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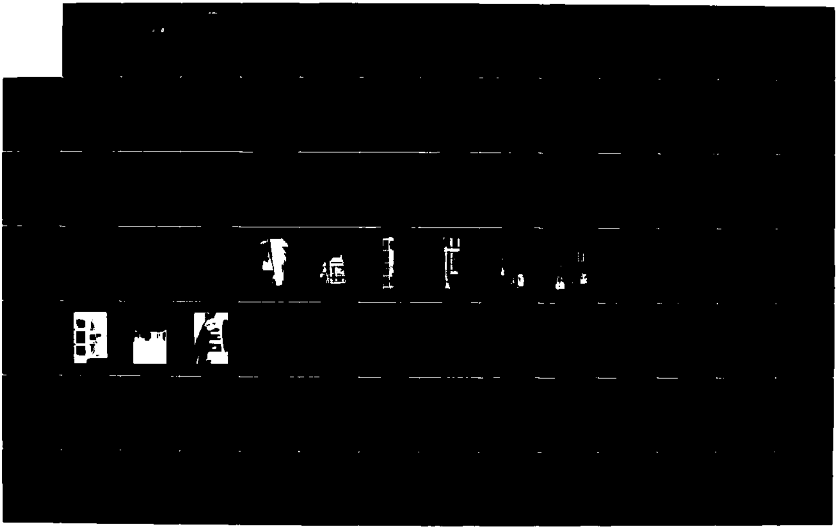

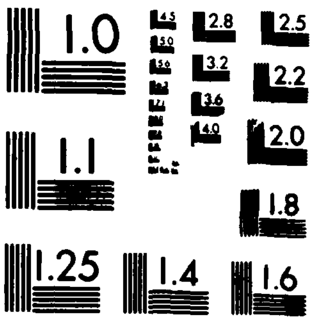
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COVER SHEET

A Disturbance Scheduling Technique for Managing Renovation Work

Captain Wayne Edward Whiteman
HQDA, MILPERCEN (DAPC-OPA-E)
200 Stovall Street
Alexandria, VA 22332

Final Report - 8 May 1987

A thesis submitted to the Massachusetts Institute of Technology in partial fulfillment of the requirements for the degrees of Civil Engineer and Master of Science in Civil Engineering

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The objective of this thesis is to develop a method for better managing renovation construction. First, a case study is undertaken to investigate managerial and technical issues peculiar to the renovation process. Results are supplemented by findings from interviews with the New England Division of the U.S. Army Corps of Engineers and lead to the formulation of a generic model of the renovation process addressing the topics of project procurement,

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SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)* management, and organization.

Taking into account the aspects of the generic model developed, a new four-phase Disturbance Scheduling Technique is presented. It is based on the Critical Path Method but resolves current shortcomings in its application to renovation construction.

Phase 1 of the technique establishes an initial, unconstrained logic network. Phase 2 results in a prioritized list of disturbance concerns. Phase 3 applies a new algorithm to systematically relax these disturbance constraints by employing time scaling of the project network, objective scheduling rules, and integration of the Line of Balance Method. Resource allocation is applied as a subsidiary consideration in Phase 4 to arrive at a total project plan.

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A DISTURBANCE SCHEDULING TECHNIQUE FOR MANAGING RENOVATION WORK

by

CAPTAIN WAYNE EDWARD WHITEMAN

B.S., UNITED STATES MILITARY ACADEMY, WEST POINT
(1975)

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June 1987

Signature of Author ______________________
Department of Civil Engineering
April, 1987

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A DISTURBANCE SCHEDULING TECHNIQUE FOR MANAGING RENOVATION WORK

by
Wayne E. Whiteman

Submitted to the Department of Civil Engineering on April 8, 1987 in Partial Fulfillment of the Requirements for the Degrees of Civil Engineer and Master of Science in Civil Engineering.

ABSTRACT

The objective of this thesis is to develop a method for better managing renovation construction. First, a case study is undertaken to investigate managerial and technical issues peculiar to the renovation process. Results are supplemented by findings from interviews with the New England Division of the U.S. Army Corps of Engineers and lead to the formulation of a generic model of the renovation process addressing the topics of project procurement, management, and organization.

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Phase 1 of the technique establishes an initial, unconstrained logic network. Phase 2 results in a prioritized list of disturbance concerns. Phase 3 applies a new algorithm to systematically relax these disturbance constraints by employing time scaling of the project network, objective scheduling rules, and integration of the Line of Balance method. Resource allocation is applied as a subsidiary consideration in Phase 4 to arrive at a total project plan.

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Thesis Supervisor: Dr. Henry G. Irwig

Title: Senior Lecturer, Department of Civil Engineering

BIOGRAPHICAL NOTE

Wayne E. Whiteman graduated from Chatham High School in Chatham, New York in June 1975. He graduated from the United States Military Academy, West Point, New York as a Distinguished Cadet in June 1979 with a Bachelor of Science Degree with a Concentration in Civil Engineering. Upon graduation from West Point, he was commissioned as a Second Lieutenant in the U.S. Army Corps of Engineers. Captain Whiteman is a graduate of the U.S. Army Engineer Officer Basic Course, Engineer Officer Advanced Course, and the Combined Arms and Services Staff School. He has completed a number of engineer troop unit assignments, to include Platoon Leader and Executive Officer, Company D, and Logistics Officer for the 76th Engineering Battalion at Fort Meade, Maryland. His most recent assignment was as Commander, Company B, 2nd Engineer Battalion at Munson, Republic of South Korea.

Captain Whiteman is a registered Professional Engineer in the Commonwealth of Virginia. He is a member of Phi Kappa Phi, the American Society of Civil Engineers, the National Society of Professional Engineers, and the Society of American Military Engineers.

Throughout his two years at MIT, Captain Whiteman concentrated his studies in the field of construction engineering and management. His secondary field of interest was in structural engineering and mechanics. Upon graduation he will be assigned as an Assistant Professor at the United States Military Academy, West Point, New York.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to Dr. Henry G. Irwig for his interest, encouragement, and invaluable guidance throughout the preparation of this thesis. I have enjoyed working with him very much, and give him my special thanks.

My research was greatly facilitated by those involved in the Center Plaza project used as a case study in this document. Although they remain anonymous, my special thanks goes out to each of these individuals. By availing their organizations to open and rigorous evaluation, they contributed immeasurably to the success of this work. In addition, I would like to thank the personnel of the Area Office for the New England Division of the U.S. Army Corps of Engineers and the numerous construction firms I visited in the Boston area. Each of the personnel interviewed willingly contributed their time and knowledge, thus providing me with keen insights and making this study enjoyable as well as rewarding.

I also extend my thanks to my officemates who made life that much easier over the past two years: Richard Davis, Greg Martin, Chuck Protasio, Bill Seymour, and Tom Sydelko; and to my faculty advisor, Professor Dave Marks, who got me started in the right direction and continually provided support during my trying times as an MIT student.

Finally, I am most grateful to my wife Cathy, who is a constant source of joy, encouragement, and inspiration. To her this work is dedicated.

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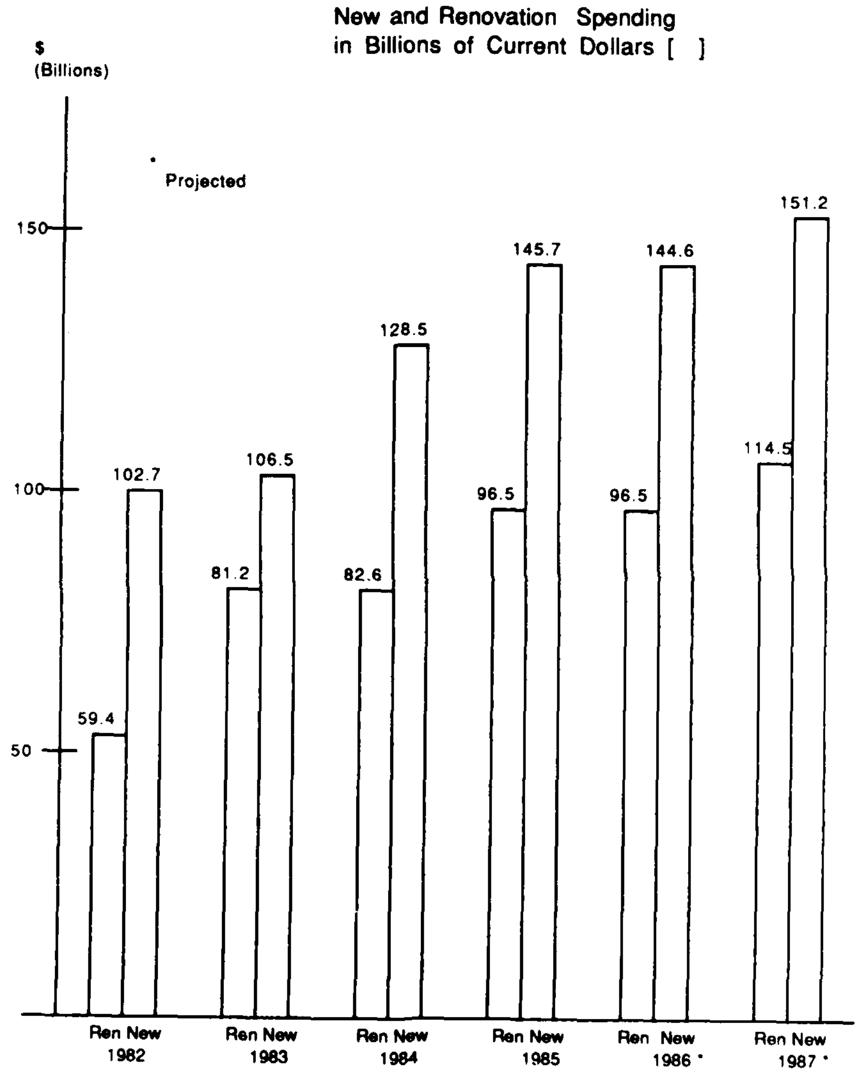
CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW OF THE IMMENSITY OF THE BUILDING RENOVATION CONSTRUCTION MARKET

The commercial, industrial, and institutional renovation market reached an all-time high in 1985 of $96.5 billion and included work on more than 640,000 buildings! This represented 40% of the total market at that time and is projected to grow. By the end of 1987 renovation spending is predicted to increase by 18.7% and reach $114.5 billion, accounting for 43% of the total market. Figure 1.1 illustrates the magnitude and growth in renovation spending for a five-year period from 1982 to 1987. [55]

FIGURE 1.1:



Source: Cahners Economics

1.2 STATEMENT OF THE PROBLEM: Problems associated with the building renovation process and establishing the need for improvement

Despite this rapid growth, only limited research has been conducted of the issues surrounding building renovations, to include strategic planning, scheduling, management, and control of the process. Only recently have attempts been made at isolating the key challenges associated with this type of project and identifying innovative managerial and technical approaches for dealing with them. The remainder of this section briefly outlines some prominent concerns and problems which are commonly encountered in this increasingly important part of America's largest industry.*

1.2.1 Failure to Understand the Differences between Occupied Building Renovations and New Building Construction

Renovation work is often complicated by taking place in building systems which must keep operating. The construction industry has not developed well-defined techniques and concepts addressing this type of work. A diversity of opinions exist on how best to approach the problems introduced by ongoing tenant occupancy. Different designers, owners, and contractors operate with various approaches. All too often the construction industry treats renovation projects in a manner completely analogous to the

---

*Construction accounts for more than $300 billion of work each year and employs 5.5 million workers. It is composed of some 1,200,000 firms. [35]

procurement process for new construction and continues to plan, organize, and execute these projects "the way they have always been done," based soley on experience, without an overall methodology on how to proceed.

The above approach is arguably inadequate. Without the development and implementation of techniques and concepts consistent with the differences observed in renovation, better productivity and efficiency can not be realized. With today's high interest rates on construction loans, reducing construction time or avoiding even a small delay on a project can save thousands of dollars.

1.2.2 Deficiencies in Planning and Scheduling

There is a resistance to using well-documented schedules in managing the renovation process. The purpose of sound scheduling management tools is not well understood. Schedules are often produced merely to satisfy a client. Many times they are simply used as a marketing tool in selling an owner on the management skills of a contractor or construction management firm. Many in the renovation construction industry feel that schedules are generally obsolete by the time they are printed and usually produced "to keep somebody happy" or satisfy an cwner with a "pretty picture" of how a project might proceed.

Renovation schedules rarely include a level of detail which accurately depicts a project. As an example, one major building renovation project completed in Boston in 1986, on the order of magnitude of $15 million, included only a scant flow chart diagram of the construction process on two notebook-size graph sheets. This alarmingly small amount of detail and lack of a documented thought-process is unfortunately a common occurence on most any major building renovation project one cares to study.

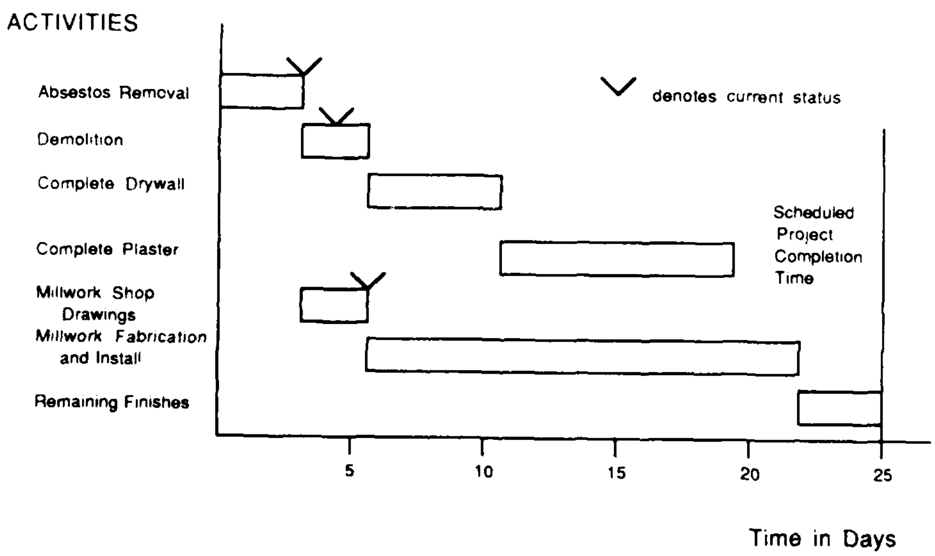
1.2.3 Lack of Knowledge and Training

Problems in failing to properly use project schedules stem from a lack of knowledge, training, and applicability of current techniques. Construction project managers are many times unfamiliar with the network analysis methods which are reviewed and modified in this thesis. These methods are often viewed as too complex and cumbersome simply because planners have not been introduced to the fundamentals and advantages of their disciplined application.

As a result of this general lack of understanding, it is discovered that simple graphic bar charts are the norm for scheduling renovation projects. An example is provided in Figure 1.2. Admittedly, these are better than no schedules at all, but there are serious drawbacks in their use. First, bar charts cannot easily show interrelationships between complex activities on a project. The detailed sequencing of activities is not readily apparent. There is a failure to show which activities are critical or potentially critical to successfully completing a project on time. There is also a failure to show the

FIGURE 1.2 :

Sample Construction Project
Bar Chart



precise effect of delays in completing activities as planned. Finally, bar charts can not easily cope with frequent changes or updating as a project proceeds through construction. The end result is the lack of a comprehensive plan for the overall construction process.

1.3 RESEARCH OBJECTIVES

This thesis is devoted to researching and documenting the complex issues associated with undertaking major occupied building renovations. While in many ways the upgrade and improvement of building facilities is similar to new construction work, it will be shown that significant differences exist and need to be accounted for.

The overall objective of this thesis is to develop systematic and objective methods addressing the unique issues that are faced in the renovation field and thereby advance the process in which renovation work is currently undertaken. Problems in scheduling renovation work with traditional network analysis models will be analyzed. The goal will then be to develop a new scheduling technique which incorporates the disturbance constraints associated with conducting construction in a facility which must remain operational. It will integrate normal construction logic with new disturbance scheduling procedures to reduce construction time, better organize the flow of a project, and provide for more efficient scheduling of specific work performance tasks.

1.4 METHODOLOGY OF RESEARCH

The methodology of research for developing this thesis was (1) to analyze the current situation surrounding the conduct and scheduling of building renovation work, (2) to couple these observations with management and scheduling tools representing the current state-of-the-art, and (3) to finally synthesize this information to produce workable, analytic systems which can easily be applied to occupied renovations and improve the efficiency of their completion.

The first part of this research process was to attain as much knowledge as possible and a consensus of rationale on the subject matter from selected firms located throughout the Boston, Massachusetts area and heavily involved in the building renovation market. An extensive interview process was initiated of these firm's top-level executives and individuals who specialize in planning, scheduling, and construction. Owner representatives, development builders, and construction management organizations were all included. Both public and private organizations were queried. The private organizations were all currently involved in major commercial building renovations in the Boston area. The public works research looked at housing renovation projects at Fort Devens, Massachusetts under the direction of the New England Division of the U.S. Army Corps of Engineers.

Concurrently, the author conducted a comprehensive review of the academic literature, coupled with a computerized literature search using the DIALOG system, on the topics of management, scheduling, maintenance, renovations, and rehabilitations as relevant to the broad field of engineering. Concepts derived from these references were explored for their applicability in improving current methods of managing and scheduling major occupied building renovations. An initial research paper was completed by the author in May of 1986 entitled "Optimization Strategies, Network Analysis and Scheduling Techniques: An Application to Building Rehabilitation and Renovation Projects."[61]

This research effort revealed advanced scheduling techniques used for plant maintenance in process-engineering disciplines, such as manufacturing, plant processing, and electronics, which seemed to display characteristics and procedures which were analogous to those needed in scheduling operational renovations in buildings, namely minimizing facility downtime during the maintenance and rehabilitaition, thereby allowing the facility to function in a fairly normal manner throughout construction. It also revealed substantial breakthroughs in optimally scheduling this type of work, thereby saving substantial time in the overall completion of projects.

The framework provided by these early research efforts stimulated an idea to develop a new technique, consistent with traditional network analysis models, for preparing schedules on renovation projects based on a disturbance scheduling approach. In addition, it was felt that the expertise and opinions of the renovation experts interviewed could be gathered, sorted, and analyzed for inclusion in and extension of this method. Also, significant portions of the new technique could draw upon the author's background, education, and experience in scheduling and construction.

As the research process continued, it was felt that the methodology for developing a Disturbance Scheduling Technique in its final form would focus of a concept of minimizing tenant concerns and meeting the operational requirements of a building, thereby allowing a facility to continue to serve its primary functions. While maintaining the integrity of an overall network logic diagram, the author would need to search for ways of scheduling activities in the most opportune manner while continuing to allow for the accomodation of all disturbance constraints.

1.5 OUTLINE OF THESIS PRESENTATION

The thesis begins with a comprehensive case study in Chapter Two that looks at the renovation process as a whole and uncovers several issues associated with the upgrade and improvement work on a major commercial building which can then be extended to occupied building renovations in general. Chapter Three is the synthesis of these generic factors in the form of a flow chart model of the renovation process. It also includes the development of a decision support system to improve the understanding and completion of occupied renovations.

Chapter Four begins with a review of the Critical Path Method in preparation for addressing the more detailed topic of how one should schedule major renovations. Chapter Five follows with considerations in renovation which require particular attention when employing traditional network planning models. In addition, it also reveals constraints in conducting occupied renovations which are unable to be addressed through the use of conventional techniques.

