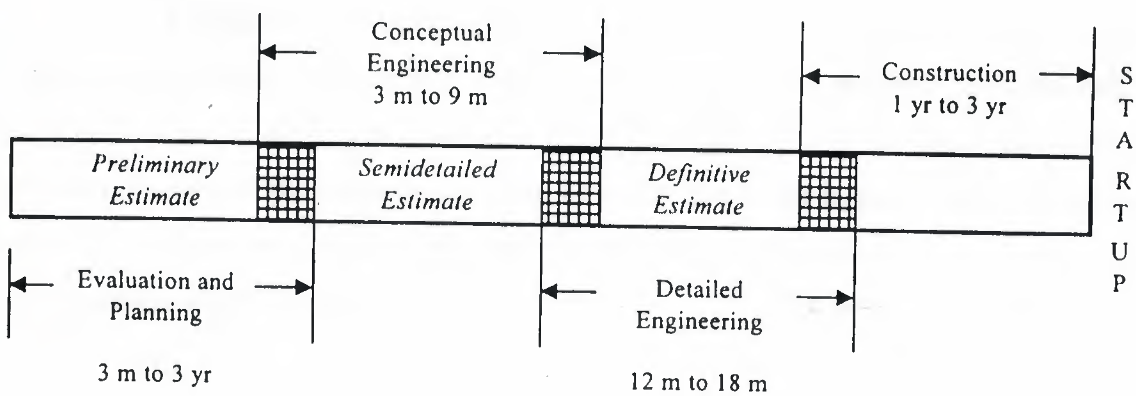


Figure 1.1. Historical project phases [3]

Evaluation and Planning phase covers the period from inception until a decision is made on a definitive plan of execution. What will be built where and why. Generally this phase lasts 3 months to 3 years. But there are projects having an evaluation period of weeks or a project evaluation, which lasts years, like to build a tunnel under the Bosphorus Straight - İstanbul. In this phase, as the scope of project is not clear yet, a preliminary estimate is made to see the general picture of the work. Main evaluation of delta costs of possible alternatives are carried out in order to select the most feasible solution of the project.

In this phase, screening, early planning and economics activities, market evaluations and political and geographical considerations are made for the project. The comparative advantages of alternatives of the investment are focused.

The second stage of a project is Conceptual Engineering phase. In this stage, rather than the core generalized approach during the prior Evaluation phase, the project management team is involved in the project and they turn their attention to the specific basis for the selected route.

Conceptual Engineering stage lasts 3 to 9 months. In this stage design basis is set, major decisions is taken and economic evaluation of the project is completed and minimum costs are set. A semi detailed estimate is done in this stage.

Detailed Engineering stages lasts 12 to 18 months. In this stage, equipment's are defined and purchased. Construction drawings are prepared and approved. As in this stage the general scope of the project is defined, definitive economic studies can be made and a definitive estimate of the cost of project can be made. The single largest potential variation in an early estimate basis is the design basis itself. Freezing the design basis consequently has a dramatic effect on estimate accuracy.

1.2. Project Management

Project Management is the planning, organization, monitoring and control of all aspects of a project and the motivation of all involved to achieve the project objectives safely and within the agreed time, cost and performance criteria. It contains the total amount of tasks, organization, technique and measures for the performance of a project [1].

Project Management is also the application of knowledge, skills, tools and techniques to project activities to meet project requirements through the use of processes such as: initiating, planning, executing, controlling and closing. The main type of work is identifying requirements of stakeholders with differing needs and expectations in order to compete the demands for scope, time, cost, risk and quality [1].

Project Management Body of Knowledge (PMBOK) developed by Project Management Institute organized project management knowledge and practice in terms of their component processes into nine knowledge areas which are areas Project Integration Management, Project Scope Management, Project Time Management, Project Cost Management, Project Quality Management, Project Human Resources Management, Project Communications Management, Project Risk Management and Project Procurement Management [1].

In this study Project Time Management and Project Cost Management is explained in detail of inputs, tools and techniques and outputs as to compare them with the current applications of Critical Chain Methodology in order to focus on the advantages.

1.3. Project Time Management

Project Time Management includes the processes required ensuring timely completion and control of the project [1]. Major processes in developing the project time schedule are:

- Activity Definition,
- Activity Sequencing,
- Activity Duration Estimating,
- Schedule Development,
- Schedule Control.

Each process may involve effort from one or more individuals or groups of individuals, based on the needs of the project. Each process generally occurs at least once in every project phase. On some projects, especially smaller ones, activity sequencing, activity duration estimating and schedule development are so tightly linked that they are viewed as single process. Schedule control and schedule development is also an important part of this process. After all the activities are defined and sequenced, their probable durations are estimated and the schedule of the project is developed.

1.3.1. Activity Definition

Activity definition involves identifying and documenting the specific activities that must be performed to produce the deliverables and sub deliverables identified in the Work Breakdown Structure (WBS). Implicit in these processes in the need to define the activities such that the project objectives will be met. Objectives should be defined clearly.

- Inputs to Activity Definition are:
  - Work breakdown structure,
  - Scope statement,
  - Historical information,
  - Constraints,
  - Assumptions,
  - Expert judgment.
- Tools and Techniques for Activity Definition:
  - Decomposition,
  - Templates.
- Outputs from Activity Definition:
  - Activity list,
  - Supporting detail,
  - Work breakdown structure updates.

1.3.2. Activity Sequencing

Activity sequencing involves identifying and documenting interactivity logical relationships. Activities must be sequenced accurately to support later development of a realistic and achievable schedule. Sequencing can be performed with the aid of a computer by using project management software or with manual techniques.

- Inputs to Activity Sequencing:
  - Activity list,
  - Product description,

- Mandatory dependencies,
- Discretionary dependencies,
- External dependencies,
- Milestones.

- Tools and Techniques for Activity Sequencing:
  - Precedence diagramming method (PDM),
  - Arrow diagramming method (ADM),
  - Conditional diagramming methods,
  - Network templates.
- Outputs from Activity Sequencing:
  - Project network diagrams,
  - Activity list updates.

1.3.3. Activity Duration Estimation

Activity duration estimating is the process of taking information on project scope and resources and then developing durations for input to schedules.

The inputs for the estimates of duration originate from the person or group on the project team who is most familiar with the nature of a specific activity. The estimate is often progressively elaborated and the process considers the quality and availability of the input data. The person on the project team who is most familiar with the nature of a specific activity should make or at least approve the estimate. Estimating the number of work periods required to complete an activity would often require consideration of elapsed time as well.

- Inputs to Activity Duration Estimating:
  - Activity list,
  - Constraints,
  - Assumptions,
  - Resource requirements and Resource capabilities,
  - Historical information,

  - Identified risks.
- Tools and Techniques for Activity Duration Estimating:
  - Expert judgment,
  - Analogous estimating,
  - Quantitatively based durations,
  - Reserve time and contingency.
- Outputs from Activity Duration Estimating:
  - Activity duration estimates,
  - Basis of estimates,
  - Activity list updates.

1.3.4. Schedule Development

Schedule development means determining start and finish dates for project activities. If the start and finish dates are not realistic, then the project is unlikely to be finished as scheduled. The schedule development process must often be iterated (along with the process that provides inputs, especially duration estimating and cost estimating) prior to determination of the project schedule.

- Inputs to Schedule Development:
  - Project network diagrams,
  - Activity duration estimates,
  - Resource requirements and Resource pool description,
  - Calendars,
  - Constraints,
  - Assumptions,
  - Leads and lags,
  - Risk management plan,
  - Activity attributes.
- Tools and Techniques for Schedule Development:
  - Mathematical analysis,
  - Duration compression,

  - Simulation,
  - Resource leveling heuristics,
  - Project management software,
  - Coding structure.
- Outputs from Schedule Development:
  - Project schedule,
  - Supporting detail,
  - Schedule management plan,
  - Resource requirement updates.

1.3.5. Schedule Control

Schedule control is concerned with influencing the factors that create schedule changes to ensure that changes are agreed upon and determining that the schedule has changed and managing the actual changes when and as they occur. Also necessary corrective actions are taken in order to overcome delays because of change requests.

- Inputs to Schedule Control:
  - Project schedule,
  - Performance reports,
  - Change request,
  - Schedule management plan.
- Tools and techniques for Schedule Control:
  - Schedule change control system,
  - Performance measurements,
  - Additional planning,
  - Project management software,
  - Variance analysis.
- Outputs from Schedule Control:
  - Schedule updates,
  - Corrective action,
  - Lessons learned.

1.4. Project Cost Management

Project Cost Management includes the processes required to ensure that the project is completed within the approved budget [1]. Major processes are;

- Resource Planning,
- Cost Estimating,
- Cost Budgeting,
- Cost Control.

Each process may involve effort from one or more individuals or groups of individuals, based on the needs of the project. Each process generally occurs at least once in every project phase.

Project cost management is primarily concerned with the cost of the resources needed to complete project activities. However, project cost management should also consider the effect of project decisions on the cost of using the project's product.

In many application areas, predicting and analyzing the prospective financial performance of the project's product is done outside the project. In other projects like capital facilities projects, project cost management also includes this work. When such predictions and analyses are included, project cost management will include additional processes and numerous general management techniques such as return on investment, discounted cash flow, payback analysis and others. When project costs are used as a component of a reward and recognition system, controllable and uncontrollable costs should be estimated and budgeted separately to ensure that rewards reflect actual performance. On some projects, especially smaller ones, resource planning, cost estimating and cost budgeting are so tightly linked that they are viewed as single process.

1.4.1. Resource Planning

Resource planning involves determining what physical resources and what quantities of each should be used and when they would be needed to perform project activities.

- Inputs to Resource Planning:
  - Work breakdown structure,
  - Historical information,
  - Scope statement,
  - Resource pool description,
  - Organizational policies,
  - Activity duration estimates.
- Tools and Techniques for Resource Planning:
  - Expert judgment,
  - Alternatives identification,
  - Project management software.
- Outputs from Resource Planning:
  - Resource requirements.

1.4.2. Cost Estimating

Cost estimating involves developing an approximation, estimate, of the costs of the resources needed to complete project activities. In approximating cost, the estimator considers the causes of variation of the final estimate for purposes of better managing project.

- Inputs to Cost Estimating:
  - Work breakdown structure,
  - Resource requirements,
  - Resource rates,
  - Activity duration estimates,
  - Estimating publications,
  - Historical information,
  - Chart of accounts,
  - Risks.
- Tools and Techniques for Cost Estimating:
  - Analogous estimating,

- Parametric modeling,
- Bottom-up estimating,
- Computerized tools,
- Other cost estimate methods.

- Outputs from Cost Estimating:
  - Cost estimates,
  - Supporting detail,
  - Cost management plan.

1.4.3. Cost Budgeting

Cost budgeting involves allocating the overall cost estimates to individual activities or work packages to establish a cost baseline for measuring project performance. Normally estimates are done after budgetary approval is provided. In order to get more feasible results, estimates should be done prior to budget request wherever possible.

- Inputs to Cost Budgeting:
  - Cost estimates,
  - Work breakdown structure,
  - Project schedule,
  - Risk management plan.
- Tools and Techniques for Cost Budgeting:
  - Cost budgeting tools and techniques.
- Outputs from Cost Budgeting:
  - Cost baseline.

1.4.4. Cost Control

Cost control is concerned with influencing the factors that create changes to the cost baseline ensure that changes are agreed upon and determining that the cost baseline has changed and managing the actual changes when they occur at every stage of the project.

Cost control includes monitoring cost performance to detect and understand variances from plan and ensuring that all appropriate changes are recorded accurately in the cost baseline and preventing unauthorized changes from being included in the cost baseline. Cost control is used for informing appropriate stakeholders of authorized changes and acting to bring expected costs within acceptable limits.

- Inputs to Cost Control:
  - Cost baseline,
  - Performance report,
  - Change requests,
  - Cost management plan.
- Tools and Techniques for Cost Control:
  - Cost change control system,
  - Performance measurement,
  - Earned value management (EVM),
  - Additional planning,
  - Computerized tools.
- Outputs from Cost Control:
  - Revised cost estimates,
  - Budget updates,
  - Corrective action,
  - Estimate at completion,
  - Project closeout,
  - Lessons learned.

1.5. Definition and Role of Cost Engineer

Cost Engineering is that area of engineering judgment and experiences are utilized in the application of scientific principles and techniques to the problems of cost estimation, cost control and profitability [3]. This definition clearly emphasizes that cost estimating and cost control are areas of engineering practices using scientific principles and techniques and requires a strong engineering background.

The cost engineer should be involved in all phases of a project life cycle, from initial planning and evaluation to the startup of the plant after construction. Cost Engineer plays an important role in each of the four phases of a project. Generally the earlier he is brought into the picture the more effective he can be. Although the first stage, Planning and Evaluation stage can often be the most critical stage, little or no Cost Engineering assistance is sought by or made available to management.

During the Evaluation Phase, the Cost Engineer provides the cost estimates needed in the economic evaluations of a number of different areas. He makes different case studies reflecting alternate processes or alternate product yields. He studies on cost changes due to choosing different geographic locations. He evaluates sketch of a new process being developed, making coordinated studies by research or work development departments. In this stage, cost is the most important factor but very little time or effort was spent establishing the basis for a total cost picture and delta costs are evaluated in order to select the most economical case.

In this stage highly critical decisions are made. Once the project is approved, future decisions can only involve a portion of the project; but at the early evaluation stage, a "make-or-break" decision is made on the total project value. But in this stage the information, which is available to the Cost Engineer, is very less and unreliable. It is very difficult to extract the necessary information to improve the accuracy of the estimate. After a decision is made to proceed, the project moves to the next phase, which is establishing a firm design basis for the selected route.

The Basic-Design phase is the stage in project development at which the project and management persons are involved in the project and they turn their attention to the specific basis for the selected route. In this phase the process or basic-design is firmed. The physical layout of the facilities involved is given consideration.

The need for support facilities like utilities and off-plot items such as storage, roads is reviewed. Cost Engineer gives more serious thought to timing and he discusses project execution strategy with the project management team.

As because most areas are not finalized, during this phase Cost Engineer must do a considerable amount of predicting to visualize what the final detailed design will look like. He must be designer of all sorts. He needs to develop a time schedule for the project and therefore has to be a scheduler. He needs to gather and analyze historical cost data, therefore has to be a data analyst. He must establish cost for different geographic locations and countries and predict escalation rates. He must predict contract strategy to estimate the kind of contract and under what conditions, so a contracts engineer. But most of important of all, to do all of the above he needs data from and the cooperation of many people involved in the project.

The next phase of project life cycle after the basic design is completed is detailed engineering. In this phase the owner select the contractor to execute the project. This phase is very important and crucial for the owner because, for the first time, he will be giving some of the controls of the job to another party. The owner reviews the qualifications of the various contractors who have been requested to bid on the project in order to select the contractor who is capable of exercising good job control.

Cost Engineer also evaluates the alternatives given by the contractor. He also evaluates the offer according to the type of contract. For example if the contract is reimbursable type, the Cost Engineer also assists the bid evaluation team in analyzing the commercial terms submitted by the Contractor. He prepares the definitive control estimate. Cost Engineer involves full-time with the project during the detailed project execution phase, which is after the award of the contract. During this Construction phase the hardware that was designed and procured during the detailed engineering phase is installed by the contractor. The Cost Engineer continues to appraise the contractor's cost control efforts, monitor changes and reviews extras. His forecasts of labor man-hour requirements are an essential ingredient for the project schedule and have an impact on the prediction of both final costs and final completion date. Cost Engineers are depended on to provide accurate and timely estimates of the current costs of the project and to provide cost alternatives and cost savings recommendations. As a result of the need for greater control and management of resource utilization Life cycle project management has emerged as the key methodology.

As a result, there is a pressure to identify all the costs associated as early as possible; this is necessary to remain on schedule, to tie down project requirements as much as possible at the budgetary phase and to identify causes for the cost increases as they occur.

1.6. Project Cost and Time Estimation

Cost and Time Estimation is one of the main duties of Cost Engineer. As mentioned earlier Estimate is a prediction of the manner in which a project will be executed and a very important concept in Cost Engineering. First, we discuss the accuracy of an estimate [3].

1.6.1. Accuracy of an Estimate

Relationship between estimate accuracy and the time of the project when the estimate is made is an essential consideration in developing the good estimate. Figure 1.2. is a graphical illustration of this relationship. Accuracy is plotted on the ordinate and expresses the probability of an overrun in the estimate. On the abscissa a time scale is plotted, splitting the time of the development of project phases. The curve expressing the relationship between the two variables indicate almost 100 per cent accuracy for an estimate made near the completion of a project, an expected result.