A new Disturbance Scheduling Technique is presented in Chapter Six. It is offered in the form of a step-by-step scheduling process which modifies the Critical Path Method to allow for the total inclusion of disturbance concerns unique to the renovation environment. Once this specific and detailed procedure is presented, Chapter Seven then applies the approach to an actual case by rescheduling a selected project. A separate schedule is also developed using traditional network analysis techniques and algorithms. These schedules, along with the schedule used during actual construction, are then be compared and analyzed in Chapter Eight and conclusions are drawn. A summary of the thesis with recommendations and areas of future research is offered in Chapter Nine.

CHAPTER TWO

A CASE STUDY OF RENOVATION WORK IN BUILDINGS: The Center Plaza Improvement Project

2.1 INTRODUCTION

2.1.1 Purpose

This chapter examines the process used for the development, design, and construction of a major renovation of a tenant occupied commercial building. The upgrade and improvement undertaken at the Center Plaza complex located in Boston, Massachusetts was selected for case study.

The objective of this chapter is to identify generic factors which are essential to the success of undertaking renovation work in all occupied buildings. The findings at the end of the chapter highlight a number of critical areas requiring particular attention in the rehabilitation of fully occupied commercial facilities. These factors, coupled with other research and case studies, are then extended into a general model of the building renovation process presented in Chapter 3.

2.1.2 Building Description and Rationale for Study

Center Plaza is a multi-tenant first class office building located on Cambridge Street in Boston, Massachusetts. It was built in the mid-1960's. Center Plaza commands a prominent urban position in downtown Boston. It is adjacent to both City Hall Plaza and Pemberton Square and it's walkways and pathways are important connectors in the Government Center pedestrian circulation system. One of its passageways is the beginning of Boston's historic Walk-to-the-Sea, a major component of the city's revitalization plan prepared by I.M. Pei.

The Center Plaza building is nine stories high with typical 70,000 square foot floors, bringing the total area to approximately 600,000 square feet. The building is partitioned into three sections with exterior lobby entrances to One, Two, and Three Center Plaza. Typical tenant floors are 23,000 square feet. The building has a curved facade which is pre-cast dressed with brick.

The Center Plaza improvement project was chosen as a primary case study for several reasons. First and foremost, it was a major renovation of a fully occupied and fully operational commercial building. In addition, its lessees were a myriad of corporate tenants of varying size and occupation, and hence introduced an assortment of tenant concerns. The scale of the project was large enough to encompass a wide spectrum of issues which might be characteristic of the renovation process. Finally, there appeared to be a number of lessons that could be learnt from this experience and the corporate owner offered fullest cooperation and assistance in uncovering these matters.

2.1.3 Conduct of the Study

Research for the Center Plaza study was conducted from February 1986 to July 1986. It consisted of a complete review of the documentation and correspondence associated with the project from early feasibility studies through actual construction. An extensive interview process was carried out with the major participants which included members of the Owner, the Architect, the Contractor, and selected individuals outside these organizations who were key to the renovation process. A complete list of positions interviewed is found in Table 2.1.

This chapter begins with a complete chronological review of the renovation process at Center Plaza in Section 2.2. The project evolution, results, and findings are grouped under three major headings: strategic planning, construction management, and technical planning and control. Findings of the strategic planning and early phases of the project are examined in Section 2.3.1. Management control topics follow in Section 2.3.2. Section 2.3.3 highlights several technical planning and control issues. Design considerations, construction schedules, and resource utilization are included topics. Some organizational issues and other peculiarities of the renovation process are also addressed. Major findings and concluding remarks complete

Table 2.1

INTERVIEW RECORD

THE OWNER

DEVELOPMENT MANAGEMENT DIVISION

President
Vice-President

PROPERTY MANAGEMENT DIVISION

President
Senior Vice-President
Vice-President, Commercial Properties
Manager, Tenant Improvement Work:
   Owner's Primary Representative/Project Manager
Regional Manager, Commercial Properties

BUILDING MANAGEMENT GROUP

Building Manager
Assistant Building Manager

LEASING DIVISION

Senior Vice President, Leasing

THE ARCHITECT

Principal in charge of project
Project Architect

THE CONTRACTOR

Project Manager
Project Supervisor

OTHER PARTICIPANTS IN THE PROCESS

Design Consultants
Project Regulatory Authority Personnel
Building Tenant

the chapter in Section 2.4. They serve as lessons learned and will be used in Chapter 3 in developing the model of the renovation process.

2.2 THE RENOVATION PROCESS*

2.2.1 Strategic Planning Phase

2.2.1.A CORPORATE POLICY AND THE ESTABLISHMENT OF OBJECTIVES AND GOALS

In order to maintain the market position of Center Plaza and upgrade its public image, the Owner proceeded in the early 1980's to plan a comprehensive renovation program. The original objectives of the renovation work, which can be considered fairly generic to tenant-occupied commercial properties, were to:

- maximize the market potential.
- modestly increase the space (or better use the available space, if possible).
- enhance and upgrade the overall building appearance.
- take advantage of all renovation opportunities with high benefit / cost ratios.

The original design program at Center Plaza was to focus on the exterior entrances, public spaces, and multi-tenant areas. The design was to address the civic objectives of upgrading the urban space associated with

---

* A detailed timeline of the Center Plaza renovation process is found in Figure 2.1. It shows major events in the evolution of the project categorized by scope, budget, and schedule changes. The reader should refer to this figure periodically while proceeding through the chronological discussion of the Center Plaza improvement.

Center Plaza. Some of the more specific project goals agreed upon to accomplish these objectives were to:

- improve the overall quality of the building; enhance and enliven the building's exterior public presence; improve its sense of identity while respecting the low scale character of the building.
- better identify the building entrances and provide for the proper transition of the passageways from Pemberton Square through to Government Center.
- enhance illumination of both the exterior and interior public spaces.
- improve public access to all areas of Center Plaza.

The objectives and goals above were established early on the project. In written communications with prospective architects, the Owner demonstrated concern for the integrity of the criginal design. To achieve continuity and maintain the original character of the building, the Owner considered consulting the original building architect. This step was excluded because of this architect's move to California.

A fact sheet describing the project summary, owners, managers, and building description was produced. Project objectives, design goals, a proposed construction budget and schedule, and a preliminary program was documented for internal use and for distribution to prospective architects.

Early renovation feasibility studies were conducted by a contracted architectural firm. Original design packages explored the possibility of work on the building's penthouse and roof top. A 1982 estimate included options bringing the total project budget to $12,590,000. This preliminary program for renovations included the following elements:

Exterior and public spaces:

- Entrances and lobbies of One, Two, and Three Center Plaza, at both Cambridge Street and Pemberton Square.
- Public passageways between Cambridge Street and Pemberton Square at One and Three Center Plaza.
- Retail arcade at Cambridge Street and Pemberton Square.
- Lighting, streetscaping, street furniture, and paving.

Interior elements:

- Multi-tenant lobbies, including furnishings and graphic.
- Public bathrooms.
- Elevator cabs.

A financial analysis and rent study was completed in April, 1983 to analyze the competition in the market place and future trends. It looked at three alternative actions over a 10 year period and concluded that the penthouse work should be dropped. Roof top changes were also later eliminated.

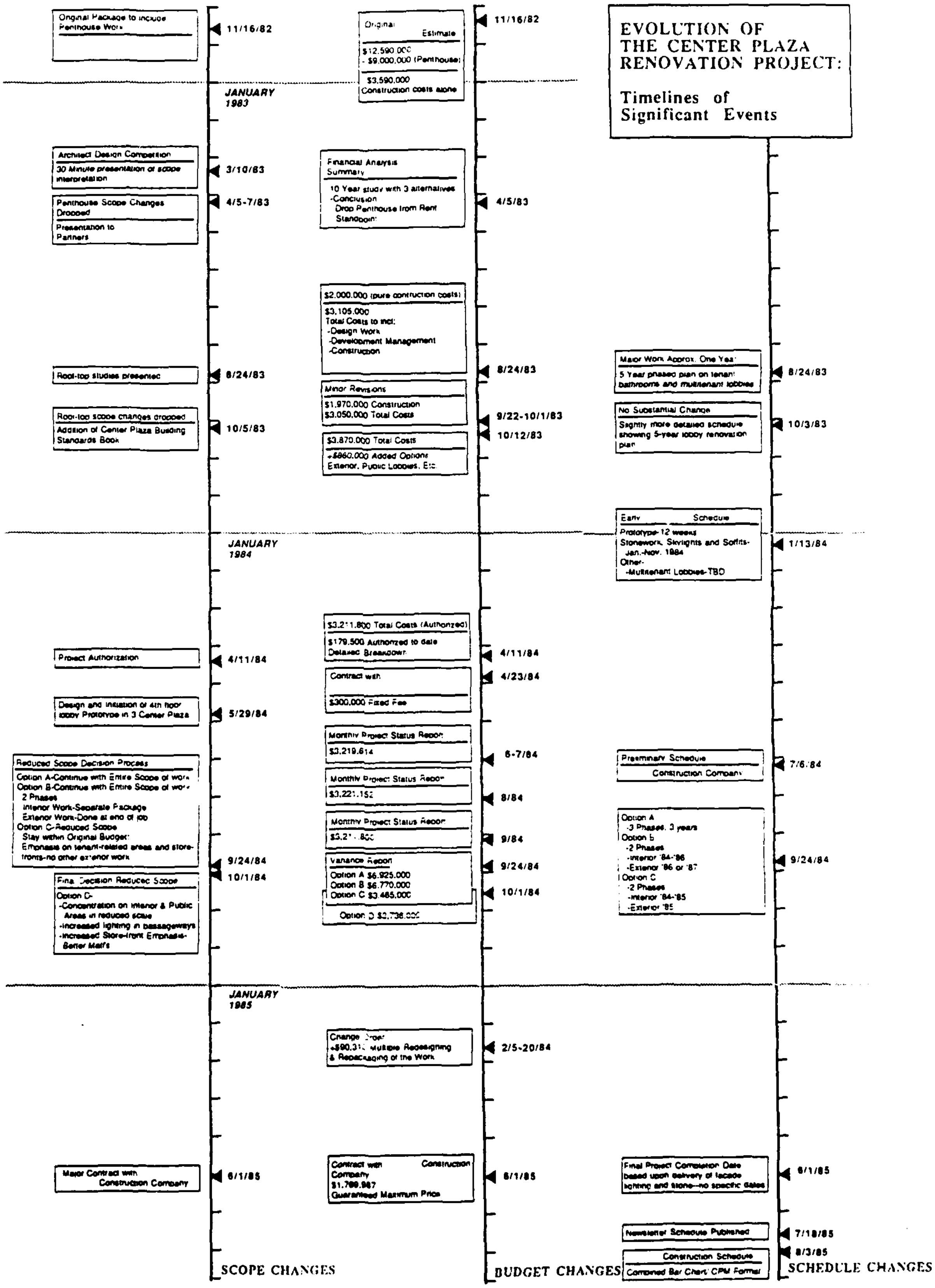


FIGURE 2.1: EVOLUTION OF THE CENTER PLAZA RENOVATION PROJECT: Timelines of Significant Events

2.2.1.B PLANNING AND ORGANIZING THE PROJECT TEAM: The Design Competition

In early 1983, the decision was made by the Owner to run a design competition. Outside consultants were contracted to advise in design development, assist in the competition, and help choose an architectural firm. The design competition was intended to help stimulate creativity on the project. It was viewed as an excellent idea-generator for attaining a superior result that no one person knew ahead of time. It was also felt that a competition would serve as a focal point for the project and provide future direction for the renovation process.

In April and May of 1983, three architectural firms were selected to participate in the competition. The criteria for selection to compete were:

1. Small, full-service architectural firm.
2. Commitment of firm's principal(s).
3. Past experience in commercial buildings-renovation, interior and architectural design.
4. Reputation for architectural design and urban design excellence.
5. Published work and awards.

Documentation of the process for architect selection clearly defined objectives, criteria for selection, a detailed timetable of events, and members of the selection committee. An in-house review defined the contents of presentations to include narrative and graphic information.

Submission requirements were offered in outline form. A fact sheet was prepared for internal use on each of the competing firms indicating the principals, notable projects, and general comments.

The owner sought out young, aggressive, and growing firms that they felt would devote the time and special effort the project deserved. It was felt a competition would stimulate professional effort on the part of the competing firms prior to the actual project beginning. The participants admitted to a feeling of terrific involvement and enthusiasm.

There were some problems with the design competition, however. A $2,000,000 construction budget was stipulated in the competition rules. This requirement was of secondary concern to the competing firms. Their primary concern was to win the competition and award of the contract. The eventual Project Architect admitted that their original submissions were beyond the $2,000,000 construction budget. At this point, there was little effort by the Architect or the Owner to prioritize a work package and clearly identify which items could and should be accomplished within a feasible working budget. We will see later that this fact contributed to significant cost overruns on the project.

In concluding the competition, each architectural firm received a stipend of $3,500 for their work in the process. The final selection of the Architect was made in the first part of May 1983.

2.2.1.C ESTABLISHMENT OF THE SCOPE OF THE PROJECT AND PREPARING THE ACTUAL DESIGN

The original scope of the work at Center Plaza was arrived at in August of 1983. It refined the preliminary program and is outlined in Table 2.2 below:

Table 2.2

ORIGINAL SCOPE OF WORK

EXTERIOR
- Passageways - Stonework, Flooring, Walls
  - @ 1 and 3 Center Plaza
- Entrances - New Doors, Glass Facades, Metal Finishes, Stone Panels
  - @ 1,2, & 3 Center Plaza
- Public Lobbies - Ceilings, Flooring, Walls, Lighting, Directories
  - @ 1,2, & 3 Center Plaza
- Storefronts and associated Stone Panels
  - @ 1,2, & 3 Center Plaza
- Skylights and Soffits
- Arcade - Ceiling, Lighting, Artwork, and Some Paving
- Exterior Facade Lighting

INTERIOR
- Multi-tenant Lobbies - 27 each
  - Ceilings
  - Installation of improved life safety systems
  - Lighting
  - Wall Finishes
  - Carpeting
  - Restrooms
  - Floors and Partitions
- Elevator Cabs
  - Complete Interior Finishes
  - Lighting

Visual renderings of the original design scope are found in Figure 2.2. The major work was to be completed in approximately one year, with a five-year phased plan for tenant bathrooms and multitenant lobbies. Minor revisions followed and the project received formal authorization in April 1984.