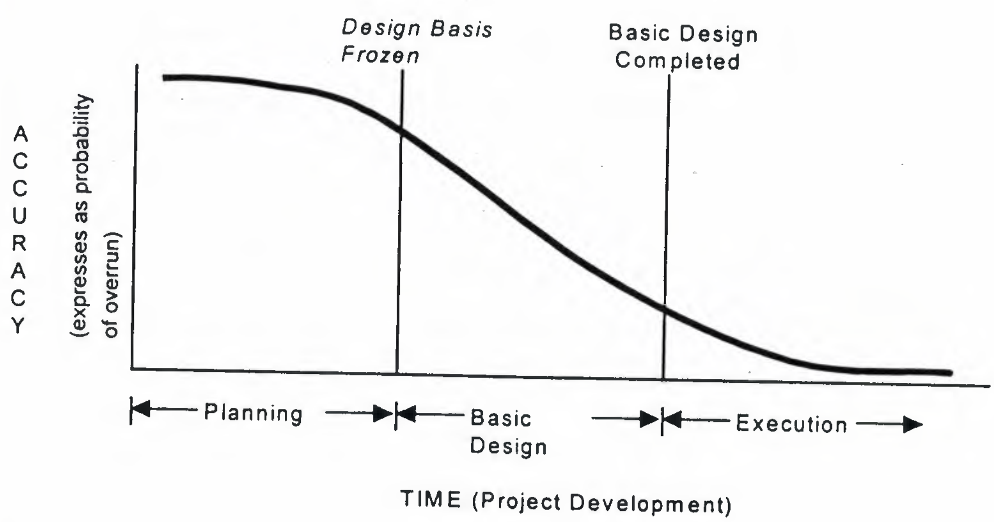


Figure 1.2. Accuracy of an estimate versus time

Two important conclusions can be drawn from this figure. First is; the rather lengthy and vague time of planning is an inaccurate period, on average, for making an estimate. Consequently, not only is the probability of overrun great but the degree or the magnitude of the overrun is difficult to predict and the second is; There is a dramatic change in slope at the moment the design basis is selected and frozen, and a very significant increase in accuracy occurs during the relatively short period of time when the basic design is being put together.

For an accurate estimate the ingredients, which the estimator must have if he is to have any measure of success are; a sound "frozen" basis, a realistic execution plan of the project, proper timing of each activity, good estimating methods and data of each project item , neatly recorded and documented, balanced detail of project and a good and experienced estimator.

These factors affect the accuracy of an estimate and all of them must be reliable, but the most critical item affecting estimator accuracy is the estimate basis. During the early stages of a project when estimate accuracy is poorest, the effort needs to be directed toward establishing a firmer basis rather than concentrating on utilizing more detailed estimating method. Knowing the accuracy of an estimate is of extreme importance to management and the project people involved.

Some of the reasons for are sensitivity to economics, cash flow and budgeting, determines the estimating method and the approach to be used, feedback which improves method development, and develops confidence and management support. If we can develop an approach that allows us to determine in advance what kind of accuracy we can expect from a specific estimate made at a certain time in project development, we can test the sensitivity of the investment level predicted by the estimate to potential variation and determine the impact on the calculated economics of the project.

Perhaps the most important reason that knowing the accuracy of an estimate is so critical is the impact this knowledge has on company management and company policy.

1.6.2. Types of Estimates

Construction projects are becoming larger in scale and competition is keen worldwide. Many factors have to be considered carefully as to their effect on the estimate. Some important ones of them are; technological advances, inflation forecasts, potential price controls, and new environmental regulations on safety and pollution and social concerns. The American Association of Cost Engineers defines three types of estimates; order of magnitude, budget, and definitive.

1.6.2.1. Order of Magnitude Estimate. Order of Magnitude Estimates have an expected accuracy within +50 and -30 per cent. They are generally based on cost capacity curves and cost capacity ratios, and do not require any preliminary design work. The principal reasons of this type of estimate are feasibility designs, selection from among alternative designs and alternative investments, and budgeting or construction forecasting. After this screening estimate whether to go or no-go decisions or which way to go for a particular project is decided. The primary concern is with the rough delta costs between to or more alternative cases. Management usually requires this information in order to select the proper route for the next step in developing the project. Regardless, in either case, the emphasis is not on detailed sufficient accuracy to insure that the results are meaningful and above all, not misleading. To accomplish this, three different approaches can be used to prepare an order of magnitude estimate.

- Gross (overall) proration,
- Curves,
- Rough semi detailed.

The most commonly used approach is gross proration. Curves and the semi detailed approach are more commonly associated with budget estimates. Prorations need historical data on similar plant or process, projects must be near duplicate, should be reasonably close in size, portion slope are critical, adjustments must be made for off-sites and utilities, must be escalated and adjusted for location. The advantages of order of magnitute estimate are being quick and all inclusive, but the disadvantage of are high degree of variation.

1.6.2.2. Budget Estimate. Budget Estimates are based on flow sheets, layouts and preliminary equipment description and specifications and have an accuracy range of +30 to -15 per cent. Design generally must be 5 to 20 per cent complete to permit such an estimate to be performed. The principal reasons of this type of estimate are budgeting or construction forecasting, authorization funds. The total budget of the project can be reached with this type of estimate. Budget estimates are normally prepared after the owner has completed his planning work, has screened out options via economics and is now in a position where normally he will require management approval to proceed.

To do this, he needs budgetary information to give management can allocate or budget money in the future for this purpose. To take advantage of this increased accuracy afforded by the frozen basis, there are commonly used estimating methods for preparing a budget estimate.

- Curve,
- Semi detailed,
- Factored.

All three methods are used with equal frequency throughout the industry. Curve is plotted from past historical data. Curve estimates predict the execution of the project. Consequently, when the estimator picks a point on the curve for his project, that point in reality represents a certain amount and type of physical hardware, consistent with the average of what is in the design of the plants that make up the curve.

This concept becomes important in the cost control approach to be used during conceptual design. As long as one has some idea of the details of the estimate prediction, one can compare what is actually happening against what was predicted.

Curve Estimates need significant historical data and can be sophisticated and accurate. Advantages are being quick and reasonable accuracy and all inclusive. Disadvantages are some variations, no details available and more on construction project site oriented.

1.6.2.3. Definitive Estimate. Definitive Estimates require defined engineering data, such as site data, specifications, basic drawings, detailed sketches, and equipment quotations. Design is generally 20 to 100 per cent complete and estimate accuracy should be within +15 to -5 per cent. The principal reasons of this type are authorization of full funds; check of an authorized project and presentation of bids. This type of estimate is the most accurate and the one requires the greatest effort to prepare. Whereas the other types of estimates can be completed in a matter of hours or days by one estimator, Definitive estimates require months to complete and, can require an considerable effort of technical man-hours and costs.

There are basically two kinds of definitive estimates. One utilizes the conceptual or averaging approach, is often referred to as an " in-house " estimate, and is used mainly by owner organizations. In this approach, estimating methods are developed from past historical data and an averaging concept is applied. It is more or less an extension of the factored estimating approach, except in greater detail.

The second type of definitive estimate is much more detailed in its approach and is used mainly by contractor organizations. Here, each item for specific project is developed engineering-wise to sufficient detail to allow a customized estimate to be made of that item. Vendors' preliminary estimate or quotations for individual equipment items are widely used. Preliminary take-off are made of piping, etc., from early detailed-engineering drawings, and there take-offs are priced up to form the estimate. Whereas the conceptual approach requires a very significant effort in the data gathering and method development areas beforehand, the detailed approach requires a large effort during the preparation of the estimate itself. The in-house approach has the advantages of requiring considerably less time and effort to prepare and is more suitable for cost control. The disadvantages lie in the fact that a major data-gathering and method development effort is needed.

Also, the end result is somewhat less accurate than the detailed approach; averaging versus specific data. The detailed approach used by a contractor is more accurate but has the disadvantages of being costly to prepare and often being available too late for early cost control on the project.

1.7. Project Cost Control

In preconstruction and construction phase of project, the project manager has the following three basic responsibilities; quality, schedule and cost control. These three responsibilities are of equal importance and to some degree interdependent. For example, quality can usually be improved with expenditure of additional money and, on most projects; schedule can be improved if one is willing to pay premiums to equipment vendors and overtime to construction workers. It is project manager's job to see that equilibrium is maintained between quality, schedule and cost [3]. Forecasting cost trouble spots before funds are committed and determining corrective action to minimize these expenditures are the Cost Engineer's job. Cost Control is spotting trouble spots and taking action.

1.7.1. Objectives of a Cost Control Program

A project cost control program has the following four objectives:

- To focus management attention on potential cost trouble spots in time for corrective or cost minimizing action to be taken by detecting potential budget overruns before rather than after they occur.
- To keep each project supervisor informed of the budget for his own area of responsibility and how his expenditure performance compares to that budget.
- To create a cost-conscious atmosphere so that all persons working on a project will be cost conscious and aware of how their activities impact on the project cost.
- To minimize project costs by looking at all activities with cost reduction view.

1.7.2. Elements of a Cost Control System

For any construction project, the elements of a good cost control system comprise of:

- A planned approach to the project in order to realize maximum economy, all activities must be carefully planned as to timing and method of execution.

- A realistic financial yardstick by preparing a controlled budget estimate.
- Accurate and timely cost forecasts by covering the costs to completion.
- Comparison of forecasts to the yardstick: preparing a detailed item-by-item comparison of forecasted costs with the budget.
- Positive action to minimize forecasted budget overruns, which is the essential in gradient of the cost control.

1.8. Project Task Duration Estimating

A project schedule is the result of the aggregation of all of the task durations. If the durations lack validity, so does the project schedule. Fidelity in task duration estimating is essential to the development of a wholesome project schedule. And such fidelity can only be achieved via a structured and consistent approach toward establishing task durations. Steps in task duration estimation as discussed by Harvey Levine [4] are:

First, we come up with a "most likely" estimate of the duration. This is the time that we feel that it would take about 50 per cent of the times that we were to execute the task. But, we're not comfortable with a 50 per cent confidence factor. So we add some time that we feel that we could support about 90 per cent of the time. Then we think about what we will need to start the task, including what kinds of conditions are required. If we are concerned that we will not have everything that we need to start the task, we add some more time to the task estimate.

Then there is the "collection factor". When a group of tasks come together, we tend to add some more safety margin, to allow for one of the tasks to slip. Similarly, we note that there is a tendency to "lose time" between tasks. Two tasks, each estimated at X days and Y days respectively, performed in series, will take (X+Y+Safety duration) days because we lose safety duration days between the completion of the first task and the start of the second task.

Finally, everyone knows that the total duration will not be accepted. They expect to be pushed for a 20 per cent reduction, so they add 25 per cent to the inflated estimate.

Furthermore, even the estimate of the actual task duration can take several paths. For instance, here are several approaches to estimating task durations:

- Elapsed time versus working time - We feel that it will take five days to actually perform the work. But we know that we will not be working on the task without interruption. So we set the task duration at ten days, to allow for the elapsed time that we expect to occur.
- Ask time versus resource time - We estimate that the task will take 80 hours to perform. Is this 80 hours by two people, producing an elapsed time of five days? Or is it 80 hours for one person, working half time, producing an elapsed time of 20 days?
- Interface losses and delays - We noted above that we could expect some loss of time between tasks and when multiple tasks converge. We incorporate these expected losses into the tasks themselves, or set up dummy tasks to allow for these delays.
- Theoretical duration versus experience - Each time that we estimate how long it should take, we come up with 20 days. So we know that we can do it in 20 days. But, each time that we perform the task, it takes about 50 per cent longer than the 20 days. Each time the reason for the delay is different. The task should be completed in 20 days and this is what we should use as a target. But, if our experience tells us to expect 30 days, aren't we deceiving the team by saying that we expect it to be done in 20 days? And, when we use the 30-day estimate, will we end up taking the 30 days, because that is the time available.
- Skill levels, learning curves and priorities – In order to handle potential performance modifiers, we add time to the duration estimate because we expect that there will be additional time and effort to do the task the first time which is called learning curve.
- PERT method - This technique provides for a quantitative method of considering uncertainty or risk. It calls for the use of three time estimates for each task. These are called optimistic, most likely and pessimistic. The most likely duration is the duration that can be expected 50 per cent of the time. The optimistic duration is the shortest reasonable duration, attainable about 10 per cent of the time. The pessimistic duration is the longest reasonable duration, also with a probability of 10 per cent.

- In the PERT method, a PERT duration is calculated, usually based on the formula: (a + 4b + c) / 6, where "b" is the most likely. Although it may appear that the PERT method takes a great deal of additional effort, the reverse is really true. In reality, we tend to go through the process of thinking of the possible range of estimates, based on perceived risk and uncertainty. But then, after mentally deriving a single duration, we fail to capture the information that went into the estimate.
- Delphi Method - This decision-aiding technique is rarely employed in determining task durations, but could be applied if desired. It calls for each member of the team to offer their own estimate to the group. Estimates at the extremes (shortest/longest) are defended by the estimator, which often introduces issues that were not considered by the others. Based on the new information, the team votes again (re-estimates). The process is repeated until there is a reasonable consensus and comfort with the task duration.

There is a self-fulfilling prophecy regarding performance of tasks within planned durations. A task is hardly ever completed ahead of schedule. There are several reasons for this. We can demonstrate these using an illustration of a task that has a 50-50 chance of being completed in five days, but has been scheduled for ten days to allow for uncertainty, risk, emergency diversions, etc.

First, there is Parkinson's Law: "Work expands to fill the time available for the work". Work on the task has commenced on schedule and is essentially completed within the first five days. But, because ten days have been allocated for the task, the performer spends the next five days "fine tuning" the deliverable. This is a natural work ethic of most people. We reach 98 per cent completion on our task and, if additional time is available, we attempt to refine it until a delivery deadline is reached.

Second, is procrastination. We are able to start the task as scheduled. But, because there are ten days allocated, and we know that we only need five days, we wait a week to start the task. Now, of course, the contingency has been exhausted before the task has been started, and the potential for a schedule overrun has been increased. But, even if there are no problems, the five-day task has taken ten days.

Less obvious are the subtle motivators to avoid "early" completion of tasks. If we estimated ten days and complete the task in five days, we might be criticized for "padding" the estimate, even though the extra five days was a legitimate allowance for uncertainty. Or, we might be under increased pressure to shorten duration estimates in the future. There rarely is a reward for finishing tasks early - only demerits for running over. So there is no the motivation to do the task in five days.

Certainly, if we do not allow for uncertainty, by adding contingency, we risk a high potential of running late and missing deadlines. However, if we bury the contingency in the individual task estimates, we almost assure that the work will slip to fill the time available.

It is this dilemma that motivated the concepts of Shared Contingency. Use of the various shared contingency conventions is one way of addressing many of the issues raised above. It is also feasible to deal with some of these issues using traditional CPM methods and tools.

More important than all of the above is the need to develop consistency in estimating task durations. There should be a blanket policy for contingency. At least that way everyone knows the basis for the estimate. Standard guidelines for task duration estimating should be established by the project's function for universal use.

The application of the guidelines should consider the key factors in achieving project success. If getting the job done as fast as possible is a key objective, and then contingencies should be minimized and identified. If protecting the firm from delay penalties is a key issue, and then contingency allowances play a larger role.

Flexibility, within standardized guidelines, together with notation of and communication of the basis for the estimates, will help reduce the potential for poor estimating and scheduling.

2. THEORY OF CONSTRAINTS AND CRITICAL CHAIN

2.1. Theory of Constraints

The Theory of Constraints (TOC) is a management philosophy that treats a corporation not as a collection of independent processes, but as a complete system. The Theory of Constraints is a system of problem analysis and decision-making. The originator of the Theory of Constraints, Dr. Eliyahu M. Goldratt, often explains his theory with a simple but effective analogy [5]. He likens a corporation to a chain. Just as the links of a chain work together to form a complete system that is capable of transmitting a great force, so too the various divisions and departments of a corporation work together to generate great profits for the stockholders or private owners. Hence the weakest link or constraint, and the fact that the constraint, whether it is physical, policy or paradigm, will always determine performance of the system.

TOC is a management philosophy that aims to improve the performance of any system. The methodology is first to find the constraint of the system and then concentrate all our efforts on elevating the capacity of the constraint.

According to the Theory of Constraints, every system is subject to at least one constraint, which prevents the system from achieving infinitely high levels of performance. For the system that is a corporation, the often unidentified constraint prevents it from achieving infinite profits, just as a chain's weakest link limits the chain's capacity to transmit force.

The Theory of constraints provides the theoretical framework and the tools with which a team of knowledgeable executives can continually identify the constraints in their corporate chain and improve performance of the entire corporation.

The systemic approach was at the center of the creation of applications such as Drum-Buffer-Rope for manufacturing and Critical Chain for project management.

It has also been used to develop a set of team building and management tools, which address issues such as conflict resolution, improving delegation, achieving ambitious team targets.

2.1.1. Toc Application Areas

The Theory of Constraints has been used at three different levels: Production Management - TOC was initially applied here to solve problems of bottlenecks, scheduling, and inventory reduction [6].

Throughput Analysis is based on the application of TOC has caused a shift from cost-based decision making to decision making based on continuous improvement of processes in which system throughput, system constraints, and statistically determined protective capacities at critical points are key elements.

Theory of Constraints Logical Processes is the general application of TOC reasoning to attack a variety of process problems within organizations. TOC logic is applied to identify what factors are limiting an organization from achieving its goals, developing a solution to the problem, and getting the individuals in the process to invent the requisite changes for themselves.

For a manufacturing organization, with the goal being to make money now as well as in the future, TOC defines three operational measurements that measure whether operations are working toward that goal. They are:

Throughput is the rate at which the system generates money through sales. This contribution margin is considered to be the same as selling price minus cost of raw materials. Labor costs are considered to be part of Operating Expense rather than throughput. Inventory is all the money the system invests in things it intends to or could sell. This is the total system investment, which includes not only conventional inventory, but also buildings, land, vehicles, plant, and equipment. It does not include the value of labor added to Work-In-Process inventory.

Operating Expense is all the money the system spends in turning Inventory into Throughput. This includes all of the money constantly poured into a system to keep it operating, such as heat, light, scrap materials, depreciation, etc.