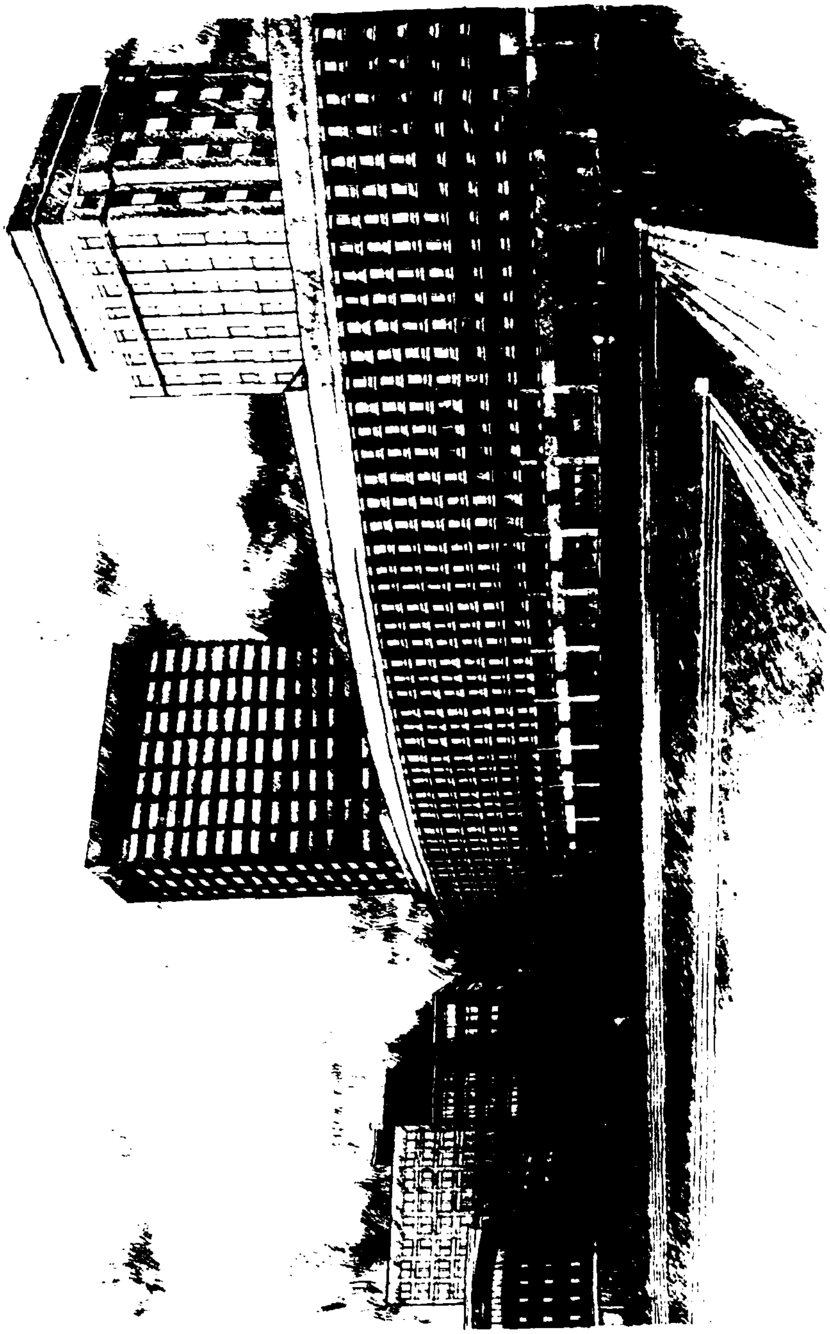
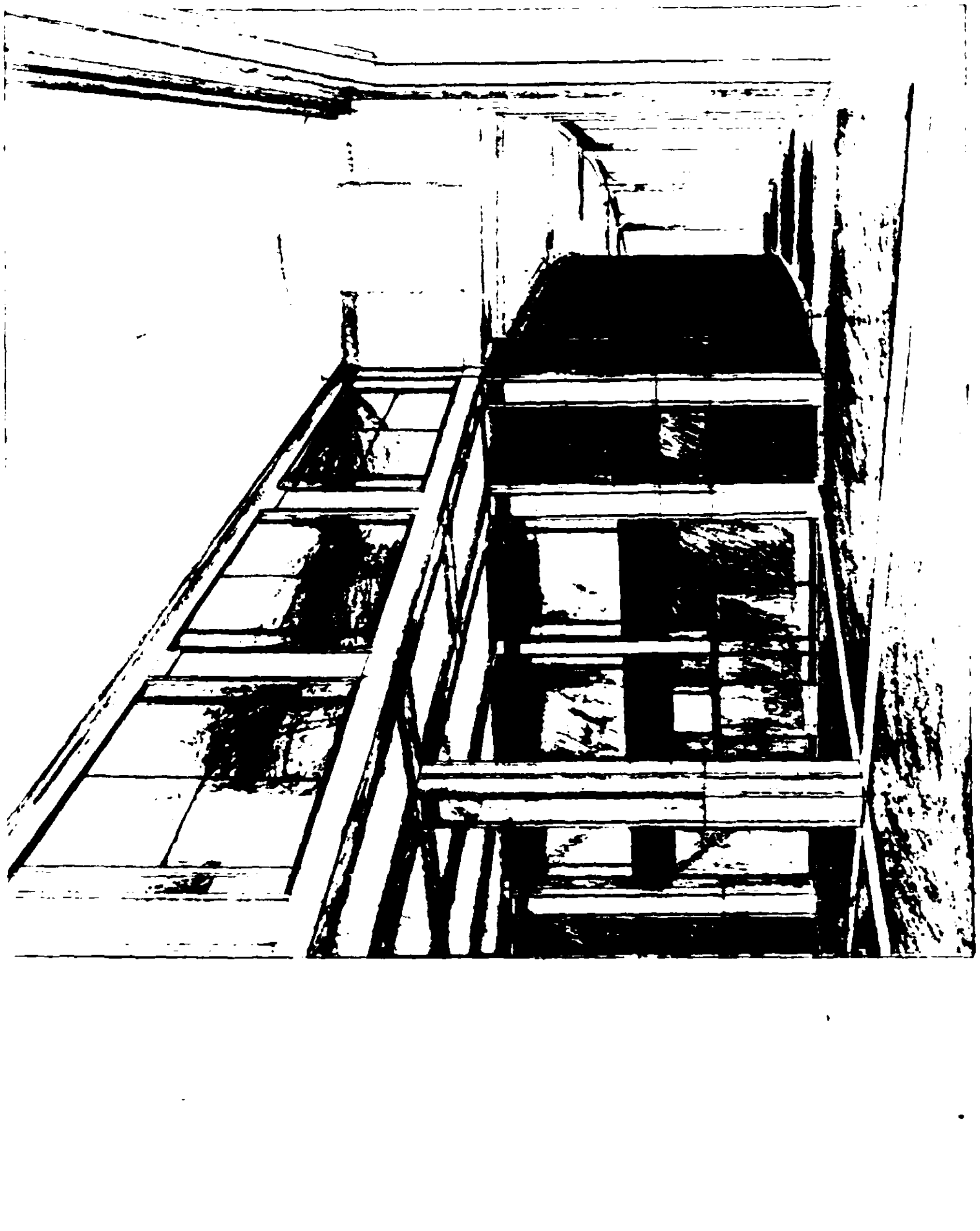
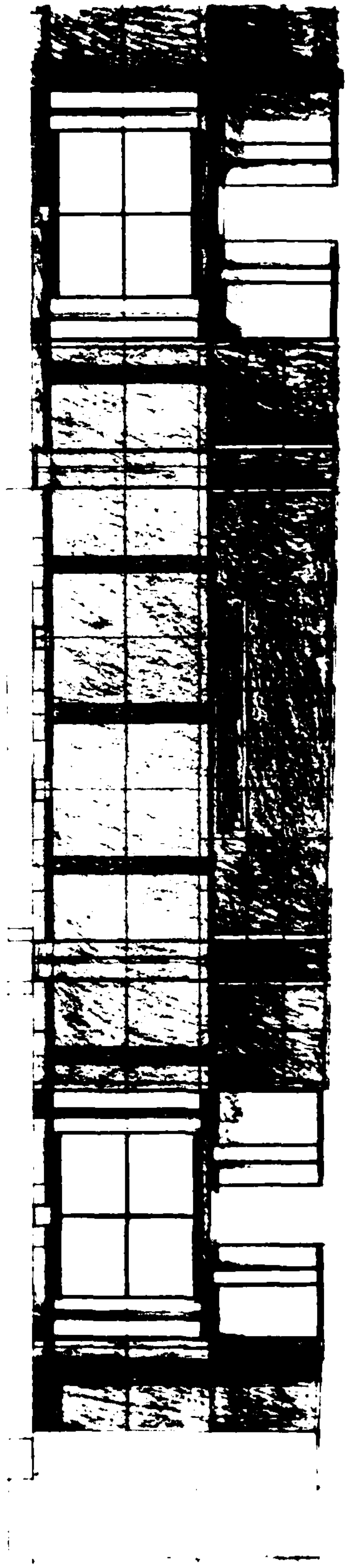
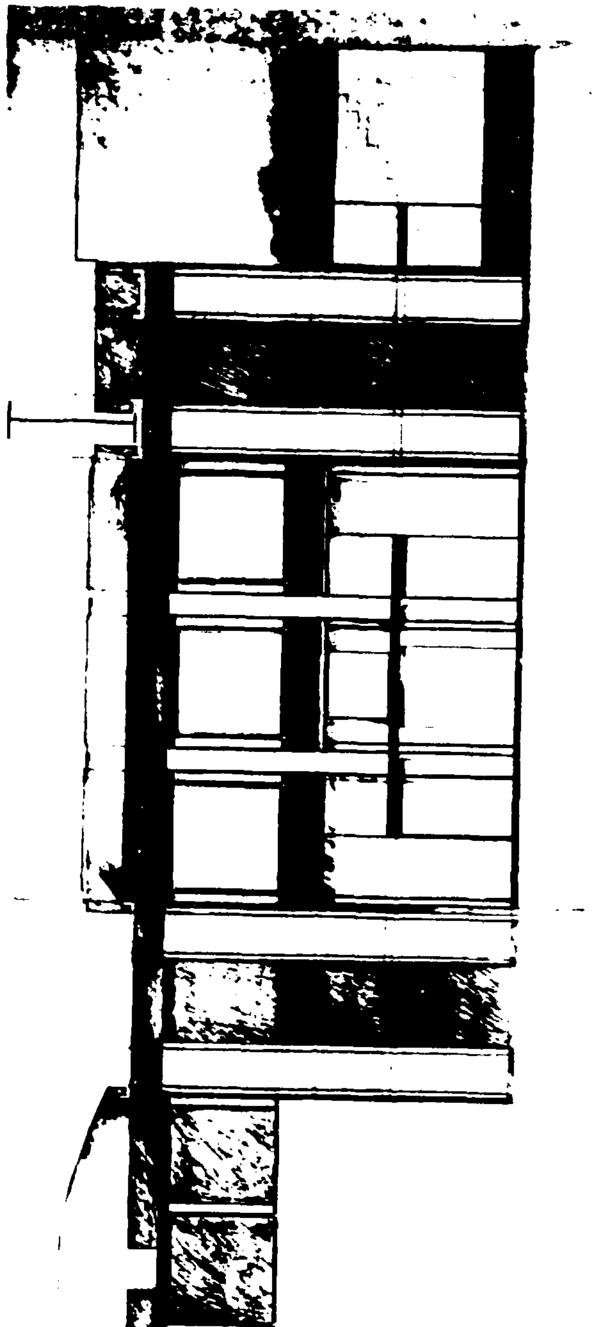


FIGURE 2.2: Original Design Renderings

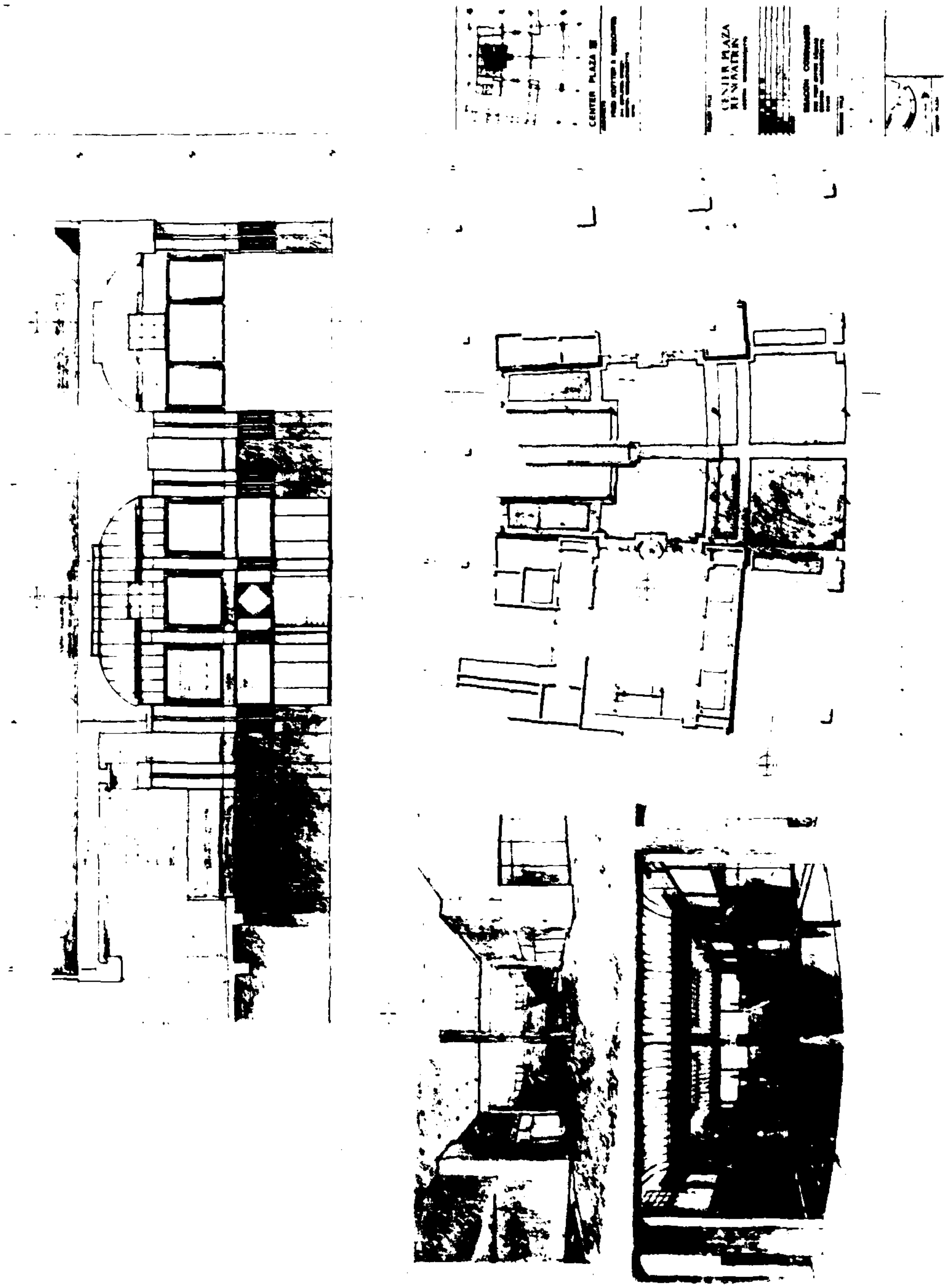




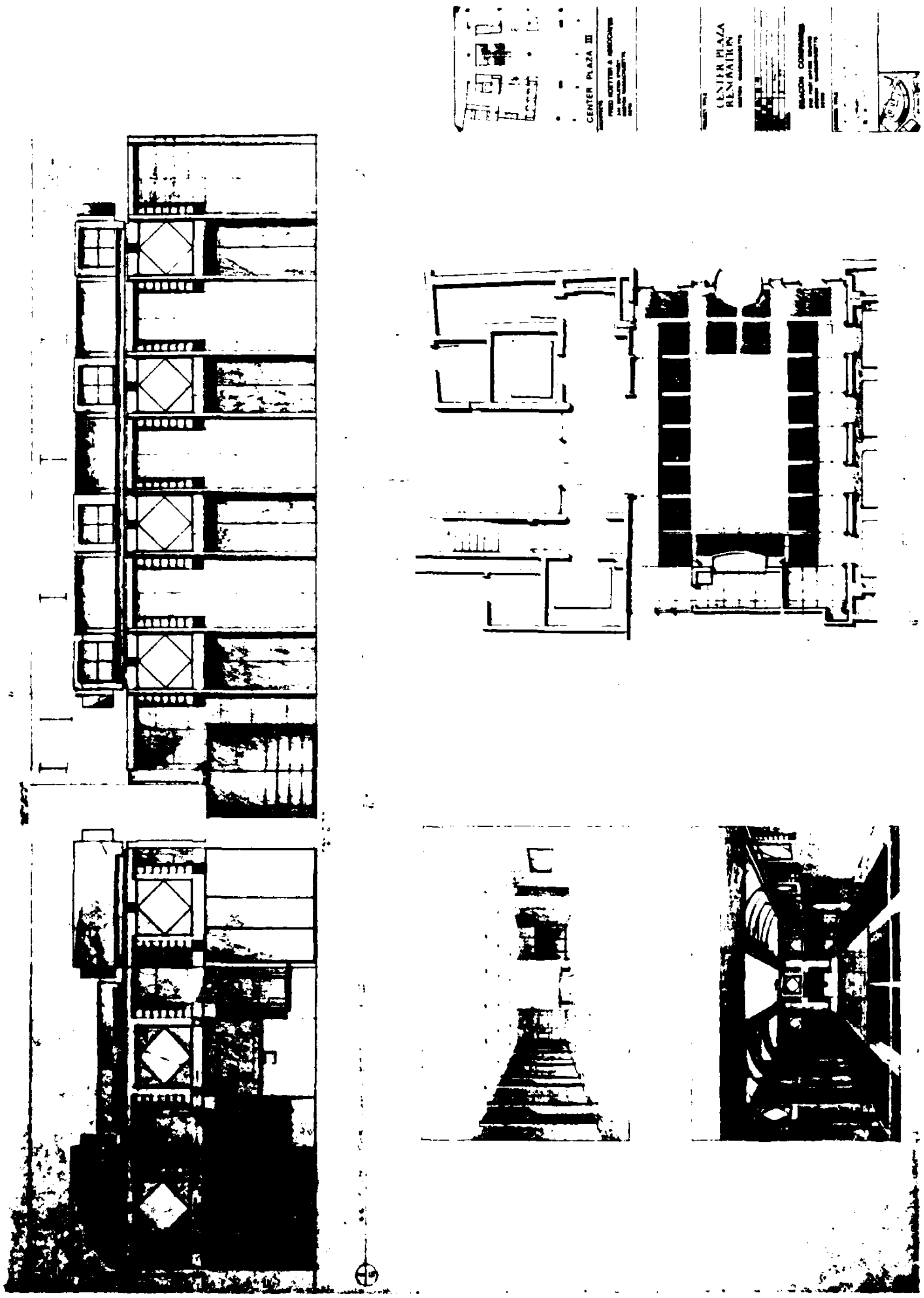
View of Two Center Plaza



3 Center Plaza Passageway



3 Center Plaza Passageway



3 Center Plaza Lobby

As outlined in Table 2.2, the original design goals of the project focused on the exterior portion of the building in addition to the multi-tenant areas and public spaces which would help to attract future tenants and improve the market position of the building. The architectural firm that won the design competition was primarily chosen for the strength of its design approach on the exterior and entranceways to the building. Of particular note was the night rendering of the building presented. It was felt by the selection committee that the Architect knew the urban nature of Center Plaza and understood how it fitted into the downtown surroundings. The exterior stonework, skylights and soffits were considered positive attributes of the design, as well as the arcade ceiling and extensive artwork.

The primary weakness of the selected architect was in their treatment of the interior spaces. There was concern over the temporal nature of their design. One member of the selection committee described it as being somewhat appliquè and encouraged the use of better materials in achieving a more lasting appearance.

In developing actual design drawings, the Architect failed to completely review original building drawings and specifications. Project meeting notes and interviews with Owner representatives revealed an ensuing need for field drawings and changes to the original design. Some physical explatory work was done, but could have been much more extensive.

2.2.1.D PLANNING AND ORGANIZING THE PROJECT TEAM: Selecting the Contractor

Two contractors were considered for the construction; one was a division of the Owner's holding company, the other was a firm recently separated from the Owner's holdings. The decision was made to proceed with the outside firm for three major reasons. First, it was felt they would be less expensive. Second, the outside firm specialized in renovation work and was very familiar with the issues of working around tenants. Finally, the Owner had previous experience with the outside firm in completing renovation projects and they therefore wanted to provide some continuity to their own tenant improvement work program.

Early documentation clearly indicated a major criteria for selection of the contractor (and the architect) to be experience in commercial building renovations. Past projects undertaken in this field of construction were considered very relevant. As mentioned above, one of the primary reasons for the eventual choice of the Contractor was extensive experience in renovation-type work. The Architect was recognized to have less experience in this regard, but was felt to possess characteristics and strengths that would offset this issue.

2.2.1.E PLANNING AND ORGANIZING THE PROJECT TEAM: The Owner's Project Management Team

During the summer of 1984 the Owner decided to shift responsibility for the Center Plaza project to their property management division. As a result of this management change, communications and coordination between those responsible for building operation and those responsible for actual construction activities improved. The property project manager communicated daily with the building managers who served as a liaison to the tenants. This communication was an effective two-way street. The property project manager fed information to the building managers concerning upcoming construction activities and changes. Corresponding information was sent back regarding tenant concerns. On-site control of the construction quality was high. The property management division now had a vested interest in the construction because of their dual property management role. They were able to devote sufficient time to monitoring the project.

Construction of a prototype multi-tenant lobby on the 4th floor of Three Center Plaza began in May. The renovation plan proceeded as scheduled for the next four months.

2.2.2 Management Control Phase: Tracking the Renovation Plan and Monitoring the Accomplishment of Project Goals

2.2.2.A THE NEED FOR A REDUCED SCOPE

Original project estimates from the Architect in August 1983 had shown a project budget of $3,105,000, of which $2,000,000 were construction costs. This estimate and revisions of the project scope varied only slightly through August 1984. When the total design package was sent to pricing by the Contractor in the late summer of 1984 the estimated budget totalled $6,925,000. This was a variance of approximately 125%.

There was a definite problem in the early estimates done by the Architect regarding the total project budget. The failure of the Owner to verify these estimates caused the Architect's original and ongoing estimating problem to go virtually unnoticed from the project initiation in 1983 until September 1984.

As a result of this large budget overrun as compared to original estimates, substantial reductions were required in the scope of the work. Three options were explored in this decision process and a modification of the third option was selected.

2.2.2.B THE REDUCED SCOPE PACKAGE

In arriving at the reduced scope, elimination of the majority of the exterior work was required. Emphasis was placed on tenant- related areas, to include public lobbies, elevator cabs, multi-tenant lobbies, and handicap bathrooms. This was a conscious decision on the part of the Management and Leasing Divisions of the Owner in implementing improvements required for future leasing of the property. At this point, albeit late in the project cycle, decisions were made to prioritize the work effort and cut out the items that need not be accomplished immediately to effectively market the building.

As a result, a minimum amount of effort was directed to the exterior and included only the lobby storefronts and entrances to the building. Focus was placed on the lobby of Three Center Plaza while significant reductions were made on the scope of work at One and Two Center Plaza. Plans for the arcade ceiling and artwork were dropped. The design to enhance the lighting of the building exterior and public entranceways was substantially reduced. Exterior work on the skylights and soffits which were considered positive attributes of the original design were dropped. Visual renderings of this reduced scope design are found in Figure 2.3.