The following four measurements are used to identify results for the overall organization:

- Net Profit = Throughput - Operating Expense
- Return on Investment (ROI) = (Throughput - Operating Expense) / Inventory
- Productivity = Throughput / Operating Expense
- Turnover = Throughput / Inventory

Given the measurements as described, employees can make local decisions by examining the effect of those decisions on the organization's overall Throughput, Inventory, and Operating Expense. A decision that results in increasing overall Throughput, decreasing the overall Inventory or decreasing the overall Operating Expense for the firm will generally is a good decision for the business.

The Theory of Constraints does away with much of cost accounting. It is clear that application of cost accounting principles (primarily the allocation of costs in order to make decisions at the local level) leads to poor management decisions at the department as well as in upper levels of the organization.

2.1.2. Types of Constraints

A constraint is anything in an organization that limits it from moving toward or achieving its goal. Of course, this assumes that an appropriate goal has been defined. For most business organizations the goal is to make money now as well as in the future. There are two basic types of constraints: physical constraints and non-physical constraints. A physical constraint is something like the physical capacity of a machine. A non-physical constraint might be something like demand for a product, a corporate procedure, or an individual's paradigm for looking at the world [7].

2.1.2.1. Demand Constraints. A demand constraint is a constraint on output. Symptoms include large amounts of final product inventory, or a production line running at a fraction of full capacity production. It means you have excess capacity given the demand for your product. You either have a problem with marketing as your customers may not know about your high quality product), you have a low quality product, undesired by customers, regardless of the marketing effort; or you have an obsolete product, undesired by customers, regardless of the marketing effort. Solution to this involves finding which of the above three problems is, and doing something about it.

This is why a relationship with one's customers and suppliers is so important in Total Quality Management. So as a result, you are getting some lead-time on solving this problem.

2.1.2.2. Production Constraints. Production constraints are generally of three types. Policy constraints which are company policies or practice create the constraint and impede its long-term solution. Machine capacity constraints which are a single or small number of machines on a line form a bottleneck. Labor constraints are insufficient labor or a skilled operator or the general labor pool are sufficient to run a line to full capacity, including extra shifts if needed. In-process inventories between production steps are often a symptom of a production constraint.

2.1.2.3. Raw Materials Constraints. Raw material constraints include shortages in the short or long term of one or more essential ingredients necessary to making the product. This is why a relationship with one's vendors is so important in TQM. The most frequent constraint is the policy constraint. The cycle is like this:

- A problem arises,
- A policy is created to solve the problem,
- The situation changes eliminating the original problem,
- The policy remains and causes a constraint on production,
- Change is emotionally difficult to implement and the policy is lived with..

2.1.3. Measuring Business Performance

The performance of a company is most frequently judged by examining its financial statements. The traditional performance measures are Net Profit, which is reported on the Profit and Loss statement of a company and the ratio of Return on Investment (ROI), the data for which is found on the Balance Sheet of a company. The third financial statement, Statement of Cash Position that assists in assessing whether a company has sufficient financial maneuvering room to accomplish its goals [7].

The goal is to find a global performance measure that we can use locally to assist in decision making. None of the traditional measures-Net Profit, traditional ROI, or cash will do this. What is needed for local decision making is a method of measuring the rate at which a company produces money through sales of which Goldratt defines this as Throughput.

Local decisions that increase company's throughput, decrease a company's operating expense, or reduce a company's inventory are most generally good decisions for the company.

2.1.4. The Thinking Process Tools

Theory of Constraints (TOC) seeks to bring any organization to substantial improved performance through a process of on going improvement based the Five Focusing Steps [8]. These steps are;

- Step 1 : IDENTIFY the system's constraint(s).
- Step 2 : EXPLOIT the system's constraint(s).
- Step 3 : SUBORDINATE everything else to the above decision.
- Step 4 : ELEVATE the system's constraint(s).
- Step 5 : If in a previous step, a constraint has been broken, go back to Step 1. But do not allow INERTIA to become the system's constraint.

The thinking processes provide people with the ability to logically and systematically answer three questions essential to any process of on-going improvement for the purpose of managing change.

The questions we try to find answers are : "What to change in the system?", "To what to change in the system?" and "How to cause and implement the change within the system of the organization?" and no matter what the subject matter is considered [9]. The tools are logic structures divided into two groups as of sufficiency and necessity based. They consist of a collection of simple declarative statements that are linked with cause-and-effect relationships.

A sufficiency-based logic diagram is one that identifies all the conditions that are necessary and sufficient to cause a particular effect.

The current reality tree is a sufficiency based logic diagram, which lets us to identify the root causes and core problem of our organization.

The future reality tree is also another sufficiency based logic construct. It begins with our solution of choice and links desirable effects. It is a what-if exercise.

A necessity based logic diagram is one that identifies conditions that are merely necessary for a particular effect to exist.

The evaporating cloud which is a conflict resolution diagram is a necessity and based on a logic diagram to identify a solution.

The prerequisite tree is a necessity based logic structure. Its purpose is to help us identify all the intermediate steps that we need to reach an ambition goal, such as our chosen solution.

The transition tree is the last of thinking process tools and a sufficiency-based logic structure. It is our step-by-step implementation plan.

2.1.5. Easing Resistance to Change

In human-based organizations, there is resistance to change. If one succeeds in answering "What to change?" and "To what to change?" the inherent difficulty lies in "How to cause the change?" TOC addresses these well-known phenomena through what is called "Overcoming the 6 Layers of Resistance to Change" [7]. In essence, having a solution without agreeing on the problem serves no purpose. Having a solution without the skills to bring about important change is an exercise in futility. By peeling the 6 Layers in succession, one is able to achieve success through:

- Complete consensus on the cause for the problems to be addressed.
- Agreement on the direction of the solution.
- Agreement that the solution will solve the problem and deliver the expected results.
- Bringing others to participate in developing a complete solution through their active collaboration.
- Developing an implementation plan to bring the solution into reality.
- Overcoming people's unverbalized fears in making important change.

Remarkably, both TQM and TOC come to amazingly similar conclusions about instituting progressive change within an organization. Both philosophies view employees as the key to change. Both philosophies agree that all the employees must very well understand the solution to a problem.

2.2. Critical Chain

The Theory of Constrains is a systems-oriented approach to process improvement. The Critical Chain is an application of Theory of Constraints' principles to project management [10]. The Theory of Constraints assumes that a system is like a chain. Also, a project operates as all the stakeholders and/or departments, which we can call links, are independent on each other to satisfy a need. In order to achieve the project's goals requires the cooperation of many different people in a series of independent actions.

The principle difference between this and the concepts underlying the Critical Path Approach is that the critical chain includes logically and resource related tasks, while the critical path includes only logically related tasks. The belief is that finding and strengthening the weakest link, which is the system constraint, gives the greatest opportunity for measurable improvement, both within individual projects and across the entire collection of an organization's projects. Every TOC improvement effort tries to find only one or two leverage points to change the system, so that the results are far better than with current approaches. For organizations that already have a well disciplined, mature approach to project management, the Critical Chain Approach will not disrupt, but rather enhance the organization. For organizations that are not such a maturity level, the combination of Critical Chain and traditional project management is a powerful one.

Uncertainty is why we need project management. How we manage for uncertainty is at the core of improvement of project performance and getting projects done both faster and with better reliability of the promised deliverable dates. The approach to project management known as "Critical Chain Scheduling and Buffer Management" provides mechanisms to allow a "whole system" view of projects. It identifies and protects what's critical from inevitable uncertainty, and as a result, avoids major impact of Parkinson's Law at the task level while accounting for Murphy's Law at the project level. Project managers need to shift their attention from assuring the achievement of task estimates and intermediate milestones to assuring the only date that matters is the final promised due date.

Safety that is typically built into tasks to cover Murphy's Law is inefficient, leading to longer than necessary or acceptable schedules, and apparently ineffective, given the impact of Parkinson's Law from which many projects suffer. Protecting the value of a project involves dealing with the uncertainty that will be associated with its delivery. The role of Project Management is to assist in turning uncertain events and efforts into certain outcomes and promises. If this is the case, then the primary process associated with project management should be that of risk management. How other processes, such as scope, schedule, and spending management support risk management is therefore critical for successful project management and for maximizing the value of our project-based efforts.

One of the more recently introduced project management methodologies has at its core a focus on the management of uncertainty and system thinking and risk. Dr. Eliyahu Golratt outlined how the Theory of Constraints (TOC) can be applied to projects to improve performance.

When Critical Chain-based project management is introduced in Dr. Eliyahu M. Goldratt's book, Critical Chain [10], it gained considerable attention on the areas of schedule development and management. But the details of the scheduling methodology – the critical chain versus the critical path, just-in-time starts replacing as-soon-as-possible starts, the eschewing of task due dates and use of buffers of time to protect the project's promise and monitor its progress – are only means to an end.

The end results of project are speed and reliability. Speed and reliability of project performance unencumbered by conflicting pressures and behaviors. Reliability of project promises is as much a result of a methodology's ability to support effective risk management of possible risks of the project, as it is a result of effective planning and scheduling.

Critical Chain Project Management approach resides in a development of new paradigm that addresses, for the first time, both the human side of project management and the algorithmic methodology side of project management in a unified discipline. Critical Chain Project Management assumes that the projects can be completed in a significantly shorter time than traditional Critical Path Project Management by eliminating the safety durations in each estimated task and by focusing on the tasks related with the limited resources.

Recognition of uncertainty and its associated risk are at the core of the initial stages of developing Critical Chain schedules. The emphasis on dependencies in the usual approach to developing a project network for a Critical Chain schedule helps to avoid risks of missing interactions of different parts of the project. The use of 2-point estimates to assess and address the early view of schedule risk associated with task uncertainty sets the tone up front for the appreciation of risk in the real world.

In addition to task uncertainty, iteration uncertainty can also be taken into account in the sizing of Feeding and Project Buffers. These resulting buffers themselves become a highly visible and direct assessment of the schedule risk associated with the project as a whole.

Critical Chain-based project management is more than just Critical Chain Scheduling and Buffer Management. The genesis of Critical Chain in the Theory of Constraints (TOC) has yielded a holistic view of project management that provides effective risk-focused approaches not only to scheduling and control, but also to initial scoping and planning, effective resource behaviors, and minimizing cross-project impacts.

Project management must reconcile two conflicting aspects of projects -- the increasingly important need for speed in project delivery and the equally important need for reliability in delivering the project as promised. Project management must deal with uncertainty in an attempt to deliver project outcomes with certainty. One way of thinking about how to deal with this conflict is to develop strategies to avoid expansion of project lead-time (Parkinson's Law) while protecting against Murphy's Law.

The way we manage for uncertainty in projects is at the core of improvement of project performance, defined as getting projects done both faster and with better reliability of the promised final project due date. In most projects managed with commonly accepted practices, this uncertainty is dealt with by focusing on delivery of tasks with the seemingly reasonable belief that if individual tasks come in on time, the project will as well.

Developed through the application of the Theory of Constraints to the subject of projects, "Critical Chain Scheduling" suggests the shifting of focus from assuring the achievement of task estimates and intermediate milestones to assuring the only date that matters is the final promised due date of a project.

The scheduling mechanisms provided by Critical Chain Scheduling require the elimination of task due dates from project plans. Each project team member focuses on project completion date, not on due dates of specific activities.

One benefit is that it allows those who use it to avoid the significant impact of "Parkinson's Law;" i.e., work expanding to fill the time allowed. Take away the idea of time allowed, and you've got half the battle won. But how to do that is the question that requires us to look at some current common project practices and how they lead to "Parkinson's Law".

People usually derive schedules and their component deadlines from estimates of duration required by the various tasks that comprise the project. In many cases, project resources know that they will be held accountable for delivering against their estimate, and equally, that the organization needs to be able to count on their promise. Therefore, it is prudent that they include not only the amount of focused effort/time they expect the work to take, but also time for "safety" to protect their promise. This safety must deal with the uncertainty involved in the work which could be aresult of Murphy's Law, the impact of distractions and interruptions they live with in their organization, and, in many cases, the effect of dealing more than one such project at a time.

So task estimates have plenty of safety in them, above and beyond the actual expected time to do the work.

The "urgent stuff" takes precedence until we see the due date sneaking up on us, or, as the following graphic shows, the due date is within even the aggressive expected duration of the work itself. Sometimes it sneaks up quietly enough ,drowned out by the louder squeaking wheels, that when we look, we realize that it has now become urgent and gets our attention.

2.2.1. Critical Chain Project Management Methodology

Critical Chain Project Management is the application developed using the full set of the TOC tools known as the TOC Thinking Processes (TOC/TP). Critical Chain Project Management Methodology is based upon great insight into human nature and what happens when a project management discipline is applied to people. If the tools are not carefully applied, the opposite of what is intended can be achieved.

Some of these unintended consequences are; Estimating, Student Syndrome, Parkinson's Law, Multi-tasking, No-Early finishes [11].

<u>2.2.1.1. Estimating Task Durations.</u> When a person is asked to estimate a task, He thinks about the task and the effort and decides that he/she can do the task in X (5) days. When he plans more detailed, based on all this uncertainty, he also adds Y (5) days to covers the effects of unplanned work interruptions and not to attract negative attention.

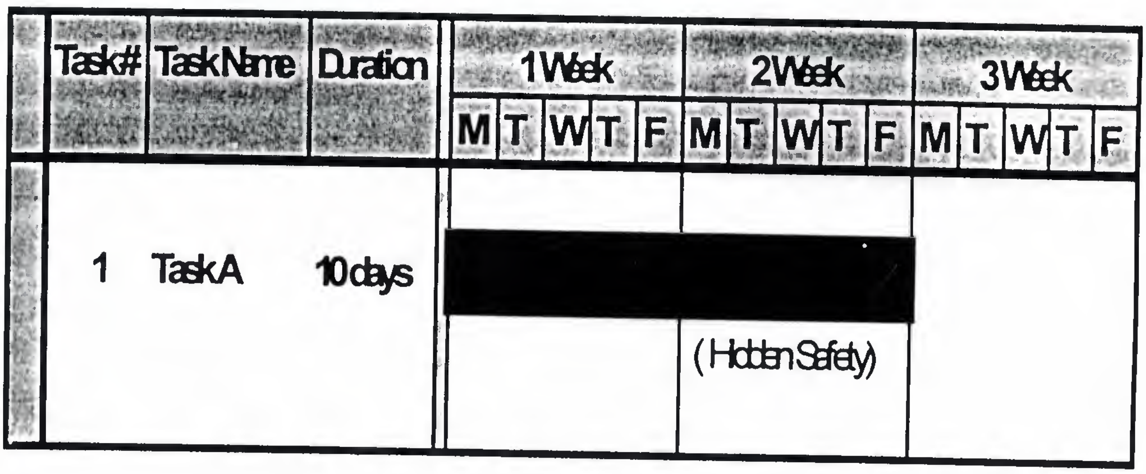


Figure 2.1. Hidden safety in estimating (Goldratt institute)

As shown in Figure 2.1. we have hidden 5 days of safety in our 10-day estimate. The safety is said to be hidden because the task is entered in the project schedule as a 10-day task; 5-day safety in this task is our private contingency factor. It is important to note that the establishment of a safety factor in a task estimate is not wrong.

It is perfectly reasonable thing to do considering the factors involved and the project environment in which we work.

<u>2.2.1.2. Student Syndrome.</u> One problem with leaving small amounts of buffer time in each task estimate, instead of aggregating it, is that the safety is often wasted at the beginning of the task period, not the end where it can do good. Goldratt outlines three ways in which safety, or buffer, is typically wasted. The first is called "Student Syndrome."

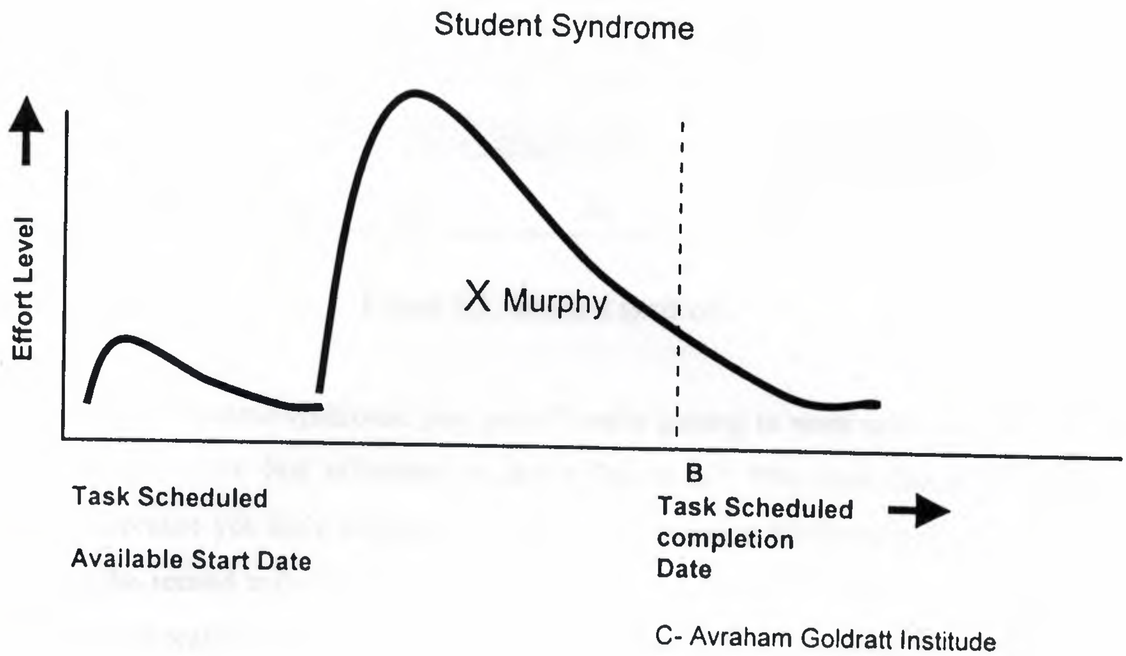


Figure 2.2. Students syndrome (Goldratt Institute)

Dr. Goldratt contends that once a resource has negotiated a "C" time, they reevaluate the task and decide how long it will most likely take. Then they get caught up working on other projects with closer deadlines. When they have only the expected duration left until the deadline, they really ramp up the effort level. At that point, if they encounter an unexpected problem, the deadline is missed. Notice that if the resource would have started the work when it was assigned, they still could have easily met the deadline, even with the "Murphy."