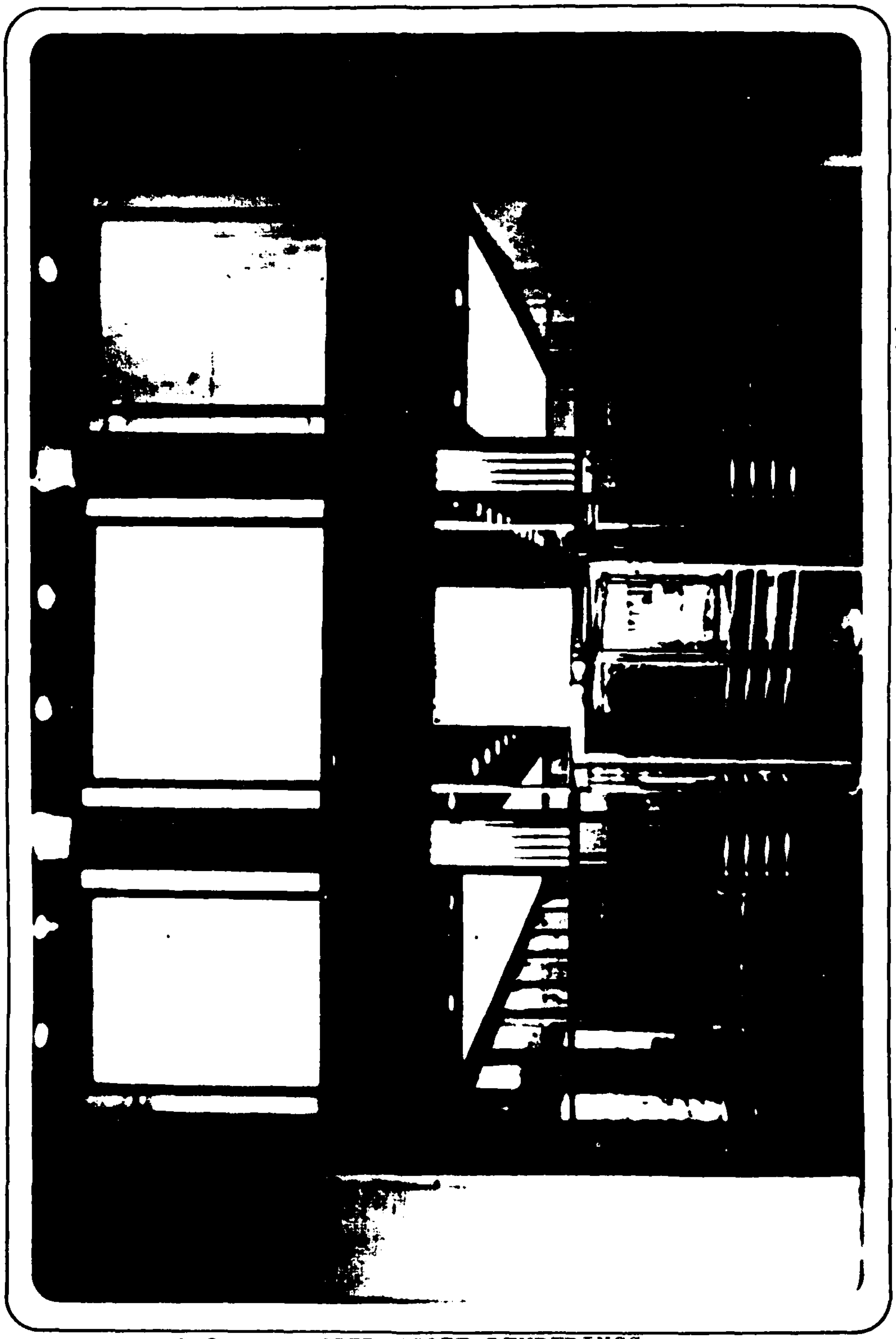


FIGURE 2.3: REDUCED SCOPE RENDERINGS
Lobby Entranceway

Multi-tenant Lobby

3 Center Plaza Lobby

2.2.2.C THE SCHEDULING OF THE WORK

Multiple redesigning and repackaging of the work continued through early 1985. A guaranteed maximum price contract was signed with the Contractor on June 1, 1985. Actual construction started in August of that year.

Early schedules on the project had estimated the work to take approximately one year with a five-year phased plan on tenant bathrooms and multi-tenant lobbies. No substantial changes were made to these estimates through August of 1984. Options for the reduced scope of work included only rough schedule estimates that again looked at phasing interior and exterior construction. At the beginning of actual construction, the Contractor and the Owner developed a construction plan that was finalized. It consisted of three separate schedules. One depicted the work to be conducted to the exterior, the lobbies and storefronts at each of the entrances, and the elevators. A second schedule presented an overall plan of attack for the interior multi-tenant lobbies and handicap bathrooms. The third schedule was a more detailed plan for construction in a typical multi-tenant lobby.

Each of the above schedules was presented in the form of a bar chart, produced using VISI-SCHEDULE, a micro-computer software package designed for use in construction project management. Although this package included capabilities of imposing construction logic and performing critical path calculations on the network, that option was not chosen by the contractor's project manager, and the result was a modified bar chart that was used as a graphic tool only.

Figure 2.4 is a consolidated version of this actual project plan. It indicates the overall duration of the project to be 198 construction workdays, with the projected completion date on January 3, 1986. Resource allocation was not delineated on the schedule. The schedule was manually revised during construction.

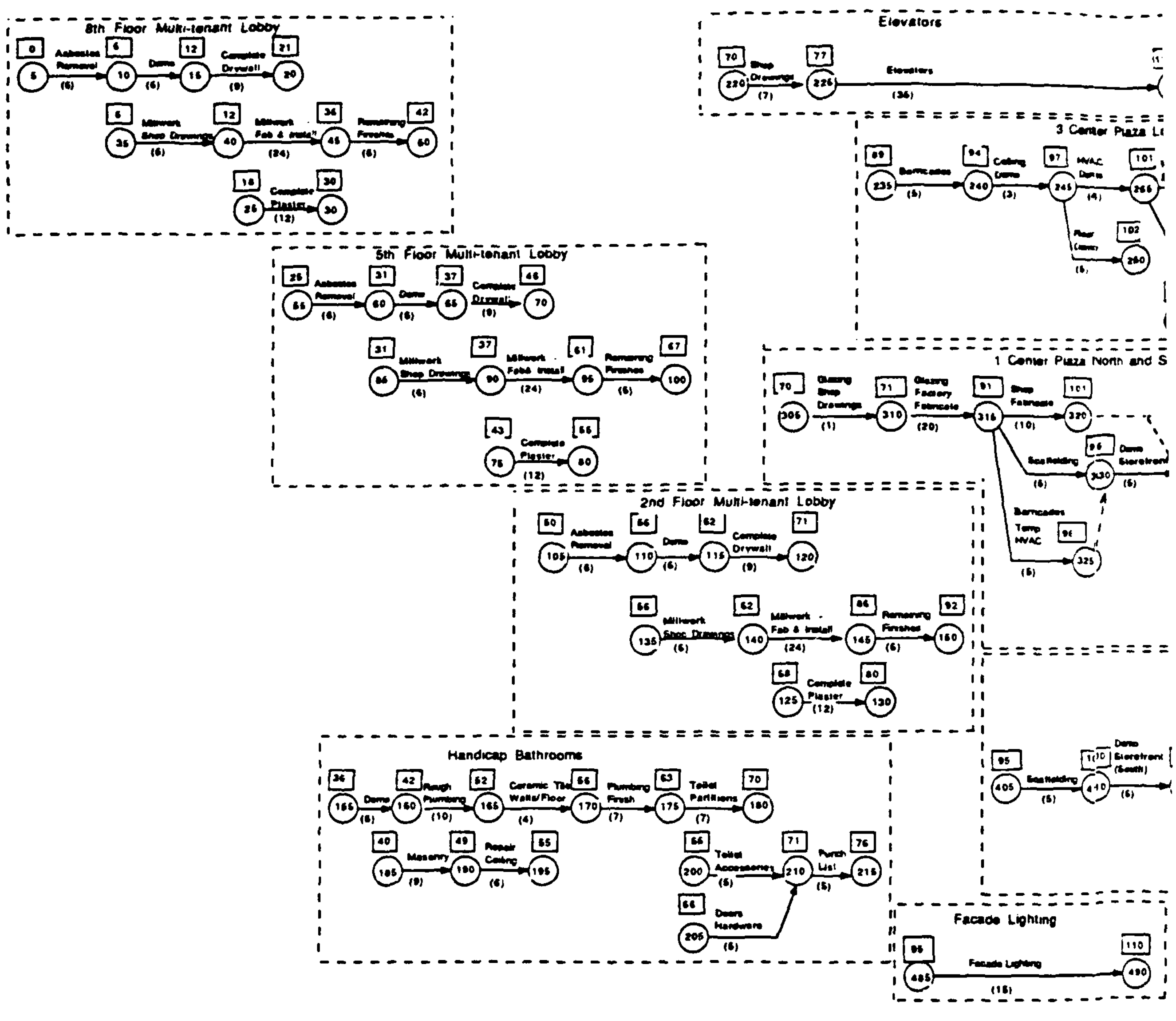
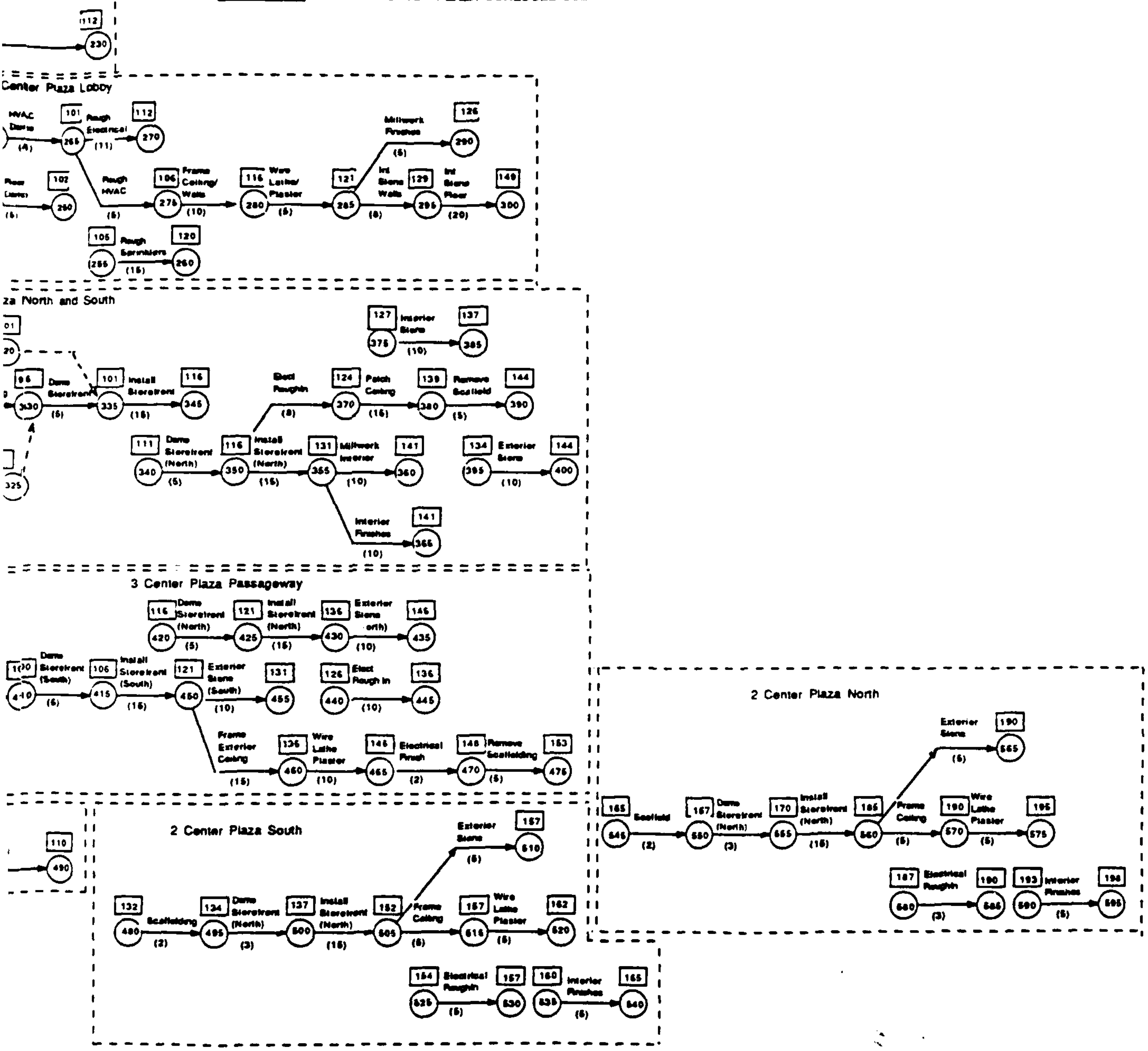

8th Floor Multi-tenant Lobby
Asbestos Removal
Demo
Complete Drywall
Millwork Shop Drawings
Millwork Fab & Install
Remaining Finishes
Complete Plaster
Elevators
Shop Drawings
Elevators
3 Center Plaza L
Barricades
Ceiling Demo
HVAC Demo
5th Floor Multi-tenant Lobby
Asbestos Removal
Demo
Complete Drywall
Millwork Shop Drawings
Millwork Fab & Install
Remaining Finishes
Complete Plaster
1 Center Plaza North and S
Glazing Shop Drawings
Glazing Factory Fabricate
Shop Fabricate
Scaffolding
Demo Storefront
Barricades Temp HVAC
2nd Floor Multi-tenant Lobby
Asbestos Removal
Demo
Complete Drywall
Millwork Shop Drawings
Millwork Fab & Install
Remaining Finishes
Complete Plaster
Handicap Bathrooms
Demo
Rough Plumbing
Ceramic Tile Walls/Floor
Plumbing Finish
Toilet Partitions
Masonry
Repair Ceiling
Toilet Accessories
Punch List
Doors Hardware
Scaffolding
Demo Storefront (South)
Facade Lighting
Facade Lighting

FIGURE 2.4 : ACTUAL CENTER PLAZA SCHEDULE USED FOR CONSTRUCTION



2.2.2.D PROJECT MANAGEMENT EFFORT

As the project continued to evolve, the overwhelming consensus of opinions in interviews with key players involved in actual construction was that management of the project was much more complex and involved than what was originally or intuitively expected. Complications of working in and around tenants and other construction constraints had a dominant effect on the construction at Center Plaza. A Property Project Manager was assigned from the Owner's organization in addition to the Construction Project Manager from the Contractor. The Senior Vice President of the Owner's property management division played a key advisory role. Two building managers served as liaison between the tenants and the construction process. It was evident from the Center Plaza experience that all of these individuals were a vital part of the construction management team.

2.2.2.E SENSITIVITY TO TENANTS DURING THE RENOVATION

Corporate tenants of the building were notified throughout the project with newsletters and signage. The building managers met with most tenants one-on-one prior to construction. Updates were provided at milestones. Additional security and guard requirements were identified early in the project schedule and executed smoothly. The Owner was always conscious of avoiding interference to the income stream of the building. Sensitivity to tenants was a priority concern to the Owner throughout the project.

It was decided early in the project cycle not to program input from current tenants about what renovations would take place. These decisions were made solely by the leasing division and management executives within the Owner's organization and focused on what they felt needed to be done for the future marketing of the building.

2.2.2.F CONSTRUCTION MANAGEMENT AND THE CONTRACTOR'S ORGANIZATION: Devotion of Key Players to the Project

As the project progressed, the Contractor was also notably sensitive to tenant issues and well-equipped to complete the Center Plaza project. There were problems worthy of mention, however. The contractor experienced some difficulty in getting subcontractors on the job. Prior to construction and in preparing estimates of the project budget, there was some evidence of an inability to provide accurate pricing. This shortcoming in pricing had been particulary flagrant in early parameter estimates, and was directly contributory to the budget overruns and subsequently reduced scope.

There was a noticeable lack of top-level involvement on the project by the Contractor as compared to what was originally desired and expressed by the Owner during the contractual phase. The vast majority of issues surrounding the project were handled solely by the project manager and supervisor, while the Owner would have desired to have seen a greater participation by the principals of the Contractor's firm. This participation could only have helped the flow of the construction process. Involvement of the Contractor's principals could have substantially eased the difficulty in attaining the timely arrival of subcontractors on the job and would have provided better leverage in solving problems with material procurement and delays.

2.2.2.G COORDINATION WITH REGULATORY AUTHORITIES

A major regulatory authority involved in the renovation of Center Plaza was the Boston Redevelopment Authority (BRA). During the renovation process, the representative from the BRA perceived his role on the Center Plaza project to be that of moderating change. He was found to be somewhat resistive to major renovations. By not including the BRA representative in the early decision-making process, he had difficulty internalizing prospective changes and became somewhat combative and defensive toward the design and subsequent construction.

2.2.3 Operational Control Phase

The major portions of the Center Plaza renovation work were completed in the spring of 1986. As the project moved into this operational control phase, ongoing plans continued by the O..ner for further renovations at Center Plaza and an update of long range plans.

2.3 RESULTS AND FINDINGS OF THE STUDY

2.3.1 Strategic Planning Phase

2.3.1.A PRIORITIZATION OF OBJECTIVES AND GOALS

The Owner issued clear and complete directives for overall strategic objectives and the identification of key success variables they felt would indicate a successful improvement and renovation. There were problems, however, in developing this plan into a short term direction setting process in which specific project goals were established.

The division of the project into a set of prioritized components was not developed until late in the project cycle. It came as a result of cost overruns which were only discovered after substantial completion of the design package. This resulted in the need to reduce the scope of the project well into the process.

2.3.1.B EFFECTIVENESS OF THE DESIGN COMPETITION

The design competition for selecting the architect achieved excellent results as an idea-generator and in developing an approach to the design. By conducting a competition, the Owner expressed a sense of caring toward their property and tenants. It failed, however, to promote the selection of an architectural firm that could convert these ideas into a realizable and easily constructible design within a programmed budget.

The design competition did have a very positive effect in establishing a focus for the overall renovation. It was the catalyst in developing a master plan for the project which did not allow the renovation to proceed in an ad hoc fashion without real purpose or direction.

2.3.1.C ALTERING THE PROJECT GOALS: The Effect of the Reduced Scope

Early project goals focused on extensive work to the exterior portions of Center Plaza. Budget limitations forced the elimination of the majority of these improvements. Unfortunately, the items that were eventually eliminated from the original scope of work were exactly the ones that the Architect had handled most creatively in the design competition and were the primary reason for their selection. This paradox was magnified even more by the design team's subsequent loss of enthusiasm and frustration over making major changes to their original design.

2.3.1.D DESIGN CHANGES: Increased Costs late in the Project Cycle

The process of arriving at a reduced scope required an extensive effort by the Owner and the Architect. This costly undertaking could have been essentially avoided if there had been an earlier development of priorities on the project and the establishment of an accurate working budget within a feasible cost range. A great deal of time and effort was spent by top-level management in changing the original package. Much of the design work and associated costs to this point was no longer needed and could have been eliminated if it had been realized that the work was going to be too costly.

A rough parameter estimate of the costs of revising the project is shown in Table 2.3. The figure is on the order of a quarter of a million dollars. Overhead costs of this magnitude and the implications of changing the project were not fully realized and understood by the Owner. The entire process of arriving at a suitable scope of work would have been more effective and less expensive if it had occurred earlier during the project feasibility stage and the short-term direction setting process.