Given a project that is composed of tasks with hidden safety, when the task is actually performed some consequences occur. Dr. Goldratt calls this Student Syndrome and gives an example of professor gives a class assignment that is due in two weeks. The students complain that the assignment is tough and will require more time. The professor agrees and gives them additional time. Later when the students look back on how they actually performed the assignment with this additional time, they note that they all thought they had plenty of time, with safety, to do the assignments so they put off starting until the last minute anyway. We can see how the student syndrome can affect your task, and the whole project in Figure 2.3.

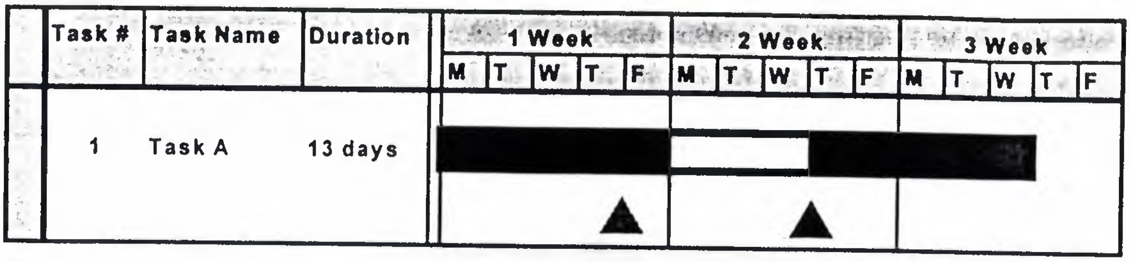


Figure 2.3. Student syndrome

Given the student syndrome, you put off really getting to work until fifth day of the task as noted by the first milestone in above Figure 2.3. This start should be seen as sufficient because you have adequate safety in your estimate. Unfortunately on Thursday noted by the second milestone, you encountered an unexpected problem with the work. Suddenly, you realize that your safety is gone, and that you will overrun your estimate no matter how hard you work. You spend the next five days working as fast as you can in the red zone, with an overrun of 30 per cent of your original estimate. Like the students in Critical Chain, you objectively look back on the task. You note that you wasted four days of safety in your slow start on the task. You also noted that the problem appeared when you were at 80 per cent point of your original estimate and that there was simply not enough safety left to cover. This simple single task example is not unusual example. It happens over and over again in the completion of a project. We are all human, and when we establish a task schedule with a hidden safety margin, most of us naturally fall into student syndrome.

2.2.1.3. Parkinson's Law and No Early Finishes. This all occurs due to the combination of task due dates and realistic, prudent, "safe" estimates. We protect our project due dates by protecting task due dates with safety. Then, from the point of view of the project, we waste that safety due to the comfort it provides, and put the project promise in jeopardy.

If there were a way of managing projects without task due dates and the undesirable behaviors they instigate, it would have to deal with several non-trivial challenges. By adapting Critical Chain and Buffer Management, we can systematically protect the promise date of an entire project from Murphy and uncertainty without nailing all the tasks to deadlines on a calendar.

This application brings Parkinson and wasted safety time and take advantage of early task finishes when they can help us to accelerate the project and maybe allow us to finish it early, freeing up the resources to address other projects.

Work expands to fit the allotted time. Most of us heard about Parkinson's Law and seen it in action on Projects. If a task is estimated to take 10 days, it usually does not take less. This adjustment of effort to fill the allotted time can come in a number of ways. People will simply adjust the level of effort to keep busy for the entire schedule. Traditional project environment stress not being late, but they do not promote being early. This environment encourages hidden safety, the student syndrome and Parkinson's Law effects.

Non-Critical Chain-based projects often rely on safety embedded within tasks and task due dates as milestone schedules to schedule and control projects. This approach runs the risk of suffering from the impact of common resource behaviors that will minimize the ability to gain time on the schedule. If you finish a task earlier than planned, you might be accused of sandbagging your estimates instead of being rewarded for completion ahead of schedule. In this environment, you worry about your future estimates being cut based upon history so you quietly enjoy the lull of your hidden early completion gives you, and officially finish on schedule. In this case you will probably get accolades for good estimating even though you know you could have finished earlier. If you finish early and announce your results, you then encounter the next problem. The task that is dependent upon your completion might not be able to start early because the required resources are off doing something else, because of the Project Schedule gave a clear start for the following task and the resources were allocated elsewhere based upon this schedule.

When we integrate student syndrome and Parkinson's Law, with the likelihood of no early finishes, we get the following result of finishing at due date. Traditional Project Management methods loose the effects of early finishes and only propagate late finishes in the schedule. In other words, the best they can do is to finish on time, and the likelihood of that happening is small.

We can systematically protect the promise date of an entire project by buffers and by buffer management from Murphy and uncertainty without nailing all the tasks to deadlines on a calendar.

This brings Parkinson and wasted safety time into the picture by building the schedule with target durations that are too tight to allow/encourage diversion of attention, getting rid of task due dates and charging management with the responsibility to protect project resources from interruptions rather than getting in their way with unnecessary distractions.

The Critical Chain methodology requires that the schedule be built with only the time to do the work without any safety. This is the time we expect the work to take if allowed to focus a full sustainable level of effort on it and if there are no significant problems. We usually describe this estimate in terms of having a 50 per cent confidence level.

This now leads directly to and supports the second requirement for repealing Parkinson's Law -- the elimination of due dates. If we're building a schedule on the basis of aggressive, 50 per cent confidence durations, we can't expect people to meet them all the time, and therefore there is no way we can think in terms of due dates.

2.2.1.4. The Effect of Multitasking. By the multiplying effect of multi-tasking safety is wasted. We all have experiences of having to stop working on one task so that progress can be accomplished on another task in other projects. Often, we wonder if all this jumping around makes sense because it comes with the penalties of reduced focus and loss of efficiency. However, there is a reason for this multi-tasking environment. Internal and external customers have a tendency for demanding. They think that their project is the highest priority and they want to see frequent progress on their project. Resources tend to migrate between projects in response to the latest, loudest customer demand in an attempt to keep as many customers satisfied as possible. This focus on showing progress on as many active projects as possible is the major cause of multitasking. This focus is the detriment of the overall project throughput of the organization because of relative inefficiency.

The bad effect of multitasking is shown in below simple multi-project example. If we assume that we have four projects A, B, C and D each of which is estimated to take four weeks to complete. The project environment is one of organized chaos. Resources migrate from one project to the next to show as much simultaneous progress as possible to the project customers.

To keep it simple, let's assume resources work one week on each project and migrate to the next project. In this environment, the projects are accomplished in intermittent spurts as shown in Figure 2.4. The completion date of each project is noted with a red milestone. This example assumes zero efficiency loss due to changing task so it minimizes the real world effects of multi-tasking.

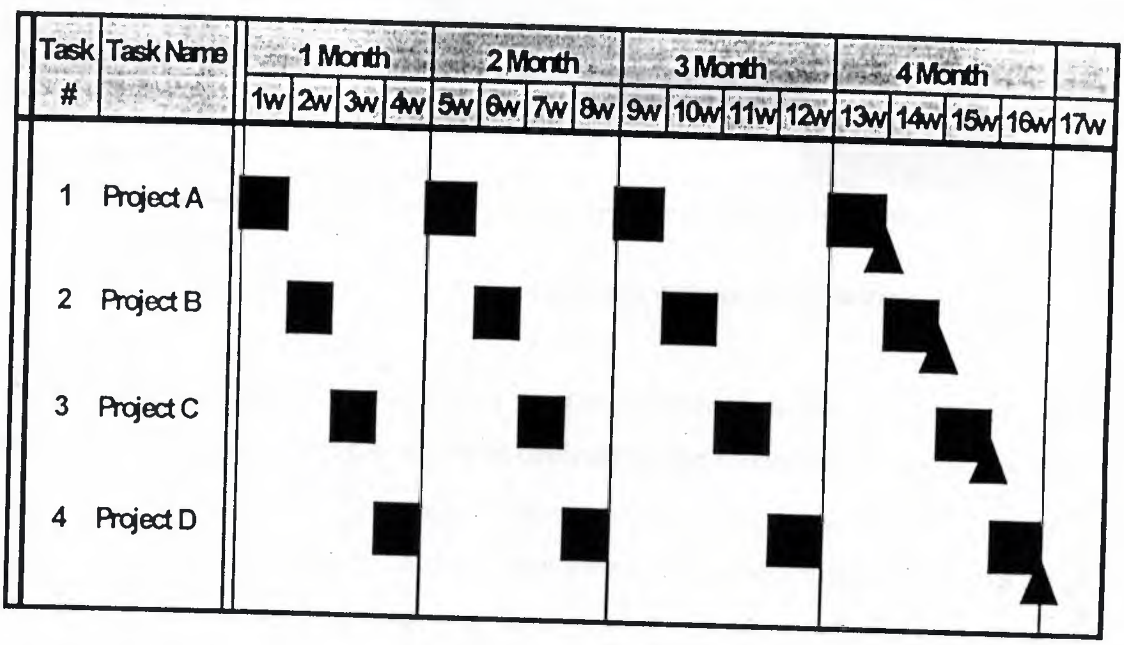


Figure 2.4. The multiplying effect of multi-tasking

These Schedule Structure Allows Delays to be passed on while Gains are not. This diagram illustrates how the structure of a conventional schedule causes a lose-lose situation. A delay in any of the three predecessors will be passed on to the successor, while any gains will not be passed on. Even if predecessors finish early, because we build our schedules around due dates, most likely the successor resource will not be ready to start his or her task early.

But if we are organized with the simple goal of doing work based upon which projects are most important and profitable to the organization. This is an important change, we are moving from organized chaos based upon sub-optimized micro level decisions to an optimized organization based upon macro level decisions. For our example, if we assume the project priority from highest to lowest is A, B, C and D. By eliminating multi tasking and executing our projects by priority, we get the results illustrated in Figure 2.5. which shows early completion of some important projects.

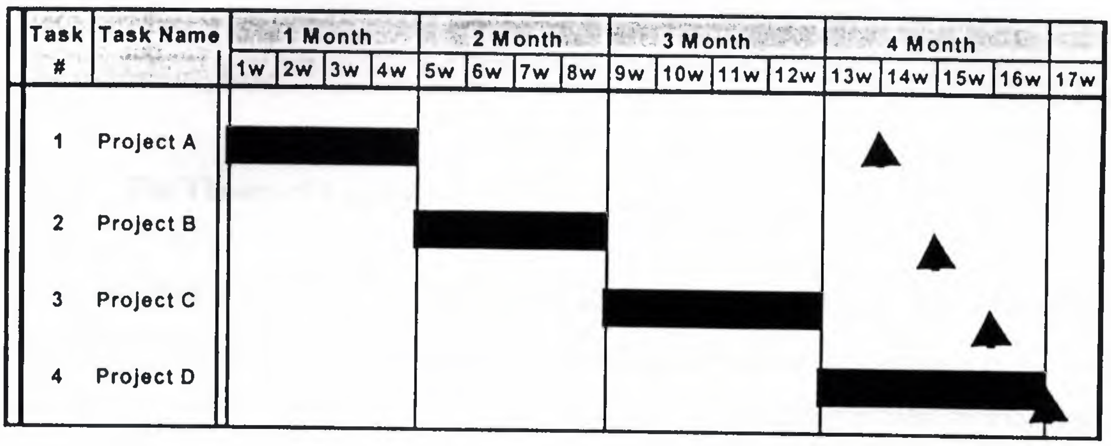


Figure 2.5. The project completion without multi-tasking

As seen in Figure 2.5. The lowest priority project, D, is still accomplished on the same date as the multi-tasking example as depicted by the milestone. However, our highest priority project A, is done nine weeks sooner, which is a 225 per cent improvement. Projects B and C also are done in much less time than in the multi-tasking environment. The elimination of multi-tasking also applies with a single project. The demanding customers can be work package managers who demand progress from limited resources of the organization or the project.

The last way in which safety is wasted has to do with the structure of most schedules. Because tasks can have multiple necessary predecessors, delays are passed on, while gains are not. The application of Critical Chain addresses four tendencies made in most project management environments that directly lead to scope, budget and due date performance compromises.

- Tendency 1: Attempting to immunize a project from uncertainty at the task level.
- Tendency 2: The failure to account for resource dependency when determining the Critical Path or the longest chain of dependent events.
- Tendency 3: The acceptance and introduction of unnecessary multi-tasking.
- Tendency 4: Always treating an idle project resource as a waste.

Critical Chain addresses these tendencies by changing the way a project is planned and as well as executed and based on rethinking what is truly critical and constraining to a project when we make decisions around up front planning as well as what is truly critical in the execution phase.

2.2.2. The Theory of Critical Chain

In Critical Project Management, task durations are treated as if they are deterministic. In fact all task durations are probabilistic. Treating task duration estimates as probabilities solves many of the problems projects are currently facing using prevalent methodologies.

A Task duration estimate is not a single number. It is a statistical entity with a range of possibilities and most schedules have safety time built into each task estimate. Figure 2.6 shows general distribution that represents possible outcomes for most tasks [12].

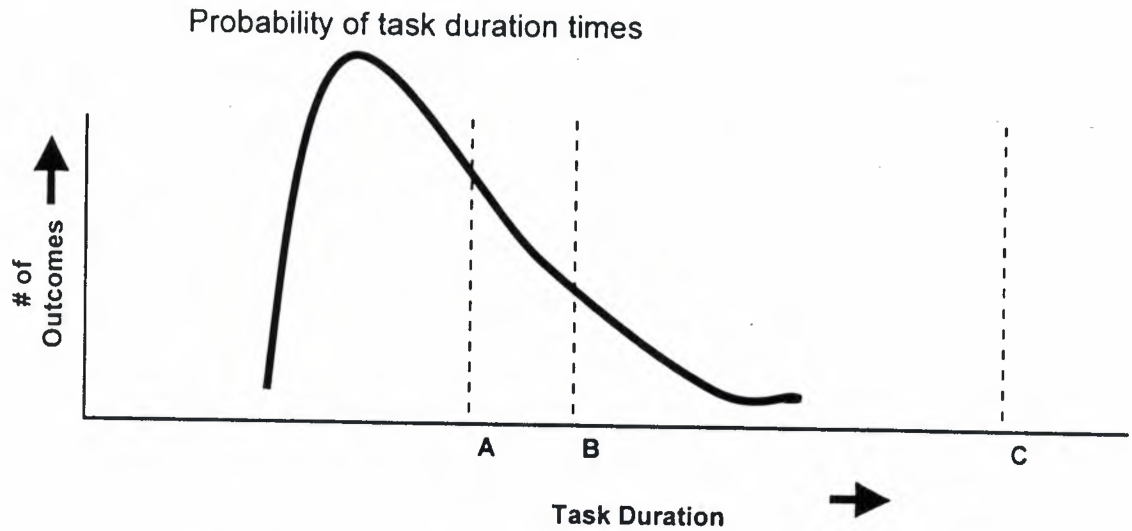


Figure 2.6. Distribution of possible task duration outcomes

It is a normal distribution with a finite left tail because things can only go so well. On the other hand, quite a lot can go amiss. This explains the long right tail. When a person is asked to estimate task duration, consciously or subconsciously he or she is picturing a graph like the one above which is built from historical data points. Time "A" is the "Pure Success" basis, minimum time to complete the task. It is not likely to repeat and. unless someone is very new to project management, will never be given as a task estimate. Time "C" is highly achievable, even with a major disaster. This is the time commonly used because this is what incentive systems have trained workers to give as estimates. Goldratt calls this the "95 per cent time" because 95 per cent time a resource will finish in less time than the given estimate.

Furthermore, if management has a practice of cutting all estimates across the board to squeeze a schedule into a given amount of time, this is even more incentive for team members to give "C" or even "C+" times. "Even though we were trying to offer our best estimates with as little safety built in, there were sufficient buffers built in there. Time "B" represents the duration estimate such that 50 per cent of the outcomes are less than it, and 50 per cent of the outcomes are greater. B is the aggressive estimate with significant safety removed. In other words, if a resource gives this duration as an estimate he or she has a 50/50 chance of finishing on time. This is the median task duration and the time estimate one attempts to build into a Critical Chain schedule.

In most projects, estimates are turned into a project schedule including task estimates with plenty of safest in them above and beyond the actual expected time to the work - a list of dependent tasks with associated start-dates and due-dates. People plan their work around these dates and focus on delivering their deliverables by these dates as per the estimated schedule. The problem comes in when the scheduled time arrives. It often happens that there is other "urgent stuff" when the task shows up in the in-box.

In any event, we have until the promised date to finish the work, which at this point looks like a long way off due to the safety included in the estimate. We are comfortable putting off or "pacing" the work in favor of other stuff because the due date is out there and nobody is blamed with using the estimated duration of that specific activity.