Table 2.3
PARAMETER ESTIMATE: Reduced Scope Preparation
(Cost to the Owner of changing the original design)

1.	Preparation of Reduced Scope Options A, B, and C (to include coordination and consultation with Architect and Contractor)	
	President, Property Management Division	
	20 hrs @ $50/hr	$1000
	Senior Vice President, Commercial Properties	
	30 hrs @ $40/hr	$1200
	Project Manager	
	60 hrs @ $25/hr	$1500
	Subtotal	$3700
2.	Construction Estimates / Pricing of Option Packages	
	Construction Estimators	
	20 hrs @ $20/hr	$400
	Subtotal	$400
3.	Presentations, Meetings, Discussion of Options and Future Directions	
	Principals, Managers, and Employees of Owner Organization	
	15 individuals- 10 hrs @ $40/hr	$6000
	Subtotal	$6000
4.	Revision of Option D (An extension of Option C modified by Architect and Owner)	
	President, Property Management Division	
	10 hrs @ $50/hr	$500
	Senior Vice President, Commercial Properties	
	15 hrs @ $40/hr	$600
	Project Manager	
	30 hrs @ $25/hr	$750
	Subtotal	$1850
5.	Construction Estimate / Pricing of Selected Option	
	Constrution Estimators	
	20 hrs @ $20/hr	$400
	Subtotal	$400
6.	Presentation of Selected Option / Approval Process	
	Principals, Managers, and Employees of Owner Organization	
	15 individuals - 10 hrs @ $40/hr	$6000
	Subtotal	$6000

7. General Partners Meeting / Presentation / Approval

20 individuals -		
5 hrs @ $40/hr		$4000
	Subtotal	$4000

8. Architect Change Order (multiple redesigning and repackaging of the work)

Change Order - Feb 85		
Koetter-Kim Assoc.	Subtotal	$90,310

9. Coordination with Regulatory Authority (Boston Redevelopment Authority--revision of required documentation and presentation materials)

10 individuals -		
10 hrs @ $40/hr		$4000
	Subtotal	$4000

10. Miscellaneous Overhead Costs (Meeting preparations, Documentation, Notifications and Correspondence, Clerical Support, etc.)

10 individuals-		
100 hrs @ $15/hr		$15,000
	Subtotal	$15,000

11. Cost of Overdesign (Estimated costs of items in original design package which were later eliminated due to reduced scope)

This figure is estimated to be half of the Architect's original $300,000 fixed fee contract.

Subtotal $150,000

GRAND TOTAL $281,660

2.3.2 Management Control Phase

2.3.2.A CONSTRUCTION PROJECT MANAGEMENT EFFORT

Despite being a small project compared to the construction of a new building, the Center Plaza renovation project required as much or more construction management effort.

Lack of full appreciation of the level of construction management effort and level of experience demanded by the comparitively small scale and budget of the project led to difficulty in making timely and accurate decisions throughout the process.

2.3.2.B THE IMPORTANCE OF INCREASED OWNER INVOLVEMENT IN CONSTRUCTION MANAGEMENT

The decision to shift responsibility for the Center Plaza project to the property management division was a sound one. This division served as an in-house construction management element. Many positive results were achieved by this increased Owner involvement in the project management and coordination of the construction work with corporate tenants as evident from Section 2.2.1.E.

2.3.2.C EXPERIENCE AND EXPERTISE IN RENOVATION WORK

Experience in renovation work on the part of the Architect and Contractor was recognized by the Owner to be an important factor and weighed heavily on the early decisions regarding the project. The Owner felt that experience in renovation work would insure sensitivity to tenant issues and a better understanding of the inherent complications of the renovation process. This rationale was at least partially confirmed by the performance of the Contractor during actual construction. The Architect, on the other hand, gained tremendous experience and understanding from the Center Plaza renovation experience, a competence that would have been more desirable at the initiation of the project.

2.3.2.D DEVOTION TO THE PROJECT BY KEY PLAYERS: The Level of Contractor Involvement

The devotion of time and attention to the project by the principals of the general contractor was less than initially intended and expressed during contract negotiations. Greater attention to the project, at all stages, would have enhanced the flow of the construction process and would have helped in attaining the timely arrival of subcontractors and reducing problems with material procurement and delivery delays.

Overall, the Contractor performed adequately on the Center Plaza project. The problems experienced were directly related to the relatively small-scale, low-budget nature of the Center Plaza project. Because the Contractor's organization continued to grow, Center Plaza became a smaller portion of their overall workload. Other construction ventures commanded as much or more attention and hence the devotion to Center Plaza suffered.

2.3.2.E COORDINATION WITH REGULATORY AUTHORITIES

Coordination with the Boston Redevelopment Authority should have come earlier in the project cycle. This would have promoted a better relationship than existed and would have resulted in a smoother process.

2.3.3 Technical Planning and Control

The results and findings of the study in this section focus on techniques and issues unique to the renovation process and broadly categorized under the title of technical planning and control.

Lack of sufficient attention to the technical and execution details of project implementation at Center Plaza, from earliest project stages through construction, led to cost and time overruns. Given a better appreciation of the difficulties involved in this type of project, these overruns could have been avoided through more avid management and control. The objective of this section is to comprehensively address many of these issues.

2.3.3.A REVIEW OF EXISTING BUILDING CONDITIONS

An intensive investigation and detailed knowledge of the existing structure was not sufficiently used to inform design decisions. This led to the late discovery of on-site conditions which had an adverse effect on cost, time and quality.

A complete review of original building drawings and specifications was found to be essential to the success of this major renovation and the Center Plaza experience confirmed the need for an extensive study of existing building conditions prior to design and subsequent construction. This step was not the glamorous part of the rehabilitation cycle and was at least partially neglected.

2.3.3.B DESIGNING FOR PRACTICALITY

There were a number of competing interests in achieving effective and "extraordinary" results as was desired on the Center Plaza project. The Owner wanted the design to conform to the building, yet be different enough to be refreshing. There was a desire to improve the quality of the building while maintaining the original character. At the same time, there was a competing desire to minimize the disruption to the tenants by keeping construction time to a minimum.

There is some basis for an argument that there may have been an imbalance on the Center Plaza project toward too much customization. This led to material procurement problems and difficulty in assembling the project. One specific example would be the elevator design in which the handrail brackets alone had an eight month - "time of purchase to receive." There were four different shop drawings involved in this action. The majority of items in the elevator cabs were designed to be special-built, yet the final effect is admittedly less than desired. The Architect admitted partially to a problem in this area and received it as positive criticism.

The key players on the Center Plaza project had a variety of opinions with regard to the practicality of the design. There was some contention on the part of the Contractor and selected members of the Owner's organization that an equally effective result could have been achieved with a more buildable design. Excessive reliance on the use of custom designed components led to procurement problems and difficulty in assembling the project.

2.3.3.C SCHEDULING FOR CONTINUITY OF SERVICE

The maintenance, rehabilitation, and renovation of Center Plaza was a complex and complicated process. Consistent with the general observations made in Chapter One, the schedules used for planning and controlling both the construction operations and their interface with the ongoing service of the building lacked detail. The scale of activities used in planning were too gross and the inter-dependency between activities was not clearly represented. Construction schedules were vague. More effort in early planning stages would have been beneficial in dealing with problems encountered later in the project cycle.

2.3.3.D TENANT IMPACT CONCERNS

Despite efforts on the Owner's part to minimize their effect, several construction activities caused disruption to the tenants at Center Plaza. This fact appeared inherent to the renovation process and it seemed that it could only be minimized, not eliminated. Several times these problems caused the need for change orders that allowed for work to be conducted after hours. Change orders due to overtime charges totalled nearly $24,000 and added approximately 17 days to the construction schedule on the project.

2.3.3.E MATERIAL INVENTORY FOR CONSTRUCTION

Problems with the availability of materials directly caused change orders totalling approximately $113,000, or 3% of the total budget, and added nearly 65 construction days to the project. In hindsight, perhaps the actual construction was slightly premature. It is fully recognized that a project must start sometime and one will never have all the material problems worked out in advance. Despite this fact, additional attention is warranted when costs and construction delays of this magnitude are the results of material delays alone.

2.4 CONCLUSIONS

The major findings which follow are again grouped under the general categories of strategic planning, management control, and technical planning and control. They represent lessons learned from the Center Plaza experience which can be extended as generic issues associated with all major tenant-occupied commercial building renovations. Many of these key concepts, coupled with the earlier results and findings of this study, will be used in Chapter 3 for the development of a model of the renovation process.

2.4.1 Major Finding #1: Strategic Planning

- In order to assemble a comprehensive and coherent renovation plan, renovation work requires the early establishment of long range objectives, goals, and a direction setting process on the project. Accurate and feasible project budgets and schedules during the early phases of a project help achieve an effective and efficient process, and provide for the ability to physically implement design goals.

- In organizing the project team, it is recommended that Owners seek out firms in which the principals are involved and the project is not lost among larger ventures. A design competition stimulates excitement and interest in a project. It can also serve as a focal point for a project and help provide direction to the renovation process. It is an excellent idea-generator, but less effective in arriving at a detailed definition of a project's scope. The alternative approach is to choose an architect apriori. There is a tradeoff in this decision, however. Fewer problems are encountered in arriving at an actual scope definition and construction plan. At the same time, much less is achieved in the way of innovative design concepts.

- Periodically during a project's evolution, construction estimates must be done by an owner to check and confirm the figures of outside contracted firms. A realistic and specific scope of work must be defined early in the project cycle.

2.4.2 Major Finding #2: Management Control Issues

- The Center Plaza Project was a relatively new venture for the Owner involving the major renovation of an existing structure. Learning points included the need for intense focus on the construction management effort. Experience in building renovation work and the acute study of existing conditions of the building were critical to the process. In general, it appears that the small-scale, low budget nature of renovation work does not reduce the need for timely and accurate management decisions throughout the construction process.

- The Center Plaza experience introduced a myriad of management issues. Building managers played a vital role in handling day-to-day problems. Not all commercial, tenant-occupied properties may have permanent positions for building managers. If a building were without such a position prior to a renovation, it is strongly recommended that the project management team be expanded to cover these liaison responsibilities for the duration of the project.

- Construction quality, cost/budgeting control, as well as timely completion and proper scheduling are all priority concerns on construction projects, and especially critical for renovation/rehabilitation work. They must be intertwined and well-coordinated from the start of the feasibility phase through to the completion of actual construction.

- The Center Plaza project underwent a substantial reduction in scope because of cost overruns; schedule changes for this new work package were an afterthought. As the thesis proceeds, it will become readily apparent that the proper scheduling of renovation activities is too important to receive this secondary attention. If anything, renovation constraints create a need for greater project management attention.

2.4.3 Major Finding #3: Technical Planning and Control

- Sufficient attention must be placed on the technical planning of renovation projects from early feasibility phases through to actual construction. "Sufficient" often means greater than one would intuitively expect and as with most building renovation projects, Center Plaza could have received more attention in this area.

- Minimization of crisis management seemed to work best when dealing with tenant impact concerns. Proper preplanning could have been the answer. Indications are that additional activities are needed to allow for more frequent and periodic clean-up of the construction site. Additional requirements were obviously needed to help in the safety, security, and the movement of tenants in and out of the building both mornings and evenings. These and many more issues are addressed in detail in later chapters of this thesis.

CHAPTER THREE

MODELLING THE BUILDING RENOVATION PROCESS

3.1 INTRODUCTION

The purpose of this chapter is to now extend the findings and conclusions of the Center Plaza study, couple these observations with information and data gathered from the study and analysis of several other projects, to include housing renovations conducted under the direction of the New England Division of the U.S. Army Corps of Engineers, and thereby develop and graphically represent a model of the renovation process along with support systems for making decisions when dealing with construction work in a tenant-occupied environment. This development will focus on the project control process and the organizational structure required to complete major rehabilitations. It will draw upon models of the construction process that evolved in the late 1970's and alter and refine these models to accurately depict the renovation process.

The models that exist constitute a fairly comprehensive body of knowledge directed toward project management in the construction industry. Research and study continue in refining these applications with state-of-the-art management techniques. The majority of this work has focused on new construction, leaving a gap in the renovation and rehabilitation field. This chapter attempts to bridge this gap by presenting a specific application of management control principles to the situation at hand.

The methodology of this development began with the research process outlined in Chapter One. By conducting the interviews and case studies of actual projects, the author gained an appreciation for the renovation process and observed common situations which recur in most building renovations projects, regardless of their scope. This phenomenon provided the impetus for formulating a theoretical framework for what can be termed as the "generic renovation process."

In the construction industry, the complexity and scale of a project dictates the degree of sophistication required in its management. Extensive building renovations, especially those involving tenant occupancy, are often more complex than one would expect. In experiencing unsuspected complications, construction project managers are often faced with a lack of time proven methods that tell them how to optimally resolve or avoid these problems. There is a definite need to document and explain the idiosyncratic nature of occupied renovations as opposed to "normal" construction. F.L. Harrison noted in his manual of advanced project management that decision making in project work tends not to be repetitive and bad decisions at any stage in a project affect a project throughout its life. Furthermore, it is not generally possible to recover from early deficiencies in project management. [15]

The rapid growth of the renovation market in recent years has served to compound the problem because time has not fully allowed for the dissemination of newly acquired knowledge. In an attempt to offset these deficiencies and provide the reader an increased awareness of the unique nature of the renovation process, the following topics will be systematically addressed:

- Formation of the Project Management Team
- The Cyclical Nature of the Project Management Process
- Risk and Uncertainty in Renovation
- Owner Involvement in Construction Management
- Organizational Structures consistent with completing Rehabilitation Work
- A Renovation Process Flowchart
- Generic Adjustment Factors modelled in a Decision Support System

3.2 RENOVATION PROJECT PROCUREMENT METHODS

There are a number of generic procurement methods in the delivery of construction projects. (See, for example, Minden, 1986 [33]) No one particular method is appropriate in all circumstances. Rather, it is advantageous to realize the implications of each of the alternatives and hence formulate a plan for the situation at hand.

3.2.1 The Traditional Approach

Traditionally, building construction has been managed by an architect acting in the interest of an owner. The traditional approach is defined as one in which the architect is hired to develop the design and construction documents. Once this phase is complete, a contractor is acquired to complete the construction. The distinguishing characteristic of this process is the separation of the design and construction phase. This is a good basis upon which to start, but practice indicates that this process is often less than adequate. The traditional method is generally employed in the absence of unusual project requirements or market constraints. Unique considerations for renovation projects are common. There is much more motivation for coordinating the efforts of the architect and contractor. In addition, renovation work often involves multiple work packaging and timely phasing of the project. The nature of typical occupied renovations is not one of a single operation, but multiple operations involving a collection of key players and their desires. Each of these requirements is beyond the capabilities of the traditional approach. Therefore alternative procurement methods need to be sought.

3.2.2 The Construction Management Approach

The Construction Management approach is defined as a procurement method which involves an additional key player, distinct from the architect and contractor, who is responsible for managing and coordinating design and construction activities. Construction Management services are typically required when cost and time are significant constraints and cost estimating and constructibility feedbacks are important.

The renovation process provides impetus and an increased pressure to separate, or at least augment, the role of construction management from design and construction. Several facts lead to this conclusion:

1) Tenant-occupied renovation work introduces the need for project management personnel to be aware of and act in the interest of the tenants and their concerns. Representatives reporting directly to an the owner are more conscientious and understanding of this issue than an outside contracted firm. This observation has been confirmed, in general, by other studies. [18]

2) Building renovations typically have smaller budgets than new construction ventures, and therefore a corresponding need for a greater degree of financial planning and cost control.

3) Shorter durations of construction schedules allow little room for variance. There is a need to meet precise completion schedules not only for overall durations but also with regard to the length of the impact of construction on each particular facet of a building's operation.

The reader should note that these observations are paradoxical in nature. One would expect that construction projects with small budgets and shorter schedules would require a correspondingly smaller amount of management control. Renovation work seems to contradict this assertion and conflicts with expectation. The reasons for this contradiction are fairly clear, namely, (1) the tolerance for cost and schedule variances is decreased , and (2) there is an introduction of concerns in keeping the building in an altered, yet functional state.

In light of alternative procurement methods, the logical move for delivery of tenant-occupied building renovations seems to be toward more formalized Construction Management. Other arguments exist in support of the Construction Management approach for the renovation process. It can be used to help stimulate architect and contractor interest in the project. We have seen this as being a significant advantage on the Center Plaza project and find it important on renovation projects in general. Secondly, Construction Management is not only helpful in managing multiple work packages but also in disaggregating a project into these packages. Finally, to address the optimization of time, cost, quality, and tenant issues on a project, one must necessarily proceed with a more coordinated team effort. This particular aspect is not unique to renovation projects, but it does hold even more importance because of the introduction of tenant concerns.

3.2.3 The Design-Build Approach

Another method for project procurement is the Design-Build approach. Design-Build is defined as the situation in which an Owner contracts with a single entity for both design and construction services. Design-Build proposals are developed based on a scope of work and a rough conceptual plan of how that work is to be carried out. These proposals, showing schematic design and specifications, eventually evolve into the basis for the project contract.

On the surface, Design-Build may seem an appropriate method for the delivery of a renovation project. Unforeseen conditions in existing buildings might appear to be a valid reason to have one firm addressing problems so that they might be quickly and easily resolved.

However, serious drawbacks would exist with this approach. It would be difficult for most owners to ensure that a renovation project meet technical requirements at a fair price. Complexities of the renovation process often require the expertise of a seperate design and construction element, if for no other reason than to provide a second opinion from a firm that specializes in one area of expertise.

Probably the most serious drawback in using the Design-Build approach for renovation work is the lack of flexibility imposed upon the Owner. Once having entered into an agreement with a design-build firm for delivery of a product, the Owner is severely limited in directing construction or changing the process of delivery. This is an inexorable handicap when corporate tenants are involved. The operational situation of a building might dictate late in a project cycle that a certain portion of construction must be altered to allow for tenant concerns (ie. out-of-sequence scheduling). The ability of the Owner to influence this type of change would be essentially lost in the typical design-build contract, save for expensive change orders or other special arrangements to fulfill corporate tenant desires.

Any advantages offered in a Design-Build approach might be better realized by the active participation of a Construction Management service by giving early and continual direction to the efforts of separate, yet coordinated architect and contractor entities.

3.2.4 The Systems Approach

A fourth alternative for the project procurement process is the Systems approach. The Systems approach is defined as employing a set of standardized components designed and produced to assemble a generic type of facility. These components are selected, configured and modified, as required for a specific project application. As such, the Systems approach is characterized by a pre-engineered / pre-designed approach to building.

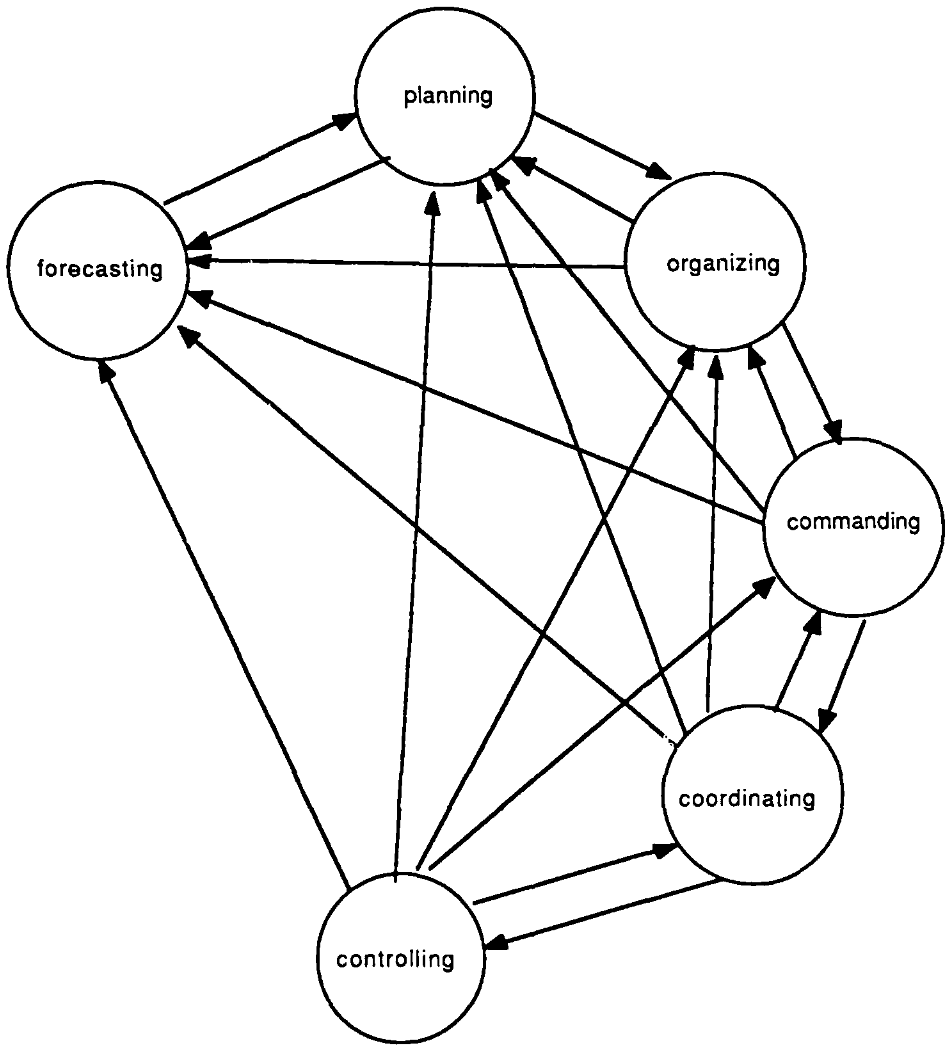
The Systems approach does not particularly lend itself to the renovation industry because of the variety of situations required in retrofitting buildings. However, some applications of the systems approach for subsystems of the renovation process might be warranted. This is especially true for repetitive tasks in which a pre-engineered component or assembly technique might serve to substantially minimize construction time. An excellent example from the Center Plaza study is in the installation of the storefront entrances. During actual construction, these aluminum frames with glazing and stone panels were assembled in a piecemeal fashion on-site. Each of the six storefronts were treated as completely separate, save for the expertise the glazing contractor gained from previous installations. A more productive process could have arisen out of a systems approach to their construction in which all of these components were assembled in a factory-like configuration, optimizing crew time by coordination through a standarized approach in assemblage at each of the six entrances. Despite being more a technical than management variable, system applications need to be recognized by project managers for their advantages and utilization when appropriate.

3.3 MANAGEMENT AND CONTROL OF THE CONSTRUCTION PROCESS

Having decided upon a particular procurement method for delivery of the renovation product, it is logical to next address the specifics of how that management approach is applied. As discussed in Section 3.2, some form of a Construction Management effort is probably the most advantageous way to proceed in occupied building renovations. This choice does not rule out the other alternatives as being appropriate at times, but suggests that the advantages realized by these other procurement methods might best be incorporated in conjunction with the Construction Management approach.

Project management is a cyclical process. It involves forecasts and plans, organization, command, coordination, and control. Feedforward and feedback links are required among each of these activities.[13] This process is graphically represented in Figure 3.1. In global terms, it is deciding what is to be done and assuring that desired results are obtained, all in an efficient manner.

FIGURE 3.1: THE MANAGEMENT CYCLE



3.3.1 Risk and Uncertainty in Renovation

Construction projects inherently involve conditions of risk and uncertainty. As such, project control must address the management and allocation of that risk. Representative risks include rising inflation, uncertainty about environmental and regulatory problems, changing technology, and the increasing scale of projects. Building renovations experience all of these factors, but also introduce unique components of risk. Additional uncertainty arises from unforeseen conditions in design and construction and delays due to tenants which cannot be easily forecast. These elements of risk, peculiar to renovation work, are tied more closely with the actual construction than with changes in the environment external to the project.

Increased risk during renovations can be subdivided into two major categories. The first involves physical aspects of the project. As indicated above, greater concern must be afforded the consequences of this risk because of its ability to heavily influence a project's outcome.

The second major category is risk arising from the interdependence and uncertainty of actions and behavior of the different actors involved. We have thus far seen that these relationships are exceedingly complex and often involve a myriad of tenants, consultants, regulatory authorities, and other outside players in the renovation process. The Center Plaza project was an excellent example of this phenomenon.

3.3.2 The Importance of Increased Owner Involvement

Historically, project management in the construction industry has addressed the control of three primary variables; cost, time, and program (scope, quality of work). As alluded to in Section 3.2 and above, occupied renovation work extends these three variables to a fourth that includes tenant concerns and building operation issues. It entails the business concerns associated with the ongoing functioning of the building, financial concerns of maintaining rent income, regulatory requirements related to the building's operation, and subjective concerns of tenant reaction to the renovation. The traditional players in the construction industry hold a narrow view of this process. Contractors are primarily concerned with actual construction. A/E firms extend this perspective somewhat to include design.

An Owner might be best able to extend their outlook to include a broader view of this project management role required in completing the renovation cycle.[18] He/she is better equipped in making decisions regarding the effects of construction on the building. This concept continually surfaced in the Center Plaza study. Thus, in examining the renovation process from a generic standpoint, and in looking at the associated risks involved in renovation work, it is best to have the Owner actively involved in the control of the project. Furthermore, if the Owner has a developed in-house staff and management capability, it should be used in the Construction Management of occupied renovations. In the absense of such a staff, it is still advantageous to employ contracted Construction Management services which actively involve representatives of the Owner.

In order to reduce,manage, and allocate the increased risk associated with renovation work, the Owner must actively be involved in the control the project. Additional benefits are realized by an Owner who is able to assume most of the financial burden associated with a project. In essence, the architect and contractor become dependant upon the Owner, and the Owner is therefore more able to directly influence the process of construction. On renovations, it is advantageous to employ architect and contractor firms in which the project represents a high percentage of their financial volume. The Owner hence has better leverage in ensuring architect and contractor devotion. Each of these results is a desired outcome and moves toward the ideal environment for completing the renovation process. In practice, many of these requirements may not be realized, yet an Owner should strive as much as possible toward placing himself in this position.

AD-A180 256 A DISTURBANCE SCHEDULING TECHNIQUE FOR MANAGING RENOVATION WORK(U) ARMY MILITARY PERSONNEL CENTER ALEXANDRIA VA W E WHITEMAN 08 MAY 87 2/4

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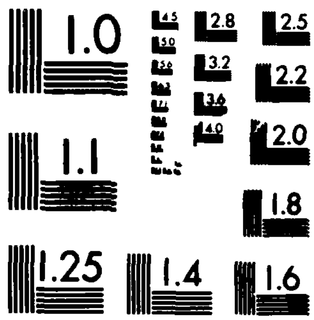


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

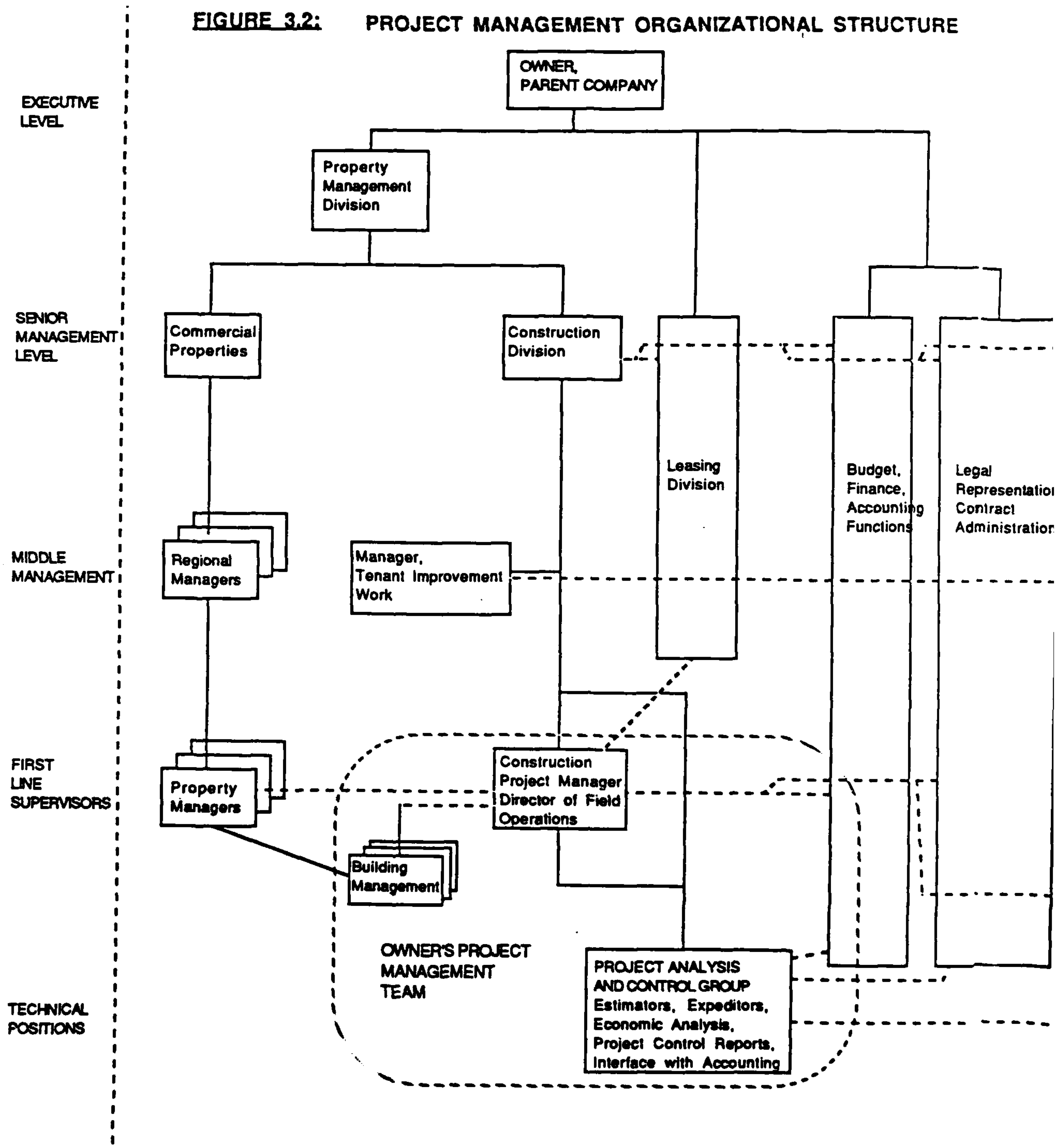
3.4 PROJECT MANAGEMENT ORGANIZATIONAL STRUCTURE AND ISSUES

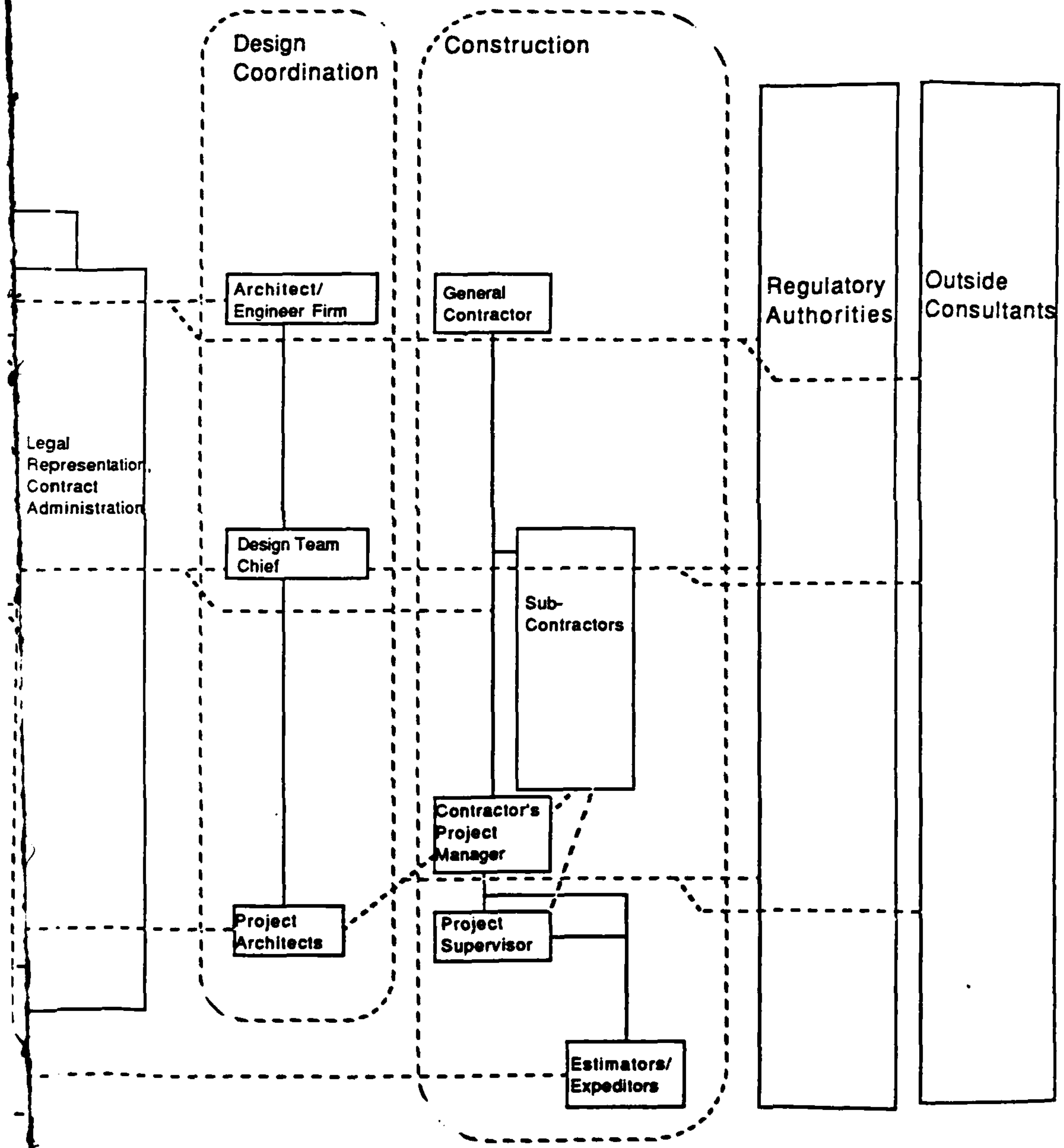
3.4.1 Structuring the Building Renovation Organization

As we continue in developing a project management model for application in building renovation, we next examine organizational structuring and issues which facilitate the completion of this type of work. It is beyond the scope of this thesis to conduct an in-depth study of the advantages and disadvantages of various organizational configurations. Rather, a generic extension of the structure emerging as a result of the Center Plaza project for completion of major rehabilitations will serve as a reference and guideline. It is depicted in Figure 3.2. The reader should be aware that this model focuses on the situation in which Owner in-house construction management services are available.

The organizational chart in Figure 3.2 is a matrix structure with a "project management team" evolving within the Owner's property management division to control each major building renovation. The owner's representative/project manager is responsible for overall coordination of each project. This individual leads the team which includes property and building management personnel, as well as a project analysis and control group. Liaison, coordination, and supervision is provided to outside organizations involved with the project. These include the architect/engineer, contractor, regulatory authorities, and outside consultants.

FIGURE 3.2: PROJECT MANAGEMENT ORGANIZATIONAL STRUCTURE




Design Coordination
Construction
Architect/ Engineer Firm
General Contractor
Regulatory Authorities
Outside Consultants
Legal Representation, Contract Administration
Design Team Chief
Sub-Contractors
Contractor's Project Manager
Project Architects
Project Supervisor
Estimators/ Expeditors

Internal coordination occurs with other owner groups to include the leasing division, a development management group, legal representatives, and budgeting, finance and accounting personnel. Corresponding levels of communications between separate organizations are depicted in a hierarchical fashion in the diagram. Senior management personnel meet regularly and oversee all major construction developments.

3.4.2 Analysis of Organizational Issues

The inference in analyzing the structure in Figure 3.2 is that renovation project organizations not only involve the various divisions of the owner's corporation but include outside entities, and as such are global in nature with complex relationships. In relating this phenomenon to the argument of using construction management services, coupled with increased owner involvement, one can make interesting observations. Research indicates that the organization of in-house construction management groups has changed with time in order to address the needs of reducing and managing risk on construction projects.[62] It has been observed that staffs tend to increase, project managers report to higher level executives, and responsibilities and lines of authority tend to evolve from a functionally-oriented to a project-oriented type of organization.

Case studies of the renovation process, to include Center Plaza, validate these observations and support the theory that renovation work involves increased risk and uncertainty. Personnel frequently report to multiple superiors and interact across disciplines and functional groups. A high degree of coordination is required without sacrificing efficiency. This interaction and coordination is most critical and intense at the lower levels of the functional hierarchy. Cross communication is facilitated by the matrix organization. The temporal nature of the project environment creates the need for flexible organizational structures that are able to adapt to specific project needs.

In further examining the organizational issues associated with renovation work, one should explore the reasons for and the essence of an extended outlook of the project management requirement. The interested reader is referred to work by Silva addressing organizational requirements for high differentiation and high integration. [5] In his thesis, Silva limits his discussion to large construction projects, but his concepts are found to be equally relevant to the renovation industry. He notes that project management cannot in itself be a fragmented series of decisions and events, nor should one focus on each project as a single entity. Admittedly, each project needs specialized work forces and differentiation of project responsibilities. At the same time, the owner needs to integrate the involvement of these diverse and specialized assets while maintaining long-term vision of corporate objectives and goals.

This concept tie in well with the results of the Center Plaza study and the study of other major renovations. Many times renovation work is undertaken as only a small portion of a larger upgrade and improvement program for a facility or group of facilities. Managers need to realize this fact and not limit their outlook to merely the construction at hand. A more global and continuous view of the management process is required and organizational structures need to be set up to facilitate this long term vision.

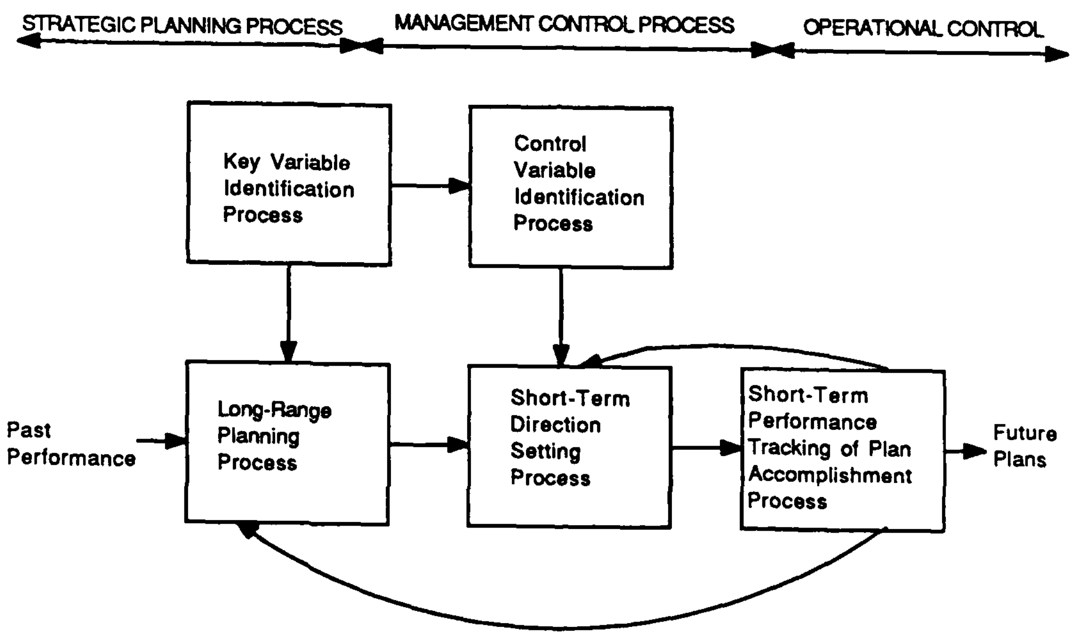
3.5 FLOWCHARTING THE RENOVATION PROCESS

We now turn our attention to developing a generic control model which describes the flow of the renovation process from project initiation through to accomplishment, with the integration of preceding and following projects and program requirements.