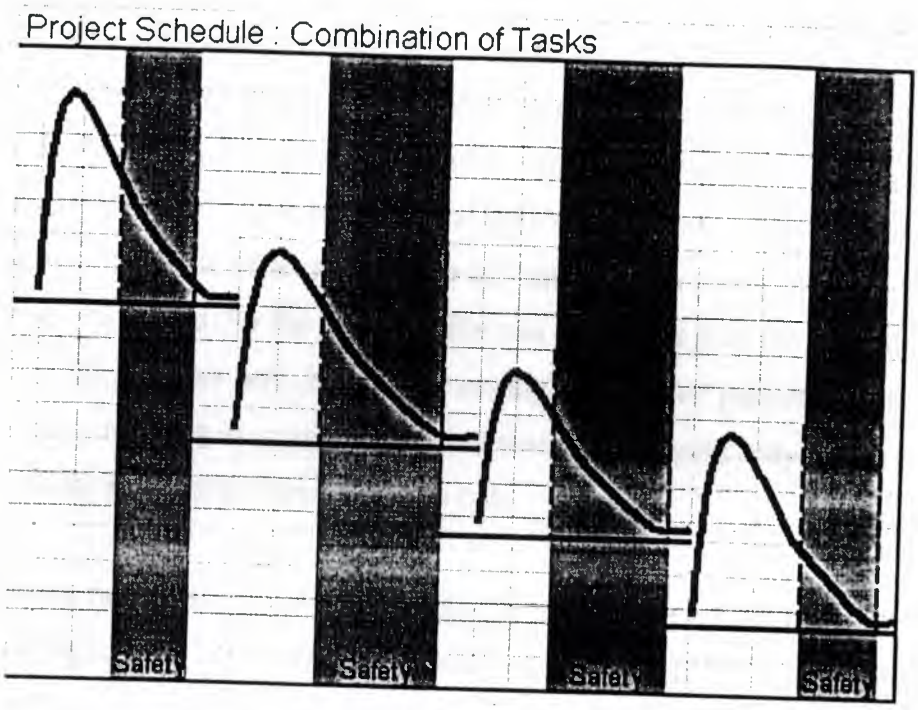


Figure 2.7. Combination of task durations in a project.

When we base on our schedule on aggressive 50 per cent confidence task estimates, we have now got a tight schedule supported by these resource alerts to assure that the critical resources are available when needed and that they can pick up the work when tasks are finished earlier than expected. The problem is that these "50 per cent estimates" don't do too much to help us promise a final due date for the project. Through management support to allow focus, short target durations to maintain that focus, and no due dates or deadlines distracting us from what needs to be done.

The original task estimates might be considered the "90 per cent confidence" estimates that we have usually built our schedules on. The difference between our 50 per cent and 90 per cent estimates is safety. Instead of spreading it around, among the tasks, where it usually gets wasted, let's take a "whole system" view and concentrate it where it will help us. The safety associated with the critical tasks can be shifted to the end of the chain, protecting the project promise (the real due date) from variation in the critical chain tasks. A portion of the time saved by moving from “C” to “B” task estimates is then aggregated at the end of the schedule to act as an overall “shock absorber” for the entire project. This concentrated aggregations of safety is called the “Project Buffer.”

There is an additional advantage to this aggregation of safety in the form of buffers. Because the tasks' target durations are 50 per cent confidence estimates, we might expect that half the time they will come in early and half the time they will be late. In Traditional Project Management we cannot be able to take advantage of early finishes of tasks. Since the early tasks will help to offset some of the late ones, we don't need all the protection that used to be spread around. So the project buffer can be smaller than the sum of the parts. I won't go into the statistics here, but we can usually cut the total protection at least in half and still be safe, resulting in a project lead-time that can be significantly shorter than in the old paradigm for a project promise of similar risk.

There are two kinds of resources; resources that perform critical tasks and resources that perform non-critical tasks. We really have to worry about are the critical chain tasks as they determine the project duration. We want to make sure that critical chain resources are available when the preceding task is done, without relying on fixed due dates. When we focus on the non-critical tasks, we do not want to micro-manage everybody to the degree we do the critical tasks with the resource availability alerts. Yet we do want to assure that, if things go wrong in the non-critical, we do not want them to affect the ability of the critical tasks to stay on track. The traditional approach is to start these tasks as early as possible, and hope that the slack or float is enough to absorb the variability. Buffer approach can be used as concentrating the safety associated with chains of non-critical tasks as a buffer protecting the start of the critical chain task they feed into feeding buffers.

Note that the feeding buffers are also relied upon to deal with resource timeliness for non-critical tasks/resources; we do not use the "work-coming alerts" because even if the feeding buffer is consumed, the worst case is that the critical tasks are delayed and maybe eat some project buffer. The feeding, non-critical tasks are two buffers away from impacting the project promise. Also, you gain more by keeping non-critical resources focused on the work at hand and to assure they finish work that can be passed on to other resources rather than interrupt them for other non-critical stuff.

As a result of this time allocation and buffer approach, we can built a Critical Chain Schedule shown in Figure 2.8.

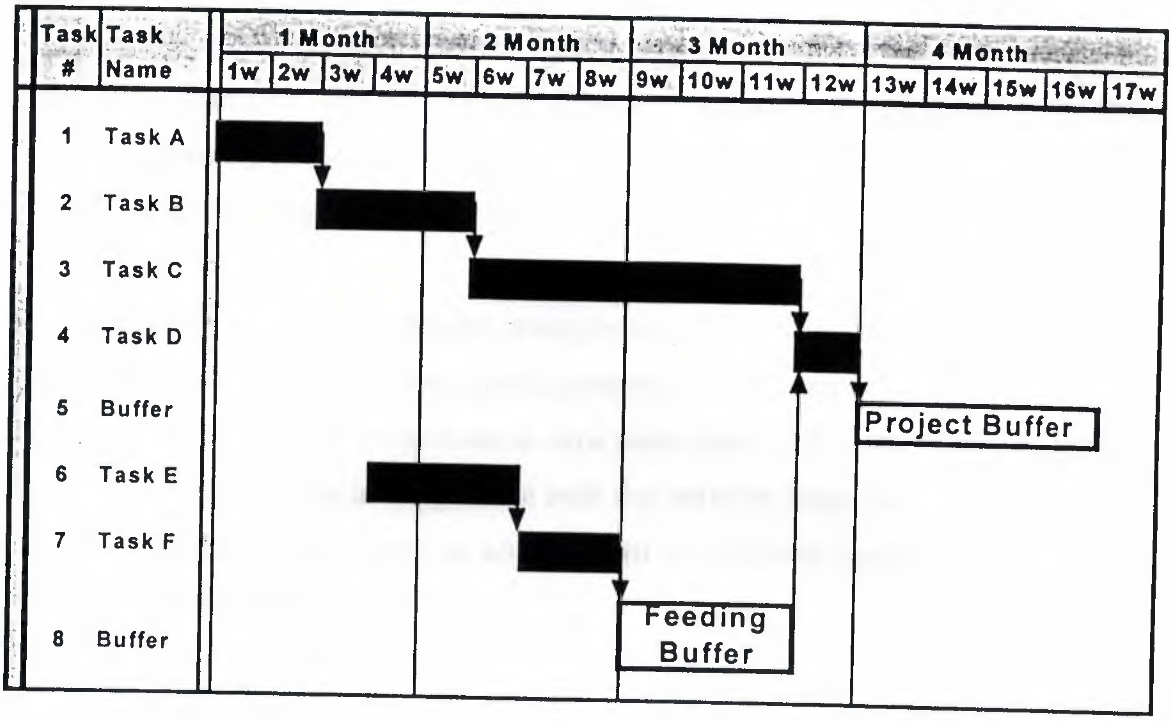


Figure 2.8. Sample critical chain schedule

As seen in Figure 2.8. Target duration estimates are aggressive, feeding buffers protects Critical Chain from Non-Critical task variations, project buffers protect Project Due dates from Critical Chain variations and resource alerting reporting assures Critical Chain Resource Availability.

The Critical Chain Schedule avoids expansion from Parkinson's Law by eliminating due dates and allowing us to take advantage of early task finishes. This schedule is also protected against untimely availability of critical resources by the alerts of work coming from preceding tasks. The project promise is protected from variation of Murphy in the critical chain by the project buffer and the critical chain is protected from variation in non-critical work by the feeding buffers.

In order to take advantage of early finishes, we can take an approach in two steps: Step one is asking the resources how much of an advance warning they need to finish up their other work and shift to interruptible work so that when the preceding project task is complete, they can drop what they're doing and pick up their critical task.

Step two is each resource provides regular, periodic updates of their current estimate of the time to complete their current task. When the estimate to complete task A matches the advance warning needed by the resource on task B, let the B resource know the work is on its way and that it should get ready to pick it up.

Compared to traditional project management, this is a bit of a shift away from focusing on "what we've done" via reporting percent of work complete to focusing on what counts to assess and address project status--how much time is left to accomplish unfinished tasks. This process puts us into a position such that we're no longer nailed to the calendar through due-dates, we can move up activity as its predecessors finish early, and we can avoid the impact of Parkinson's Law.

During the execution stage, the key to the management of the project is the set of feeding and project buffers and a process known as "Buffer Management". As tasks are completed, we know how much they have used or replenished the buffers. Because we are now getting updated estimates of time-to-completion from currently active tasks, we can stay on top of how much of the buffers are consumed in an ongoing fashion. As long as there is some predetermined proportion of the buffer remaining, all is well. If task variation consumes a buffer by a certain amount, we raise a flag to determine what we might need to do to if the situation continues to deteriorate. If it deteriorates past another point in the buffer, we put those plans into effect. This process allows us to stay out of the way of the project resources if things are on track, build a contingency plan in something other than a crisis atmosphere, and implement that plan only if necessary.

The Critical Chain Approach is a way to manage all of an organization's projects holistically. Developed using the Theory of Constraints improvement methodology, Critical Chain puts forward only a few strategic changes in how projects are planned, scheduled and managed. However, these few changes are resulting in claims of tripling the number of projects completed, reducing project cycle times, and increasing company revenues. Critical Chain methods focus mostly on improving project cycle time. Sometimes, conscious tradeoffs are made in resource cost, in order to generate a much higher throughput from the project.

2.2.3. Single versus Multi-Project Implementation

There are two main categories of Critical Chain Management [12]. The first is called single project implementation. The definition of single project implementation is that the projects are not predominantly utilizing the same resources. Within an organization, there can be multiple single Critical Chain projects. The second type of implementation is called multi-project implementation. Multi-project implementation indicates there are multiple simultaneous Critical Chain projects and many of the resources are shared across projects. It is more difficult to schedule resources across multiple projects because there is no clear decision metric when deciding which project to first allocate a constrained resource. Goldratt contends that CC and TOC can provide this global project metric.

Multi-projects require a higher level of implementation with much higher coordination requirements. At this level, an organization identifies which resource is the constraint across all the projects it undertakes. More strategically, an organization would identify which resource should be its constraint, and then have this resource or group of resources pace when new projects are undertaken by the entire organization.

2.2.4. Fundamentals of Project Planning and Scheduling

The use of Critical Chain does not exclude the use of other common sense project management tools. The more tasks can be decomposed into finer detail, the more this will allow the team to overlap tasks and shorten the Critical Chain. The team members need to understand the requirements of tasks, which have to be performed sequentially or in parallel. We have to change the thinking style that tasks do not always have to be performed sequentially or performed by specific people [12].

Once the Critical Chain for a project is identified by the project team, they can take a much closer look at those tasks to identify opportunities for performing them in parallel. First, the project team will identify the constraint of the project and then work to break that constraint. Once they have broken the first constraint, they begin to work to break the next constraint, until they get to the shortest practical schedule.

Network building process is the primary aspect of planning in a Critical Chain environment. It is a multi-pass approach designed to assure that no key dependencies for the project are missed. No matter how good a project schedule is or how well resources perform in the execution of tasks in that schedule, if critical dependencies associated with the project are not included in the description of the effort, they represent considerable risk.

Once the end result is understood, network building quickly shifts to a focus on task dependencies required to get there. The clear definition of deliverables serves as a high level WBS, but rather than continue developing the individual hierarchical branches of a WBS, Network Building shifts to dependency identification. Once the first pass of major dependencies, from end to beginning has been developed, it is addressed for identification of the minimum resource capability needed for task completions. The emphasis of Network Building in a Critical Chain environment is on clarity of task inputs necessary to support that task's deliverables. Any effective planning process is about the identification and inclusion of necessary handoffs. These handoffs are the linkages of the chain of tasks – they serve as inputs to some tasks and are developed as outputs of others.

The plan, which is the dependency network, is simply the sum of handoffs that need to occur to overcome obstacles on the way to the project's objective and to minimize the effect of potential pitfalls along the way. To the extent that careful consideration is given to the completeness of necessary inputs, identified risks can be avoided or mitigated by adding additional tasks to the network. Too often, plans include assumptions regarding the existence of necessary inputs. The focus on whether all identifiable inputs are sufficiently provided for in the network goes a long way to avoiding and mitigating risks that might have otherwise been buried in those assumptions.

The final step in Network Building is the development of range estimates for both task durations and iterations. Critical Chain Scheduling utilizes a 2-point estimate, for both durations and iterations. A Critical Chain schedule takes advantage of the 2-point estimate process to translate the dependency network into a reliable project promise. Reliability comes first from feasibility assured by explicitly including resource dependencies as well as handoff dependencies in the determination of the critical chain/path of the project.

Secondarily, the two estimates developed in the planning process are used to aggregate and concentrate safety where it will do the most good to protect the project's promises and its intended value. The body of the schedule, which is the network of tasks and resources used to identify the critical chain, makes use of the smaller of the two estimates.

The difference between the "safe" estimate and that "aggressive but achievable" estimate for critical chain tasks is used to develop the primary characteristic of the critical chain schedule with the buffers. A project buffer, which protects the final project due date from the variability in performance on those tasks is built from the estimates associated with the critical chain tasks. Feeding buffers, which are related to chains of tasks that feed into or merge with the critical chain, are similarly sized and placed to isolate the critical chain from the integration effects of those chains.

To this end, resources are first queried for a safe estimate, one in which they have a high level of confidence, and are willing to consider a commitment. This defines the upper end of the possible requirements of the project components in terms of time. Once this upper limit is initially established, a second "aggressive but achievable" estimate is solicited, one that reflects a near "best case" situation that is "in the realm of possibility" if things go well in the performance of the task in question.

<u>2.2.4.1. Two-Point Estimates and Risk Assessment/Avoidance/Mitigation.</u> Schedule and cost risk assessment are inherent in Critical Chain's 2-point duration and iteration estimates. Once basic dependencies are identified in the Network Building process, the uncertainty and potential variation associated with individual tasks and groups of tasks are the next link related to the risk of keeping project promises and delivering desired value.

Even if identified, mitigated, or avoided through additional tasks in the network, task delivery is still subject to technical or performance risk. Some of the major beneficial effects of the Critical Chain approach come from the linking of scope and time management to risk management.

Once developed, assessment of the full schedule, including the contribution of the buffers to project lead-time, provides a clear view into the identified potential of schedule risk for the project. In non-Critical Chain environments, when contingency is included in tasks, it is often hidden, either in management reserve, or in internal and external commitments.

The common practice of keeping these components off the table hides their true impact and implications. The open and explicit communication of buffers, which are important because of being project control tool, allows a clear assessment of what could happen "in the best of all possible worlds," versus what might happen if individual concerns accumulate to affect project performance.

The ultimate risk of a project is not delivering the promised value in the required time frame. If the schedule results in a lead-time that does not support business needs of the project, the critical chain schedule provides two primary sources for reduction – the critical chain and the project buffer. Assumptions that have been made on key critical activities can be revisited to assess whether additional actions or activities can be added to the project to reduce variability and the size of the project buffer, or whether task handoffs can be restructured to allow more parallel activity and reduce the length of the critical chain. At some point, limits on corrective action are reached, resulting in a buffered schedule that reflects the accepted risk of the project's lead-time and schedule promise.

2.2.4.2. A Relay Race Approach. Most projects are managed by carefully watching the calendar, comparing where we are today against some baseline schedule. That schedule typically consists of a series of start and due dates for consecutive tasks, with due dates of predecessors matching start dates of successors. Like a train schedule, if a task arrives at its completion on or before its due date, that portion of the project is considered to be "on track." Successor resources plan other work and their availability around those dates. If the predecessor is finished early, the successor resource may not be available to pick up the handoff. Even if the resource is available, there is commonly little or no urgency for the successor to start (or to focus on it exclusively), since we're "ahead of schedule," and that resource will typically tend to other priorities.

In order to take advantage of early finishes and deal effectively with late finishes, schedule must be very dynamic. Most project managers worry that a dynamic schedule will become unmanageable, and use a "simpler" approach of trying to lock down the schedule by assigning due dates. The CC schedule does not become unmanageable because only the CC tasks must remain flexible. Unless there are major variances, feeder paths remain set.

The team makes a pact during the implementation of CC that all members will drop what they are doing to work on CC tasks and work non-stop on those tasks until they are complete. In this regard, a CC schedule is very similar to running a relay race. Team members wait to get the baton and then run as fast as they can until they pass the baton on to another teammate. The CC by definition defines the overall length of the project, thus it makes sense to concentrate all management attention on these tasks and "sprint" them as quickly as possible. Resource behaviors for timely projects in critical chain is like a relay race. Due dates for some tasks are start dates for others. Successor resources plan other work and their availability around those dates. If the predecessor is finished early, there is no pressure on the successor to start, even if the resource is available.