Project management control system models have received noteworthy attention in recent years. They have come mainly as offsprings to earlier works on general corporate planning. A study done by R.N. Anthony in 1965 categorized organizational planning and control into three phases; strategic planning, management control, and operational control.[3] This classification system has been extended to fundamental applications in a variety of disciplines. Taken together, project management literature establishes a framework and basic theory for modelling the construction process in an effective, efficient, and economical manner. These underlying principles can also be applied, extended, and modified for specific applications as will be done for the building renovation process.

One project management control process model, easily adaptable to the construction industry, was proposed by Peter Lorange and Michael S. Scott Martin in 1974.[24] Their model, overlayed with Anthony's categorization of organizational planning and control, is shown in Figure 3.3. Its objective, as with any basic control system, is to provide a formalized framework in helping management

FIGURE 3.3: **PROJECT MANAGEMENT CONTROL PROCESS MODEL**



accomplish organizational goals in the course of completing individual projects. It accomplishes this purpose through:

(1) the identification of pertinent control variables;

(2) the development of good short-term plans;

(3) the recording of the degree of actual fulfillment of short-term plans along the set of control variables;

and (4) the diagnosis of deviations.

This flowcharted process should not be taken out of context or applied to a single project as an entity unto itself. It is imperative that one capture the cyclical nature of project planning as a continuous process.

Application of this type of model to the building renovation process is fairly straightforward. The strategic planning phase establishes corporate policy, objectives, and long range plans. It is very broad in nature and is primarily a top-down management decision process. It is at this point where the need for renovation of a building is established. Feasibility studies are conducted to assess the impact from a long range perspective (ie. rent studies and financial analyses).

Once the need for renovation is established, one begins to move into the management control process. Key success variables are identified. These are indicators of success but cannot be directly controlled by a corporation. Typically, for commercial property renovation, these would include occupancy rates, rent schedules, ability to attract future tenants, and subjective measures such as aesthetic quality.

The next step is the identification of control variables which are more specific and which can be monitored as the process continues. Examples include cost tracking, time schedules for completion, and quality standards. As discussed earlier, occupied renovation work also requires the control and monitoring of tenant issues and concerns. As much as possible, these control variables should be measurable quantities.

The short-term direction setting process follows. Here specific project requirements and goals are established and the project is divided into a set of prioritized components. This is an iterative process and is often bottom-up in providing alternatives for higher level management decisions. It is at this point where one is able to narrow down and refine the definiton of specific tasks which can be controlled by the organization. The ultimate objective is the creation of a detailed project plan for renovation that clearly delineates the work to be accomplished within budget, time, and other constraints. A necessary by-product is a means of monitoring the design and construction phases as they evolve. Coordination issues are complex; the early establishment of an agreeable plan to all parties involved is desirable and usually cost- effective as clearly evident from the Center Plaza case study.

As the renovation process continues, management control begins to focus on the accomplishment of project goals. This is essentially a feedback phase. Measured performance is tracked against success and control variables. Progress reports prepared by personnel at the project management level allow higher level management to make decisions concerning how the project should proceed. The system must remain responsive, dynamic, and allow for taking advantage of immediate opportunities as work evolves. A continual comparison of actual to planned performance facilitates the evaluation of time-cost tradeoffs and the ability to make timely decisions. Deviations from short-term plans are assessed, diagnosed, and followed-up with corrective action or altered project plans. These alterations to plans must continue to guide the overall project toward original long term objectives. This phase is perhaps the most complicated and critical part of the management control cycle and manifests the need for some type of decision support system as will be developed in detail in the next section.

The operational control phase ends in task accomplishment and the formulation of future plans. This is also a good point for evaluation and feedback for fine-tuning the project as it moves from the construction phase to an operational and functional facility. This is not the end of the cycle, however. At this point, feedback should also affect the strategic planning of future renovations, as the cyclical process continues.

3.6 EXTENSION OF THE PROJECT MANAGEMENT CONTROL MODEL FOR CLARITY AND APPLICATION IN BUILDING RENOVATION WORK

The flowcharted process developed and discussed in Section 3.5 provides a solid framework for guiding the overall building renovation process. It primarily focuses on general issues and how organizations and control systems evolve in achieving corporate goals and objectives leading to success in the industry. Because of the complexity of the management control process in building renovation work, there is a need for a decision support system to improve the understanding and completion of these projects. In order to be useful, the rudiments of this system must:

- capture and adapt to the requirements of the dynamic nature of the renovation industry.

- orient toward the decision-making process with emphasis on management by exception to quickly locate problem areas. (Carried a step further, it must therefore anticipate possible problems and prescribe corrective action.)

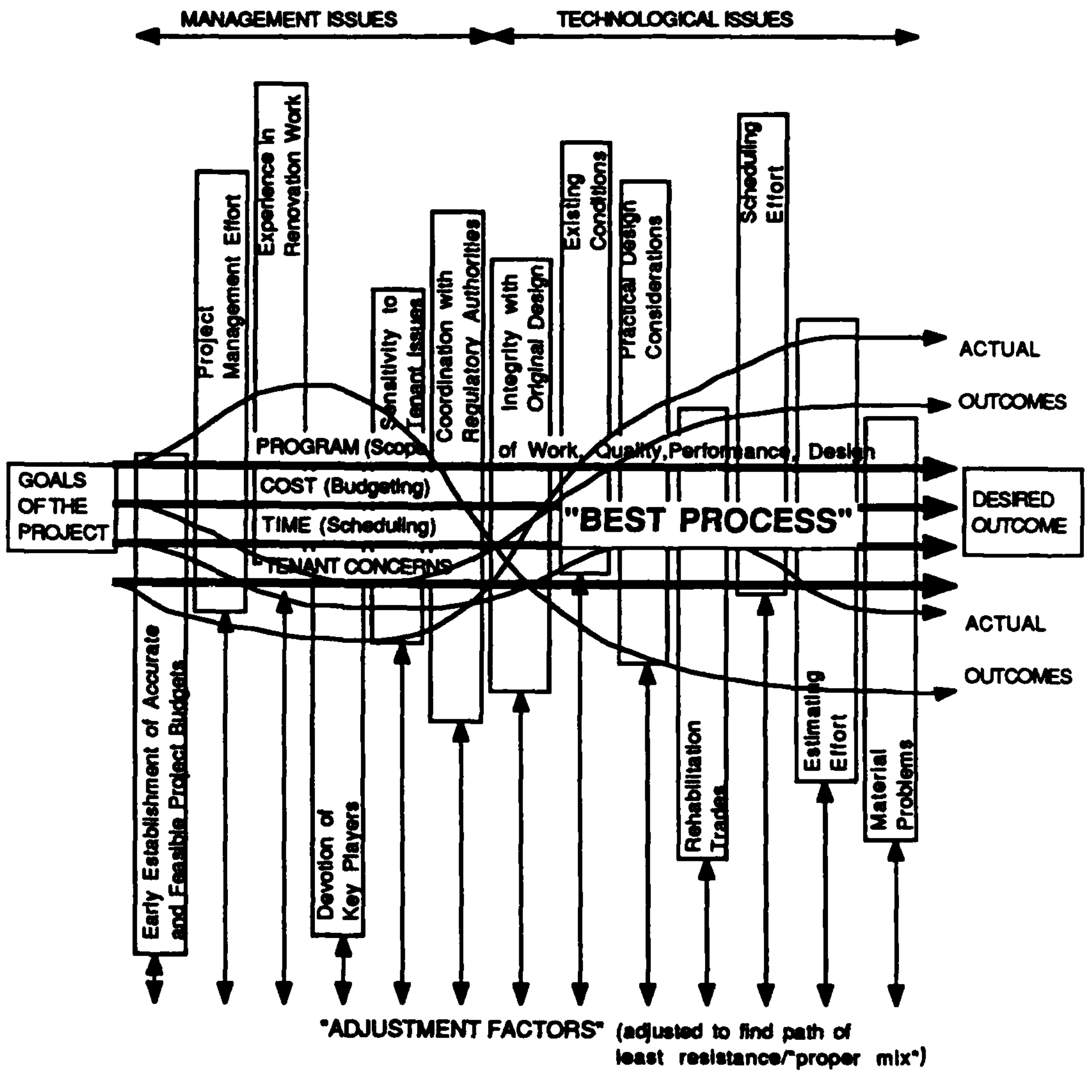
- be comprehensive, yet easily understood and available to the personnel who require its use. (ie. project managers, supervisors, etc.)

- be flexible and general enough to be easily adaptable to an assortment of individual projects.

Figure 3.4 is a graphic framework of a basic decision support system for occupied renovation work in buildings. It depicts the variables of construction program (scope of work, quality, cost/budgeting control, timely completion/proper scheduling, and tenant concerns as all priority issues on occupied renovation construction projects and running through the center of the diagram from established goals through to desired outcomes. These variables must be intertwined and well-coordinated from the start of the feasibility phase through to the completion of actual construction. This concept is also depicted by the encircling of the control variables with "adjustment factors" that affect the way the process proceeds to the actual outcome. These "adjustment factors" are critical in fine-tuning and ensuring that the influence of control variables are properly balanced. They highlight a number of crucial areas which require attention in the major rehabilitation of buildings. Management control must account for these issues to thereby successfully achieve the desired outcomes.

Further examination of the "adjustment factors" described above reveal that they describe accepted practices and possible pitfalls associated with undertaking building renovation work. The information they contain represents an ever growing knowledge base for comprehension of the renovation experience. These generic factors were extrapolated as a result of research, the actual case

FIGURE 3.4: DECISION SUPPORT SYSTEM FOR TENANT-OCCUPIED BUILDING RENOVATIONS



studies completed in both commercial and public facility renovations, and the numerous interviews with construction renovation experts.

As individual projects and the renovation market as a whole becomes even larger and more complex, this type of formal mechanism becomes invaluable. It helps ensure necessary information is provided to decision-makers at the right time to make the best decisions. A formal description of each of the "adjustment factors" follows and they are grouped into two major categories, managerial and technical issues.

3.6.1 Management Issues

Early Establishment of Accurate and Feasible Project Budgets

The division of a project into a set of prioritized components must be developed early in the project cycle. This is true for all construction projects but especially critical in renovation work because of generically these projects have small budgets and thus little room for variance. They are alos generally shorter in duration with less flexibility allowed in scheduling.

Project Management Effort

Management of occupied renovations is more complex and involved than what is intuitively expected. Owner's representatives are required to coordinate construction activities with building operation. Building managers are often required as liaisons with tenants. Construction expertise of managers is not reduced because of the smaller relative size of projects.

Experience in Renovation Work

Skill level and experience of key players on the project (owner, architect, contractor) must be greater than what is normally expected because of the complications of working around tenants, ongoing operations of the building, and other construction constraints which are typical of the renovation process. This must be an overriding concern in assembling and contracting the project team.

Devotion of Key Players

Renovation work has an intrinsic problem with devotion to the project because of its relative small-scale nature in comparison to new construction. Project participants must be selected as being aggressive and committed so that a renovation project is not lost among larger ventures.

Sensitivity to Tenant Issues

Tenant-occupied renovations introduce additional requirements for notification of tenants and construction updates. Additional security and guard requirements are often required. A caring attitude toward tenants must be maintained. These are all unique characteristics of the renovation process and not normally found in new construction.

Coordination with Regulatory Authorities

These include planning/zoning and environmental requirements, building regulations, building permits, construction codes and regulations, etc. They are similar to those required for new construction but are often more complex. Coordination must come early in the planning cycle. It is interesting to note that regulatory requirements associated with tenant-occupied commercial properties typically tend toward high complexity because of the nature of the urban environment.

3.6.2 Technological Issues

Integrity with Original Design

Building renovations are unique because of the need to achieve continuity and take into account the character of the original design. Original architects might be consulted or at least a comprehensive look at original drawings must take place.

Existing Conditions

A complete review of original building drawings and specifications is essential to the success of any major renovation. Extensive physical exploratory work is almost always required. This reduces uncertainty on the project and subsequent changes to the design.

Practical Design Considerations

This refers to the delicate balance required in improving the quality of a building through intricate design while minimizing the disruption to tenants by keeping construction time to a minimum. Standard improvements to a building can often achieve effective results without severely impacting on the operation of the building.

Rehabilitation Trades

Renovation work involves trades not normally found on new construction but critical to achieving desired outcomes. These trades are competent at repair and restoration, and include such activities as sandblasting, patching, and refining. They are unique from new construction as well because they are typically labor intensive, involve small quanities of materials, and almost no heavy equipment.

Scheduling Effort

Research on the Center Plaza project and other projects studied confirm that detailed plans and schedules are often lacking in building renovation and rehabilitation projects. As a result, there is an overwhelming need to systematically plan a well-developed and workable network analysis diagram.

Estimating Effort

A similar lack of detail is often found in the estimating procedures for renovation projects. Accurate estimates are critical to cost/budget control.

Material Problems

Because of concerns with minimizing the duration of construction and thereby reducing the impact on tenants, renovation work requires a higher percentage of materials on hand prior to the construction start date. Tenant impact concerns also lead to the argument of using more standard materials and controlling the degree of customization. Material procurement is also affected. Unit prices are higher than anticipated because of the smaller quantity of materials required to complete the work. This also often leads to inaccurate pricing and estimates.

CHAPTER FOUR

NETWORK ANALYSIS TECHNIQUES: The Critical Path Method

4.1 INTRODUCTION

To date, new building construction has concentrated on network analysis as a popular technique for long-range planning and scheduling because each step is logically and sequentially related to other steps of the project. Network project scheduling, primarily the Critical Path Method (CPM) and the Project Evaluation and Review Technique (PERT), were developed in the late 1950's and early 1960's. They arose primarily from a need for advanced management and scheduling tools when dealing with large, complex research and development, as well as construction projects. Since their inception, there has been a proliferation of research and technological advances in the area.

It is beyond the scope of this thesis to provide extensive treatment to the development of traditional network models. The reader unfamiliar with these methods or simply interested in further review of their application is referred to bibliographical references [38],[41], and [58]. It will be instructive, however, to simply summarize the method by which these techniques are normally applied. This discussion will be restricted to the Critical Path Method (CPM) using activity-on-arrow precedence.

4.2 OVERVIEW AND USE OF THE CRITICAL PATH METHOD

Until the advent of Critical Path methods, there was no generally accepted formal procedure to aid in the management of projects. The development of network based planning methods provided for a general approach toward a discipline of project management. Critical Path methods involve both a graphical portrayal of the interrelationships among the elements of a project based on construction lcgic precedence, and an arithmetic procedure which identifies the relative importance of each element in the overall schedule.

In addition to research and development programs and all types of construction work, Critical Path methods have been used with notable success on equipment and plant maintenance and installation, the introduction of new products or services or changeovers to new models, the development of major transportation and energy related systems, strategic long-term planning, management information systems developments, production planning, emergency planning, and even the production of motion pictures, conduct of political campaigns, and complex surgery.

The basic concept of management with CPM is concerned with developing a workable plan of activities that make up a project, including a specification of their relationships. This must be done in an acceptable time span and must consider manpower and other resources required to carry out the program as it progresses in time.

The methodology for applying this network-based project management concept is a dynamic planning and control procedure. It includes six basic steps, each which will be described in the following section.

Step 1: Identification of Project Activities and Establishment of the Appropriate Level of Detail

Step 2: Developing the Logic Network

Step 3: Time and Resource Estimation

Step 4: Basic Scheduling Computations

Step 5: Resource Allocation

Step 6: Time-Cost Tradeoffs

4.3 THE PROCEDURE FOR NETWORK-BASED PROJECT MANAGEMENT

4.3.1 Step 1: Identification of Project Activities and Establishment of the Appropriate Level of Detail

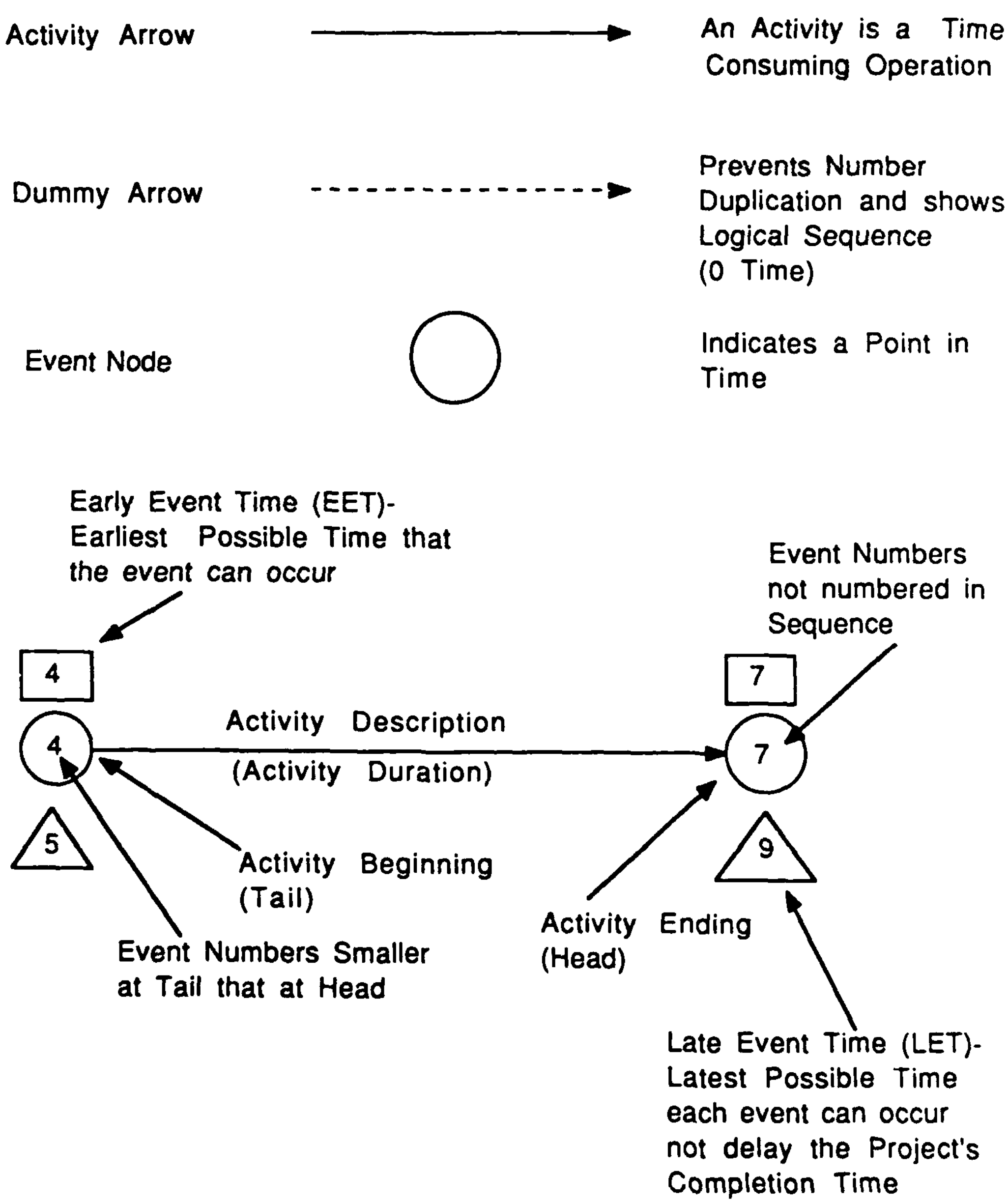
The first step in the networking process is to analyze the project and develop a list of all the activities necessary for completion. This process entails dividing a project into time-consuming, definable tasks. With each activity there should be a description or definition of what work is to be performed.