The problem with this common practice is that while it is important for trains to arrive at and depart from their stations (their milestones) at appointed times, project value is more often tied to the absolute speed from beginning to end. The sooner the entire project is completed; the sooner project benefits can be accrued. A more appropriate metaphor to guide projects is a relay race, in which resources are encouraged to pick up the input handoff as soon as it is available, "run with it" in a full, focused, sustainable level of effort, and hand off the output as soon as it is complete.

This Relay race behavior is very useful in projects where schedules are built upon estimates that are considered commitments by the resources,and contain a substantial amount of safety in each task to protect that commitment. If a project is deemed "on track," and a resource realizes that there is chance of completing the work well within the "safe" estimate, the desired sense of urgency is again diminished. As a result, resources are momentarily comfortable sharing their time among several tasks or issues, extending out the time that they would otherwise be able to hand off their output to the next leg of race.

Milestone schedules, like training schedules, become, at best, self-fulfilling prophecies, at least in terms of expectations of speed. They may still and often take longer due to being derailed by Murphy's Law because they have wasted what might have been early finishes which are now not available to offset tasks that take longer than anticipated in the early stages.

2.2.5. Project Control and Risk response Control

The need for project control and benefit of effective project control is very important. Planning, scheduling and synchronization are all processes that will create a model of expectation for the project organization. But that model needs to be managed once it comes into contact with reality. Resource behaviors, especially the required focus on the most important task at hand; require the occasional guidance to clarify priorities in a shifting situation.

The buffers also help management to act proactively. Buffer management highlights potential problems much earlier than they would ordinarily be discovered using typical project management techniques. The feeder and project buffers are broken into three zones similar to a traffic light indicator. The "green" zone is labeled "OK." If this portion is eaten into, management does nothing.

The next zone of the buffer is labeled "Watch & Plan." In this "yellow" zone, the team would form a plan to put into action if further buffer is eaten in order to protect the completion date.

The last zone is labeled "Act." This is the "red" zone wherein management would expect its team to initiate the plans to increase the size of the buffer or at least prevent further erosion of it. This is extremely powerful, especially because management can set the size of each zone based on past performance, inherent variability of the project. Setting the size of each zone will in some regards define the degree of management involvement in the project.

2.2.5.1. Project Control with Buffer Management. The buffers introduced in the Critical Chain scheduling methodology do not only serve to protect project promises in a static manner. They also provide an ongoing view of the health of the project as reality impacts the expected model that is the original schedule. As tasks take longer than the schedule anticipates, buffers are consumed. As they take less time, those buffers are replenished. Awareness of project buffer consumption relative to the completion of the critical chain provides an important forward-looking focal point for managing project execution.

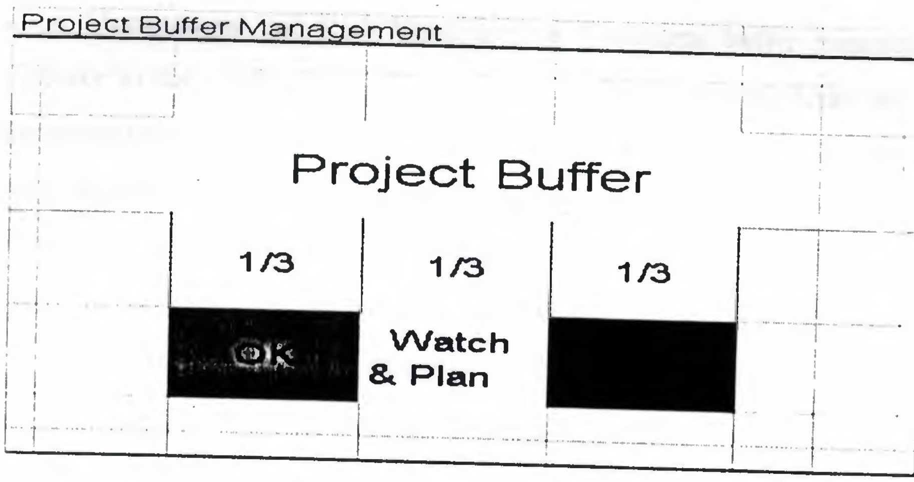


Figure 2.9. Project buffer management

In Figure 2.9. the buffers are shown divided into three equal parts. Management should expect buffer to be eaten as the team advances through the project and runs into unexpected iterations or "Murphy's." Management needs to monitor the buffers relative to how much CC or feeder branch remains, and the rate of buffer consumption.

Effective Buffer Management is a critical factor in successful implementations of Critical Chain-based project management systems. Buffer Management typically involves a combination of real-time access to buffer condition and periodic "buffer management meetings." Real-time, daily updates of project and buffer status are feasible in a Critical Chain environment due to the simple data needed to update active tasks. That data requires only one number at the end of each day – a current estimate of time to complete the task at hand. Immediate issues can be quickly identified through this process.

Periodic multi-project buffer management meetings, typically involving project owners, project managers, and resource managers, start with buffer status of the portfolio's projects. Those with buffers "in the green" require little if any discussion. Those "in the yellow" or "in the red" are rightfully the focus of the meeting, with project managers highlighting identified opportunities and actions for buffer recovery. These meetings are also useful for supporting regular, forward-looking risk management as well, again with an eye to current buffer condition and to its ability to absorb the impact of identified risks to the project schedule.

2.2.5.2. Buffer Management and Risk Identification. Consistent buffer management is a major contributor to the establishment of a risk management culture. Risks are potential future occurrences that require a forward-looking approach to support their identification. The everyday process of developing an estimate-to-complete task status keeps short term risks in the forefront of the mind of the reporting resources. In addition, the elimination of task estimates as commitments and the related transfer of safety to the buffer should support a greater willingness to raise concerns, if the buffer is there to absorb them and they are not expected to have to have an immediate solution to protect their personal performance.

Buffer management also provides a clear view of the cumulative risk effects of project performance. Buffer consumption at any point in time is the result of all previous work, which can eat away at the buffer quietly but insidiously as the project progresses.

2.2.6. Critical Chain Project Management Software

There are currently three packages for Critical Chain applications. Prochain was the first used for implementations, in the market. It proved to be reasonably effective for single project environments but less effective in multi-project environments. Prochain is essentially a macro sitting on top of Microsoft MS Project which is a scheduling software using Critical Path Methodology. Scitor have a product called PS8, and Concerto, a product from East-to-Market.

2.3. Comparison of Critical Chain and PM Body of Knowledge

This section is to expliam how Critical Chain Approach integrates with and adds value to the current body of Project Management knowledge. It is based on a dialogue between Dr. Kerzner and Dr. Goldratt and IIL [13].

Since projects are undertaken to bring benefits to an organization, the sooner they are completed, the sooner the benefits are realized. Critical Chain focuses on the amount of time it takes to complete any single project. In a collection of projects, Critical Chain focuses on the factor that most effects the cumulative cycle of all projects. This factor is known as the organization's strategic or critical resource, also called the "Drum".

Critical Chain's focus on the critical factor to improve overall project performance is one of its major contributions.Accepting cycle time as significant target of our improvement efforts, we must focus our attention on the causes of long cycle times.

In projects, there is a difference between elapsed time (duration) and effort. Effort can be applied in a dedicated or non-dedicated way. For example, non-dedicated would have a resource assigned to several tasks simultaneously, whereas a dedicated resource would be fully assigned to one task until that task is completed. Non-dedicated effort implies extending the duration.

Critical Chain highlights the importance of dedicating effort to streamline and optimize the cycle time. Critical Chain analysis shows that within single projects, the biggest factor impacting cycle times as the practice of estimating tasks according to non-dedicated elapsed time, and managing the execution of those tasks to a due date.

Within the multi-project environment, the biggest factor impacting cycle times is the resource bottleneck. This factor is created by the current system of pushing work as in the form of new projects or more involvement into the organization, irrespective of the capacity of the most critical resource – the one that most impacts the cycle time of all projects.

Critical Chain addresses both the single and multi-project factors in the reduction of duration. Critical Chain assumes a good critical path network that has been effectively resource leveled. Starting from that point, Critical Chain enhances the ability to optimize the schedule and set the stage for improved project monitoring and control. It should be noted that some of the actions needed to implement Critical Chain successfully might be significant changes for an organization. Following are specific ways that the Critical Chain Approach works and adds value.

Using the Citical Chain approach, team members are asked to dedicate themselves to a project task, to complete it as quickly as possible and periodically report how many days are remaining. When planning a project, task times should be estimated much closer to how long the task will take with dedicated resources, rather than elapsed times assuming the organization's current practice of assigning resources to work on several tasks at once whcich reduces behaviours called "student syndrome" and "Parkinson's Law".

Bad multitasking is significantly reduced, permanently. The reduction of bad multitasking goes hand in hand with reducing task estimates to dedicated elapsed times and having people complete tasks before starting new ones, as much as possible.

In executing a project, people are not measured and are not held accountable for completing their tasks on time. Managing tasks by due dates is not done. People are asked to pass on their outputs to the next resource as quickly as possible with a relay runner ethic.

By taking resource dependency, as well as logical task dependency into account, the longest sequence of dependent tasks can be seen more clearly. This longest sequence, the Critical Chain, may cross logical paths in the network.

Buffers which are equivalent to schedule contingency reserves, are key part of the schedule and how it is managed. The ability to increase the certainity of project completion dates is closely related to the use of buffers. The use of buffers allows the planner to clearly accommodate all common cause variations. Buffer types include Project buffers, Feeding buffers, Resource buffers, Drum buffers and Strategic Resource buffers.

Critical Path uses a concept of slack time or float to the determine how much flexibility there is in non-critical path tasks. Critical Chain Approach groups tasks on each non-critical or feeding) path entering into the critical chain and "protects" the critical chain with a Feeding Buffer. The feeding buffer is equivalent to a schedule contingency reserve that is local to a part of the project. The Critical Chain Approach is explicit and systematic about the use of Feeding buffers throughout the task network.

This buffering allows for non-critical tasks to be scheduled at their latest possible start times to discorage costly early investment of work in process. This also significantly reduces behaviors called "student syndrome" and "Parkinson's Law". Early starts are discouraged unless there is a major strategic reason for starting as early as possible. Early starts require the resources allocated earliar which also affects the cash flow of the project.

Often, the Critical Path changes during execution because there is no buffer to absorb the variation in task times. If implemented correctly, the Critical Chain plan and the Critical Chain itself do not change througout the life of the project, because the buffers absorb the uncertainities in task duration.

Critical Chain recognizes that there are multi-project environments in which projects have resource-based interdependencies. In other words, projects share a common resource pool, for at least some tasks.

The Critical Chain Approach identifies the critical resource (called a Drum Resource) across a collection of projects. When overloaded or not available, this resource is the one most likely to impact the project cycle time of all projects.

The staggered introduction of projects into the system is issued to improve the flow of projects, to increase the predictability in each project outcome and to increase the effectiveness of critical resources by minimizing the effect of bad multitasking. Shorter project cycle time and an increase of the number of projects that can be pushed through the system without increasing resources result from sraggering the release of new projects.

Similar to vertical traceability in Critical Path, in the Critical Chain plan and prepare detailed schedules with linked entities. Any logic at the detailed levels must be reflected in the summary levels. The benefits of Critical Chain will be secured permanently for the organization with the implementation of a performance measurement system, policies and education that are in keeping with the Critical Chain Approach.

2.3.1. Project Time Management

The Critical Chain Plan must represent every activity but may not schedule every activity in detail in a large project. In other words, the Critical Chain Plan schedules summary level activities. For example, in a large project involving high level activities are typically sufficent capture the major dependencies for Critical Chain. In such cases, it is important that a detailed plan for controlling the work at the detailled level is linked properly to the Critical Chain plan.

<u>2.3.1.1. Activity Sequencing.</u> The Critical Chain method includes any resource dependencies in activity sequencing. A resource-loaded and leveled schedule is an input.

<u>2.3.1.2. Activity Duration Estimating.</u> The Critical Chain activity durations are estimated assuming no bad multi-tasking and resource dedicated to tasks. The duration is the actual time dedicated to perform a task, or something very close to this time. These assumptions are possible if the organization makes the change required.

<u>2.3.1.3. Schedule Development.</u> Schedules are developed using the The Critical Chain method as the primary tool. Schedules include a Project Buffer, Feeding Buffers, Resource Buffers, Strategic Resource Buffers and Drum Buffers.

Tasks normally start as late as Possible. The objective is to minimize any work in process and to eliminate "Student Syndrome" and " Parkinson's Law". In Critical Chain, early starts would represent investment that was too early to provide a return. Early starts also significantly increase the risk of bad multi-tasking. Safety is provided by the buffers and help to avoid the need for, and hence the practice of padding at the task level.

Resource leveling is greatly simplified due to the multi-project Critical Chain practice of staggering the introduction of the projects into the system according to the availability of the strategic resources of the organization. This typically results in the reduction of bad multi-tasking and of the number of active projects in the entire organization at a given point in time. Experience shows that, because of this practices, more projects can be delivered in the same time period with the same resources on critical tasks, even though inefficient in terms of the individual productivity of that resource, makes it easier to compress schedule.

2.3.1.4. Schedule Control. Buffer Management is the primary schedule control mechanism, for the overall project. In large projects, traditional methods still apply at the most detailed level. Team members are not given due dates. Rather, they are asked to report the days remaining on each task.

2.3.2. Project Cost Management

As a general principle, The Critical Chain Approach looks for the best impact on the organization, taking into account throughput, operating expense and investment. Many organizations have managers who are measured by the "efficient" use of their resources. ritical Chain strategy, using other measures, promotes decisions that support what is best for the project or the organization as a whole.

If it reduces the total project duration significantly, as benefits exceeds added cost, this mighty imply individual resource inefficiency. As a result, Net Present Value of Cash flow from critical chain Environment is significantly higher that multitasking environment.

2.3.2.1. Resource Planning. Resource Requirement quantities are considered in terms of the three global parameters of Theory of Constraints, throughput, investment and operating expense. The amount of labor resource in a critical chain plan is typically significantly smaller than for a traditional plan to accomplish the same work. This is because the labor consumed with bad multi-tasking and non-dedicated task times is removed.

<u>2.3.2.2. Cost Budgeting.</u> The cost baseline should include some calculated worth of the project and Feeding Buffers. These buffers allow for uncertainty in task estimates. Generally, a project's promised delivery date is at the end of the Project Buffer. Therefore, the value of these buffers, perhaps computed at some average running rate of the activities the buffer is intended to protect, should be translated to allow a Cost Buffer as well. This is equivalent to the traditional project cost reserves.

<u>2.3.2.3. Cost Control.</u> The Theory of Constraints suggests that a system approach is vital, with respect to cost control and measuring performance to budget. Some cost tradeoffs during a project are good, provided that the impact on the organization and/or customer's goals is significant. The key is to get project managers to better understand the real cost of a late delivery, to make project cost decisions with those figures in mind, and to keep key decision makers informed so that there are no surprises.

Some organizations use cost as their number one criteria for decisions. In Critical Chain, throughout is the number one priority, not cost control. It does not mean that costs are not ignored. Rather, any cost accrued that d o not contribute to thoughput are considered a waste.

<u>2.3.2.4. Conclusions.</u> Many organizations today must achieve a major breakthrough in project cycle time in order to stay competitive. They must drive more projects through their organization to increase throughput. To make things more difficult, this often must not be done without increasing the number of people allocated to projects.

Many organizations do not have the option of hiring additional people. In expanding economic conditions, skilled resources are difficult to find. In tough economic times, executives are reluctant to hire, even though the demands for new projects remains. Critical chain is a new option that gives organizations the ability to increase the number of projects that can be done by the same number of resources and to reduce the average durations of projects. Critical Chain Approach enables organizations to confront the problems that may exist both on systemic and individual project levels to achieve these benefits. Critical Chain can be seen as a logical extension of current project management practices.

2.3.3. Case Study Application

The Case Study is the application of Critical Chain Methodology to the project schedules developed with Critical Path Methodology. The sample project is "A Feasibility Study Project" for an industrial Plant. Resources are consultant engineers and engineers from subcontractors. The aim of this case study is the application and comparison of both methodologies of the Critical Chain and Critical Path and identify the benefits and advantages of each of them.

In order to develop the Critical Path Method Schedule MS Project 98 [14] is used. An add-on, Prochain [15] is used for Critical Chain Methodology. Prochain Project Scheduling helps to implement critical chain scheduling based on the schedules prepared by MS Project.

A project schedule is the model of a set of tasks, resources and the linkages between those tasks and resources, which together describe a project. The schedule can be as a PERT schedule. The durations of tasks must be defined clearly. The allocation of resources for tasks and dependencies of each task must be defined clearly. Resources needed for the project should be identified. Resource plans should state what resources would be required by the project, when they will be required according to the time schedule. Constraints on resources should be taken into account.

As seen in Figure A.1. in Appendix A, for sample project "Feasibility Study", the original estimated task durations are given in Durations column of the schedule. The durations are based on safe estimates which includes safety times.

Task dependencies are given the predecessor column and the resource dependencies are given in the wording beside each activity represents the resource (usually a person or group of people) necessary to complete the given task. Assume there is only one available resource for each given resource. The schedules are prepared in Microsoft Project. Prochain reads and manipulates this network in order to create a schedule based on the data in the project network.

In order to convert the Critical Path Schedule The primary step in the conversion is to attempt to pull the safety out of each duration estimate and get at the median times for each task ("B" times). In our examples, this is shown as half of the initial "C" estimate. This is the rule of thumb that Goldratt recommends using.

The first step is to level the schedule as per the availability of resources and defining the critical chain. The Prochain load leveling procedure tries to produce the best possible schedule, ignoring uncertainty. Uncertainty will be dealt with the buffers inserted. This means that all resource contention is resolved and tasks are placed at their latest possible starting points. Prochain's load leveling algorithm takes into account resource availability, resource requirements and task dependencies.

The second step is for identifying the Critical Chain. Prochain will identify one critical chain for each project endpoint, which is the deliverable.

The next step is to aggregate all of the safety at the end of the project where it can act as an overall buffer for the entire project. The date one would commit to the customers or to the senior manager. Project Buffers are created after each task with no successors; Feeding Buffers are created for each link that joins a non-critical chain task to a critical chain task. If there are more than one non-critical chain tasks feeding into a single critical chain task, same chain task, same number of feeding buffers will be created. Resource Buffers are created whenever a resource starts to work on critical chain tasks.

Since a resource buffer is assumed as a "wake-up" call, it will not be created if the resource is assumed to be already "awake". The safety from the non-critical tasks branch has also been consolidated into the feeding buffer.

This serves to immunize the critical path against negative variations of the feeding path. In effect you are giving the feeding path its own safety so that if it runs into delays, unless the entire feeder buffer is "eaten," the delays will not be passed on to the rest of the schedule. When all the buffers are created Prochain gives us a chance to review and revise the Buffers before inserting to the schedule.

Once buffers of the correct sizes are created, they should be inserted into the network. This is done by moving tasks as early as possible to make space for the buffers.

The last step is creating a Prochain Critical Schedule is to produce a Project signoff sheet. This report provides information and warnings for the project. It enables others to see the schedule was created and what the characteristics of the schedule are.

During the executing stage of the project, we can update task progress and buffer usage, track actual and produce Project Task, Buffer and Resource reports.

In general with Critical Chain, one starts tasks as late as possible, which is a departure from how Microsoft Project will automatically schedule a project (it will start all tasks as early as possible). Because work is started later and generally worked on until it is complete, this helps reduce work in progress (WIP). From a management point of view this is beneficial because WIP is costly and can serve to bog workers down. This can also be a difficult paradigm shift for a team to make. Feeder paths are started a defined amount (feeder buffer) earlier than necessary as a risk reduction.

The next step is considered one of the most powerful aspects of Critical Chain. Because of random number aggregation theory, the overall variance of the critical chain will be much less than the addition of all the individual variances for each CC task. In other words, the amount of protection necessary when we aggregate all of the tasks is much less than if you added the protection originally built into each estimate. Dr. Goldratt recommends to cut the buffer in half, leaving a buffer length of one half the length of the CC. The same applies to feeding paths, so that a feeding buffer is optimally one half the length of the feeding branch against which it is protecting. The results of the case study can be seen in Appendix A.

3. RESULTS AND DISCUSSION

As we can see from the schedules prepared for different methodologies for the case study in Appendix A. for the Feasibility Project, the total structure of the schedules are very different for Critical Path Methodology and TOC-Critical Chain Methodology.

The main difference between Critical Path and Critical Chain is;

Critical Path is the sequence of interrelated tasks in a project that takes the longest time to complete. The Critical Path defines the duration of the project and the project end date.

Critical Chain is the longest set of dependent activities, with explicit consideration of resource availability, to achieve a project goal. The Critical Chain is not same as the results we get from performing resource allocation on a Critical Path Schedule. The Critical Chain defines an alternate path, which completes the project earlier by resolving resource contention up front.

The Critical Chain aggregates safety in strategic places in order to protect the project. It requires stopping multi-tasking; any resource has to finish his/her specific task before jumping to the next task. It allows us to stop the behavior of waiting resources by tying up them longer in a project than needed.

Resource Buffers allow a project team to remain aware of the Critical Chain. Resource Buffers are a form of communication between the schedule keeper and the rest of the team. The schedule keeper will get task updates from all resources currently working on tasks as the schedule progresses. The resources merely need to report how many workdays remain until they estimate their task is complete. When a predecessor Critical Chain resource reports to have five days remaining, the schedule keeper informs the successor they have approximately five days until they are on the Critical Chain.

This is a dynamic countdown for the successor. If the predecessor reported two days later that he or she hit a glitch and still had five days remaining, this would be passed on to the successor.

This allows Critical Chain resources to plan their work schedules and keep other project managers aware of their pending Critical Chain status.

The major distinction of Critical Chain Methodology is the way in which the schedule is managed. Management controls the project by monitoring status of the buffers. This allows them to highlight the tasks that need immediate attention. A typical project will have numerous feeder buffers.

The most consumed feeder buffer is protecting the feeder path with the highest probability of delaying the Critical Chain. Thus, management can focus attention on the feeder paths with the most depleted buffers. Of course, the CC tasks by definition are always considered crucial.

The main benefits of Critical Chain Scheduling are throughput oriented priorities for tasks and resources; on-time projects, controlled scope and cost, significantly improved project lead times and focus on continuous improvement.

By revising the target durations as an aggressive target duration schedule, along with elimination of task due-dates, we can minimize impact of "Parkinson's Law."

Using buffers allow resources to focus on work without task due-date distraction and efficiently protect against "Murphy's Law" with shorter project lead-times through concentrated safety protecting what is crucial to project success. Resource alerts and effective prioritization of resource attention allow projects to take advantage of good luck and early task finishes while buffers protect against bad luck and later than scheduled finishes. Buffer Management provides focus for schedule management, avoids unnecessary distraction, and allows recovery planning to take place when needed, but well before the project is in trouble.

The Critical Chain approach to single projects allows the multi-project environment to avoid the lead-time multiplying effect of multi-tasking. In order to achieve the benefits of Critical Chain Scheduling and Buffer Management, we must change the process how we design the processes in project management like stopping spreading safety, hidden and wasted in the tasks.

The Project Team must concentrate safety in strategic places that protect what is important to the project from Murphy's Law. The Project Team must stop the behaviors that waste time in the project by avoiding task due-date focus and Parkinson's Law. The Project Team must avoid resource multi-tasking which results in the lead-time multiplication and focus on the task at hand. Management team must take responsibility for protecting resources from competing priorities that drive multi-tasking. The Project Team must account properly for resource contention. Project managers, when building project schedules must realize resource dependency is as real as task dependency when determining what is critical for the project.

The goal of Critical Chain (CC) is to help projects finish on time, within budget, and without curtailing the objectives of the project (scope). The main points of Critical Chain are:

- Throughput oriented priorities for tasks and resources.
- It is a cultural change in how to manage projects and evaluate team members.
- Avoid multi-tasking, especially while on the Critical Chain.
- Protect against inherent uncertainty by aggregating all safety time at the end of the project rather than building it into individual task estimates.
- Concentrate on the constraint of the project: the longest chain of dependent tasks or resources (dependency can either be the standard CPM finish-start dependencies or resource dependencies).
- Most importantly focused continuous improvement.

APPENDIX A : PROCESS PLANT FEASIBILITY STUDY

The CPM schedule for Feasibility Study Project and its resource distribution are illustrated in Figures from A.1 to A.7.

In Figure from A.1. to A.3. Critical Path Schedule and resource usage of Project Manager and Commercial Manager are shown. The Critical Path Schedule has 20 activities and a project duration of 65 days.

In Figures from A.4 to A.7, Critical Chain Schedule and resource usage of Project Manager and Commercial Manager are shown. The Critical Chain Schedule has 27 activities and a project duration of 62 days. The project buffer is 21 days. The other six feeding buffer are just to protect critical chain.

The selected resources Project Manager and Commercial Manager are leveled in Critical Chain Schedule compared with Critical Path Schedule.The estimated task durations in Critical Chain Schedule is taken to be as 50 per cent durations of Critical Path Schedule.

During the execution of the project, control of schedule is carried out by reporting of remaining durations of each activity to complete is reported in Critical Chain methodology. But in Critical Path methodology completed percentage of each activity is reported.

As shorter durations are used in Critical Chain, some tasks may be completed late. So the feeding and project buffers are consumed for these delays in order to meet the project due date.

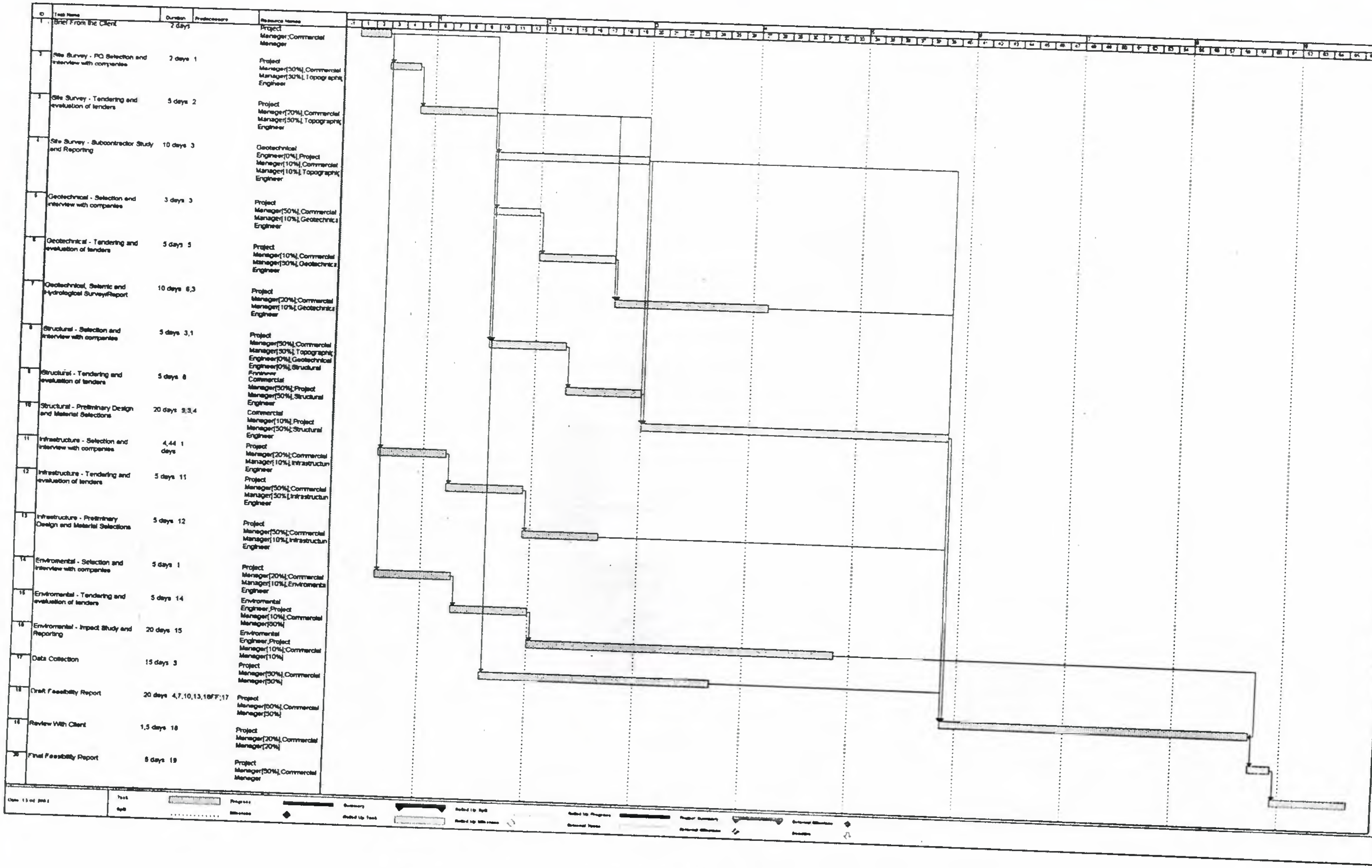


Figure A.1. Process Plant Feasibility Study-Critical Path Schedule

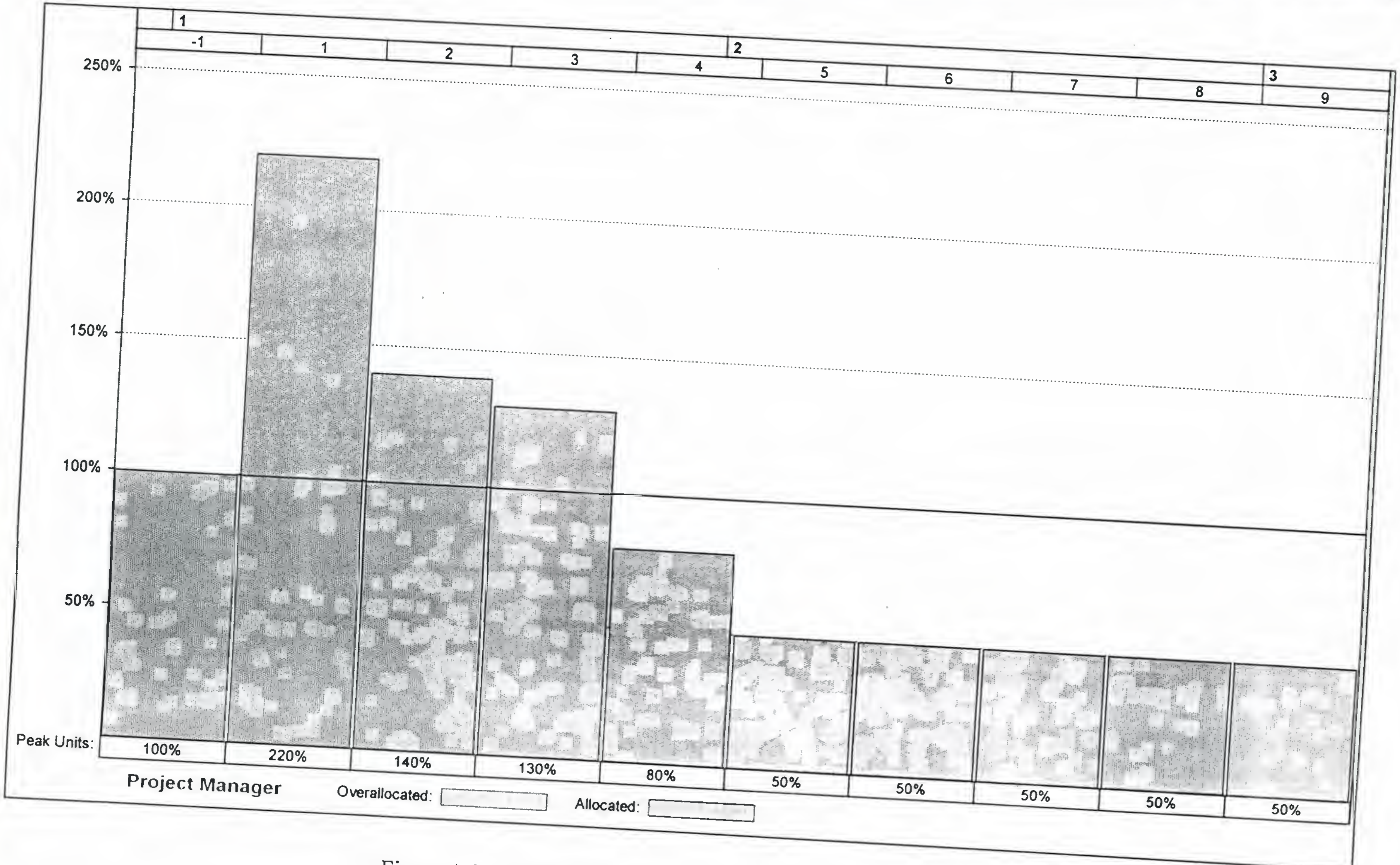


Figure A.2. Critical Path-Resource Graph of Project Manager

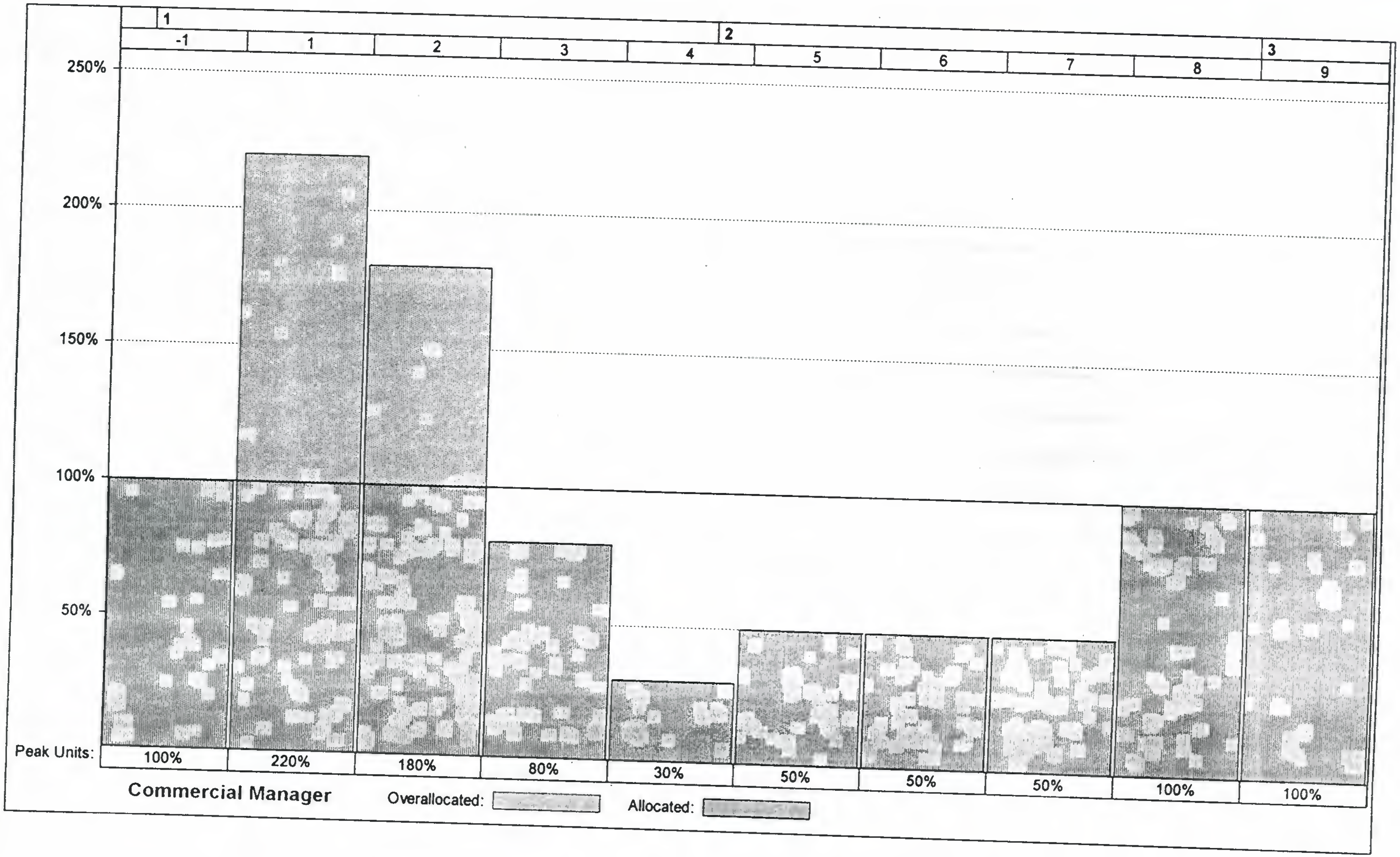
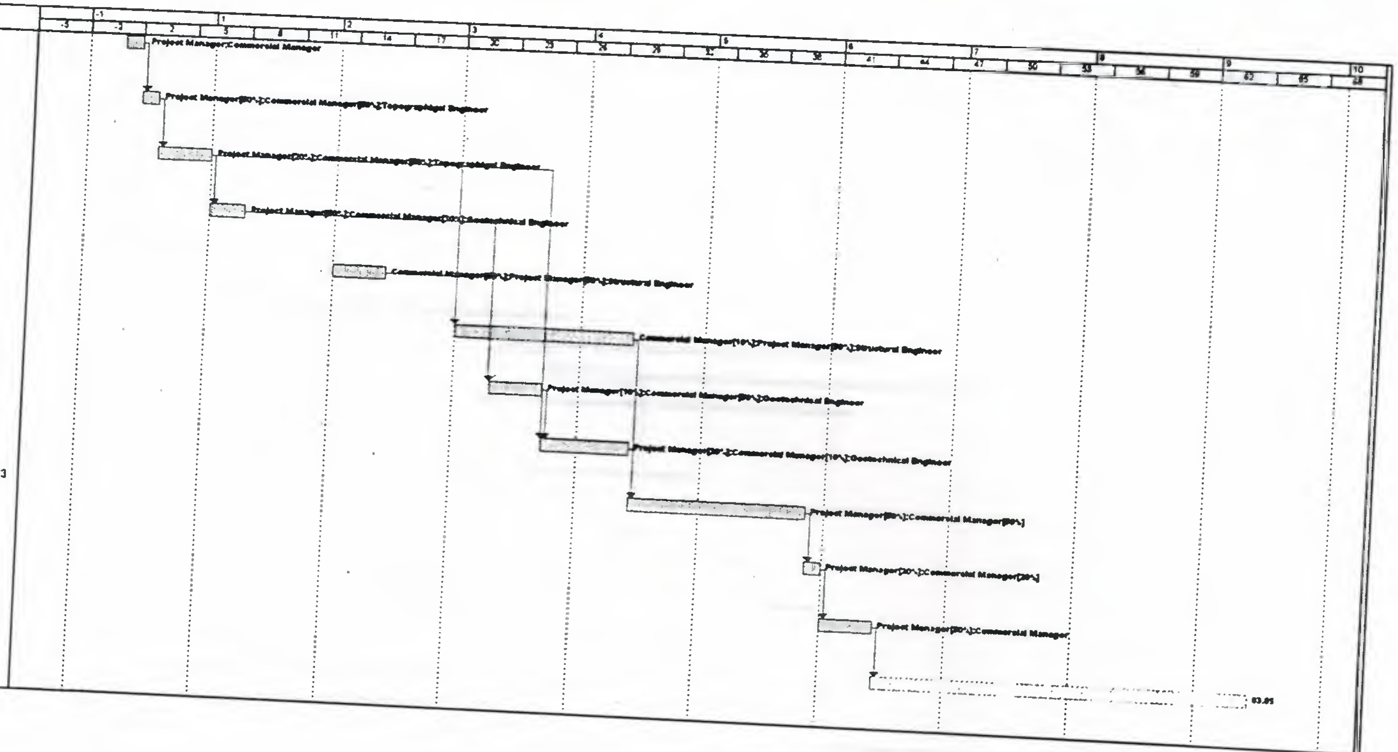


Figure A.3. Critical Path-Resource Graph of Commercial Manager



ID	Task Name	Duration	Predecessors
1	Brief From the Client	1 day	
2	Site Survey - PQ Selection and interview with companies	1 day	1
3	Site Survey - Tendering & evaluation of tenders	3 days	2
7	Geotechnical - Selection and interview with companies	2 days	3
12	Structural - Tendering & evaluation of tenders	3 days	10;11
13	Structural - Preliminary Design & Material Selections	10 days	12;3;4;5
8	Geotechnical - Tendering & evaluation of tenders	3 days	7
9	Geotechnical, Seismic & Hydrological Survey/Report	5 days	8;3
24	Draft Feasibility Report	10 days	4;9;13;16;20FF;22;17;8;21;23
25	Review With Client	1 day	24
26	Final Feasibility Report	3 days	25
27	PB|Final Feasibility Report-70	21 days	26

Figure A.4. Process Plant Feasibility Study – Critical Chain Tasks Schedule

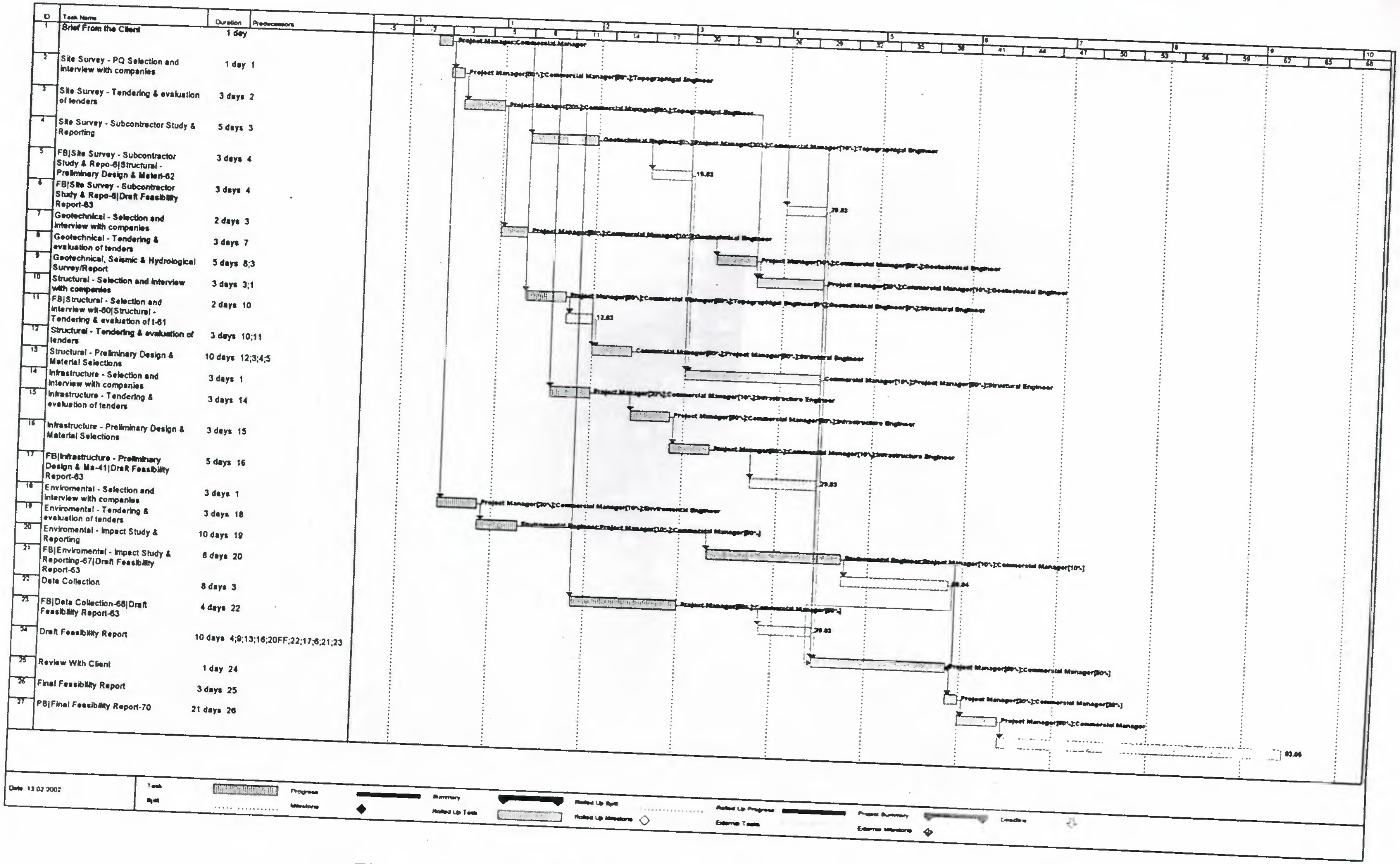


Figure A.5. Process Plant Feasibility Study-Critical Chain Schedule

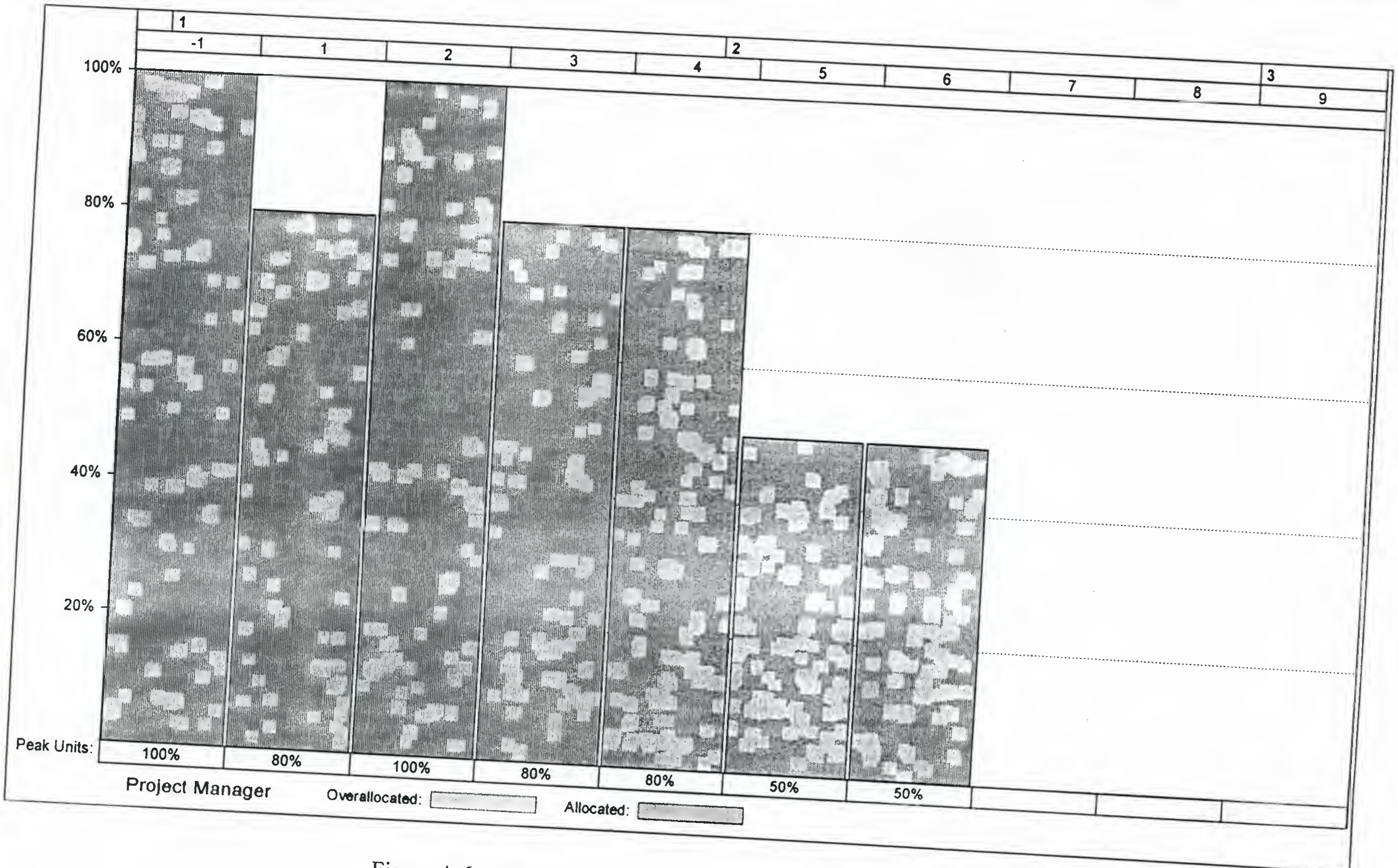


Figure A.6. Critical Chain-Resource Graph of Project Manager

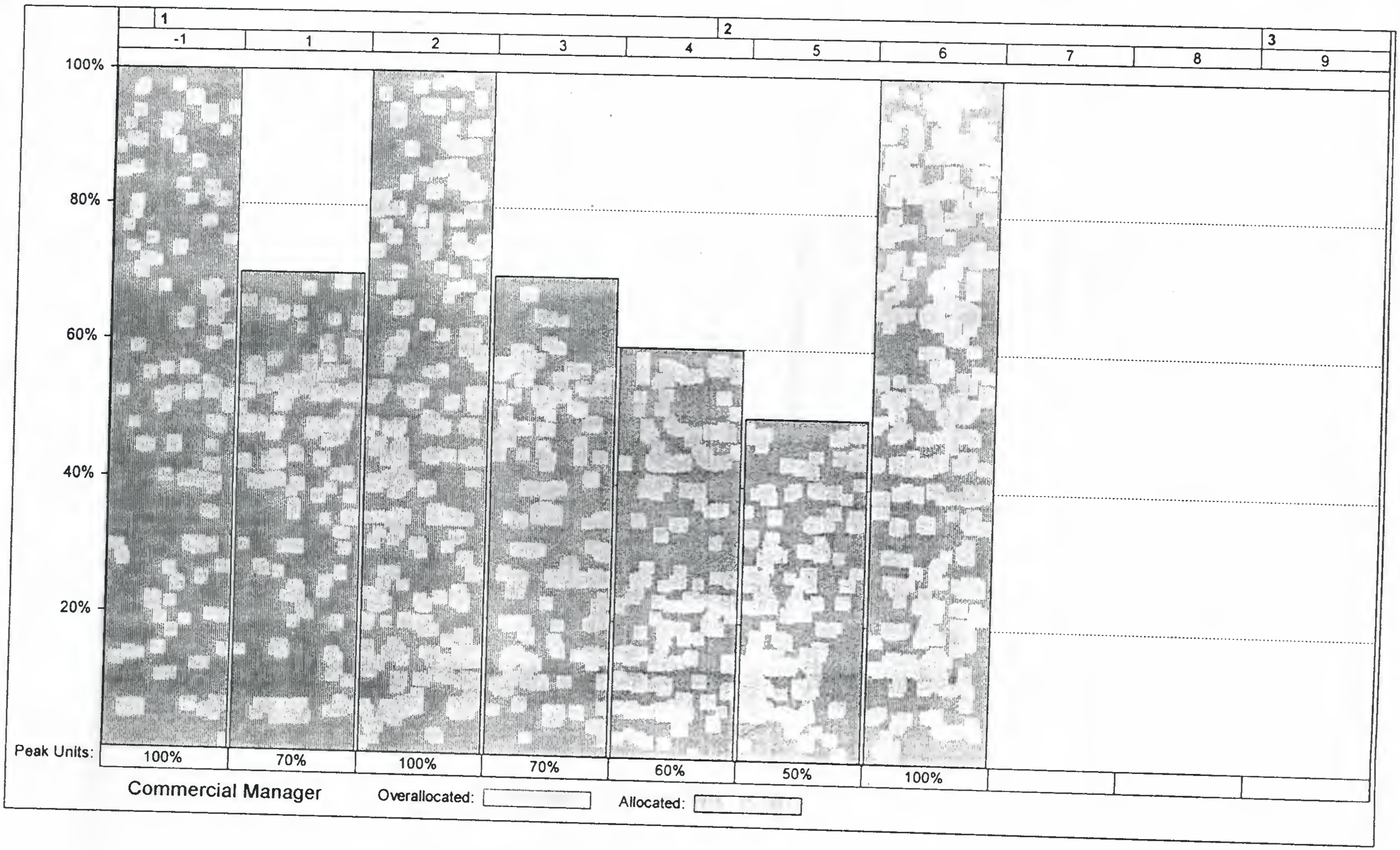


Figure A.7. Critical Chain-Resource Graph of Commercial Manager

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