In defining activities, the degree of detail into which tasks are broken down is a concern. The ultimate objective of network planning is to represent the project accurately and at the desired level of detail. There are a number of factors involved in determining the most appropriate level. Who uses the network, the feasibility of expanded activity detail, separation of skills and areas of responsibility are all pertinent questions which should guide this decision. Obviously, there are no firm rules in this determination. Generally, project planners develop a sense for the appropriate level of detail over time and with experience.

4.3.2 Step 2: Developing the Logic Network

The Critical Path Method showing activity-on-arrow precedence uses the symbols in Figure 4.1 for graphically representing the project. It is at this point that each of the individual activities are connected into a network which is solely based on the logical or technical dependencies among the tasks. These activities are joined by the event nodes

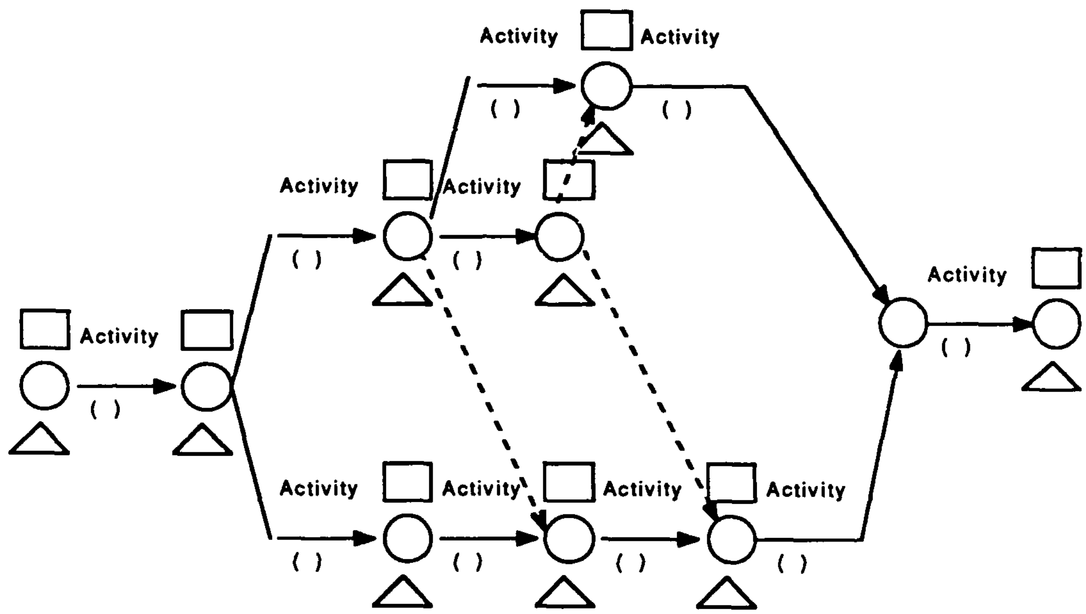
FIGURE 4.1 : CRITICAL PATH METHOD SYMBOLS



representing points in time. Emphasis is placed on strict construction logic and sequencing and is a fundamental part of the networking discipline that causes planners to think about their projects in a thorough, analytical manner. Dummy arrows are introduced merely to maintain proper logic sequencing.

This logical thought process is favorable because it forces the planner to think through the project, anticipate, and plan ahead. Without such a formal approach, planning details might be easily overlooked. A typical network diagram is shown in Figure 4.2.

FIGURE 4.2: TYPICAL NETWORK DIAGRAM



4.3.3 Step 3: Time and Resource Estimation

The next major step in the networking process is defining each activity in detail with time estimates and the amount of resources that will be required to complete the task. The resources involved may be personnel, machinery, facilities, funds or other types of resources. Figure 4.3 shows a typical activity estimate sheet which might be used for assembling these calculations.

FIGURE 4.3: ACTIVITY ESTIMATION SHEET

PROJECT:

ACTIVITY DESCRIPTION:______________________________

MATERIALS TAKE-OFF

Material	Computations	Quantity	Waste	Total Quantity	Remarks

EQUIPMENT - MANPOWER

Component	Quantity	Work Rate	Efficiency	Crew Size	Duration	Remarks

PERSONNEL	EQUIPMENT	FUNDS	OTHERS
Supervisors ______	______	______	______
Carpenters ______	______	______	______
Plumbers ______	______	______	______
Electricians ______	______	______	______
Gen'l Labor ______	______	______	______
Masons ______	______	______	______
Painters ______	______	______	______

4.3.4 Step 4: Basic Scheduling Computations

Specific rules are given for basic scheduling computations in arriving at the duration of the project and total resources expended. This time analysis is based on the results of the two earlier steps in the project management process, using the logic diagram and the activity durations from the resource estimation procedures.

Forward Calculations start with the first event of the first construction day by entering a zero as the Early Event Time (EET). Working sequentially forward through the network, activity durations are added to the EET at the tail of the arrow, placing the sum in the event node at the head of the arrow. When more than one activity ends at an event node, the largest duration is calculated, since the event cannot take place until all activities ending at the node have been completed. The number above the last event node is the project's earliest possible completion time.

Backward calculations are done next to determine the latest possible time each event can occur and not delay the project's completion time. The earliest project completion time is entered as the Late Event Time (LET) for the last event node. Working sequentially backward in the network, activity durations are subtracted from the LET at the head of the arrow, placing the difference in the event node at the tail of the arrow. In situations involving multiple activities leaving the event node, the smallest duration is always used. This will lead to at least one path which produces a Late Event Time of zero at the first event node.

Critical activities in the network are those activities in which the EET and LET are equal at both the arrow's head and tail and the difference between these times is the exact duration of the activity. A network may contain one or more critical paths. It is the longest time path through a network and if any activity on the critical path is delayed, the overall project will be delayed.

The EET at the tail of an arrow is the activity's earliest start date. The LET at the head of the arrow is the activity's latest finish date. Not all of the activities will require the amount of time allowed by the Critical Path network. The "extra" time is called total float and is time a manager can use to control the project.

Total float can be further divided into two distinct types, free and interfering float. Interfering float occurs when an activity, moving within its time frame, interferes with the early start of a dependant activity. The remaining time periods constitute the free float. These time periods are important to a manager because they indicate areas where activities can be delayed with a minimal effect on the project.

It is at this point the the network planner has arrived at the "best case" estimate of the minimum amount of time it will take to complete the project.

4.3.5 Step 5: Resource Allocation

The basic procedures outlined thus far have implicitly assumed that available resources are unlimited and that only precedence requirements constrain the project start/finish relationships. In reality, there are often restrictions in the amount of resources one may expend on the project. These constraints must be considered in order to produce a feasible and realistic schedule. Any of a number of heuristic scheduling rules may be applied to account for these resource constraints. Table 4.1 lists seven of the more common algorithms.

Table 4.1

RESOURCE SCHEDULING ALGORITHMS

1) Greatest Resource Usage
2) Most Possible Activities
3) Minimum Slack
4) Minimum Finish Time
5) Greatest Resource Demand
6) Random
7) Shortest Duration

Resource constraining is performed on the completed logic network in a chronological fashion. Resource totals are computed for each scheduled construction day of the project. If available resources cannot meet these requirements on any particular day, activities must be pushed back or spread out so that the constraint can be met.

This leveling process is continued on a day-by-day basis until the entire project network is altered to meet all known resource restrictions.

The algorithms listed in Table 4.1 accomplish the above procedure in a variety of ways. One method, Greatest Resource Usage, is applied to the network by sequentially pushing back the activity that exhibits highest usage of the "problem" resource for the construction day in question until the constraint is relaxed for that particular time frame. Again, this is systematically continued until the entire network meets all resource requirements.

A second method, Most Possible Activities, is an attempt to schedule the highest number of activities in the particular time frame in question while still relaxing all resource constraints. The Minimum Slack Technique sequentially pushes back the activity with the least amount of slack time. The Shortest Duration Method objectively chooses the activity with the smallest duration to move back in the network. The Minimum Finish Time and Greatest Resource Demand techniques are similarly applied.

4.3.6 Step 6: Time-Cost Tradeoffs

Many times there may be a requirement to impose time constraints on a project. This may be to satisfy a particular schedule completion date or perhaps to make up time because of earlier delays on the project. Time-cost tradeoff procedures or "crashing" techniques may be used to reduce the project duration time with a minimum increase in the project direct costs, by buying time along the critical path where it can be obtained at the least cost. This requires establishing relationships which define time as a function of the resourses expended. Systematic methods of carrying out the above procedure are well-documented. [38]

4.4 FINAL PROJECT NETWORK

Other project constraints are normally nominal and the systematic application of the above procedure has allowed the planner to develop a workable plan of all the activities that make up the project, including a specification of their interrelationships.

Once the network schedule has been developed to a satisfactory extent, it is prepared in final form for use in the field. The project is controlled by checking off progress against the schedule and analyzing the effects of delays. When major changes are required, the network is revised accordingly, and a new schedule is computed. This continues until completion of the project.

CHAPTER FIVE

CONSIDERATIONS IN OPERATIONAL BUILDING RENOVATIONS: Application of the Network Planning Concept to Renovations and the Need for a New and Appropriate Scheduling Technique

5.1 INTRODUCTION

It became evident from the Center Plaza study and from the development of the generic model of the renovation process in Chapters 2 and 3 that the planning considerations of operational building renovations add new dimensions to the scheduling of the work which may go beyond the capabilities of traditional network techniques, such as CPM reviewed in the last chapter. Constraints not normally associated with new construction must enter into the thought process and rationale of preparing a workable network diagram. Flexibility is required to adapt to diverse situations. The risk and uncertainty in the work that will be required and the supporting logistics also need attention in the overall scheme of scheduling activities.

This chapter addresses these considerations and separates them into two distinct categories:

1) Section 5.2 looks at how traditional network analysis techniques can incorporate many of the differences unique to the renovation environment. It does not propose any new procedures, but merely expands and elaborates on the basic concepts of the Critical Path Method to make those who use it more sensitive to the concerns which often arise in the conduct of renovations.

2) Section 5.3 discusses considerations in renovations which state-of-the-art traditional network planning models can in no way address. It focuses on construction disruption to the occupants of the building and to the operational status of the facility. Although we have seen that these factors represent a huge effect on renovation planning, conventional scheduling techniques fail to offer any method of accounting for their impact.

5.2 APPLYING THE NETWORK PLANNING CONCEPT TO MAJOR OCCUPIED BUILDING RENOVATIONS

5.2.1 Additional Activities Unique to the Renovation Process

Although the process of identifying activities is no different for renovation than for any other type of project, the purpose of this section is to outline items that might otherwise be overlooked because they are peculiar to the renovation experience. As such, this identification process may also significantly impact the logic of how the project should be assembled in later stages of the scheduling process.

A) ACTIVITIES ARISING FROM THE INFLUENCE OF ENVIRONMENTAL CONDITIONS

In surveying the renovation work site, surrounding environmental conditions may be as important as actual construction. Access to the site is often a concern. This may encompass the planning and access of truck traffic or the movement of foot traffic. Tenant-occupied renovations introduce the additional concern of competing with the everyday traffic requirements of the operational building and its surroundings. Access to the facility may often require the construction of tunnels or temporary walkways. Each of these additional tasks must be identified for scheduling purposes.

B) DEMOLITION TASKS

Once construction begins, demolition in preparation for new renovations is an added occurence often not found in new construction. Temporary debris chutes may need to be built. Special precautions may need to be taken for activities such as asbestos removal. Barricades are often constructed to protect occupants of the building from the work. Many owners may require the removal of demolished materials daily. The study of renovation work in government housing showed this to be particularly true and many additional activity provisions of this nature were written into contracts.

C) ACTIVITIES ASSOCIATED WITH THE LOADING AND STOCKPILING OF MATERIALS

In preparation for new construction, the loading and stockpiling of materials may require particular attention on renovation projects. The physical size of the area for stockpiling materials may be restricted. Movement of these materials may be difficult because of the confines of the building. Older buildings are often without service elevators; cranes may be required to lift and place supplies on upper floors. Associated activities should be specified for each of these planning concerns.

D) CLEAN-UP ACTIVITIES

As construction proceeds, the issue of cleanliness of the work site is a general concern in tenant-occupied renovations. Contractors universally acknowledge that they need to be more cognizant of work site appearance in these types of renovations. Extensive and frequent clean-ups of this nature take more time and should be scheduled accordingly.

E) TEMPORARY CONSTRUCTION

In identifying activities unique to renovation, a great deal of temporary construction is often required. In addition to the demolition barricades described above, temporary partitions and walls may be needed between work areas. Other examples might include temporary shoring and structural work, temporary electrical service, lighting and heat. Activities of this type are also required as part of the integration of new systems into an older building. The activities associated with these tasks are as important a scheduling concern as the installation of the final product. Planning is also required to ensure that these new services or systems have adequate space for installation in the existing structure.

F) ACTIVITIES ARISING FROM UNFORESEEN CONDITIONS

Besides the categories outlined above, unforeseen conditions can also introduce a great deal of additional work and activities not originally forecast on the project. One example studied was a project in which physical exploration of the exterior facade revealed that the flashing had deteriorated and the result was an additional portion of the project involving major reconstruction of the exterior wall. Hopefully, these types of problems can be discovered early so that they may be scheduled in original plans. If not, it is imperative that they are included in schedule updates.

5.2.2 Network Logic and Precedence Relationships

Another scheduling consideration which requires particular attention in its application to renovation projects is the arrangement of activities into a graphical flowchart of the project by employing pure network logic and precedence relationships. Research indicates this to be a critical but often partially neglected step of the scheduling process in renovations. Interviews with scheduling personnel in construction firms uncovered a tendency toward assembling a project's logic framework based on knowledge and skill acquired primarily through frequent construction practice. Planners were prone to only partially completing the list of anticipated activities and proceeding by dividing a project into recognizable tasks which were similar to those completed on past renovations. This predictably led to an oversight of any unique or particularly complex aspect of the project currently under consideration. In hindsight, these areas are often identified as the "problematic aspect" of the renovation experience.

5.2.3 Time and Resource Estimates

The basics of the mechanics in estimating activity time and resource requirements are unchanged when applied to renovation work. It is generally recognized in the construction industry, however, that renovations often take longer than expected and require more schedule flexibility. In addition to the reasons of unforeseen conditions, more time is required because one must build to fit and meet the dimensions of the existing structure.

Impacts on time/resource estimates are even more pronounced when one adds the constraints of occupants in the building. Renovation contractors agree in general that this may as much as double the overall time of construction. Rather than arbitrarily adding time to the schedule or "padding" individual activities, it is much more important to recognize all the factors that will impact on durations and estimate them accordingly. Almost uniformly, the renovation contractors interviewed indicated that they did not haphazardly add buffer zones to their schedule. They felt they could not operate in this manner and stay competitive in the market and therefore relied on "proper" and accurate estimates instead.

5.3 CONSIDERATIONS IN RENOVATION NOT ADDRESSED BY THE TRADITIONAL NETWORK PLANNING CONCEPT

Section 5.2 focused on topics which can be incorporated into the conventional Critical Path planning model by strictly adhering to sequential scheduling rules. This section addresses considerations in renovation which can not be addressed by this traditional approach.

5.3.1 Schedule Coordination Constraints

The project planner on a new construction project often need only consider the scheduling of those participants involved with the actual construction; the renovation project planner must also consider and attempt to coordinate with the schedules of the owners and tenants of the building. Accommodation of the tenants cannot be overlooked and the planner will most likely need to solicit these schedules for the time period of the construction. Owner/tenant schedules indicate time periods and durations in which certain types of work may not take place. Government contracts reviewed as part of the research effort often stipulated legal holidays and other times in which construction could not take place without owner approval.

Several cases of owner requirements were found to be critical in the major projects researched. One example was the renovation of a major university dormitory which stipulated quiet hours during the hours of 11 a.m. to 1 p.m., much of which is normally prime construction time. Several days were also blocked off from construction time during graduation exercises. Break periods during vacations were designated as prime times for major construction activity. The contractor on this project estimated the construction constraints imposed by these owner requirements to add approximately $25,000 to construction costs and add an obvious scheduling concern.

Similar examples commercial buildings with corporate tenants were examined. Overall, it became apparent that the project planner must avidly collect this owner/tenant schedule information. The question then becomes one of how to effectively deal with these constraints when assembling the final construction network schedule. Traditional network planning models fail to provide a procedural step for imposing these constraints. A scale adjustment must be made to the construction project workday calender and will need to become a step in the implementation of a new disturbance scheduling process.

5.3.2 Minimum Building Operational Requirements

In arriving at a total project plan, the project planner must ultimately determine and meet a building's minimum operational requirements required throughout construction. In a more global sense, the project team must decide how much of an assault the building can take in the form of actual construction and continue to function at some threshold level. Traditional network planning models again afford no objective way of meeting these requirements. The examples below list some of the typical constraints a project planner might face in refining his plan of attack for reconstruction of a building.

1) Specification of the minimum fire lanes required.

2) Restrictions on exits, exitways, and passageways of the building to adhere to safety regulations.

3) Requirements for the number of elevators which must be operational at one time. Restrictions on how many elevators can be put out of service and for what periods of time.

4) Minimum space requirements for individual and corporate tenants.

5) Computer facilities in the building which require dedicated service with non-interruption.

6) Vertical circulation requirements of building and other associated mechanical requirements.

7) Dead storage and files in the building which may be moved temporarily to another location to ease construction space requirements.

5.3.3 Construction Disturbance Constraints

This section categorizes and discusses some of the more prominent tenant disturbance concerns which arose continuously in interviews with individuals who were experienced in major building renovations.

A) UTILITY DISRUPTIONS, SHUTOFFS, AND TURNOVERS

This proved to be one of the biggest concerns expressed by all key players in the renovation process. Disruptions of service were universally recognized as a sensitive issue and worthy of particular concern when scheduling. This included all aspects of utility service (mechanical, electrical, plumbing, etc.) and many individuals expressed particular concern with the disruption of computer facilities and the installation of new cabling, electrical, telephone, and associated services.

B) ACTIVITIES INVOLVING HIGH LEVELS OF NOISE, DUST, DIRT, AND DEBRIS

Construction sites are inherently noisy environments, often with a proliferation of dust, dirt, and debris. Much of this is unavoidable, yet there is a spectrum of the tolerability of various tasks. In both reinforced concrete and steel buildings, activities which penetrate or contact the steel are particularly annoying. The structure serves as a conduit for noise and carries it great lengths through the facility. Most individuals agree that coring and drilling activities are a primary concern. Ramsetting was also mentioned as a problem. This was an issue when shooting tracks for studs, some installation of ceiling hangers, and other framing tasks. When installing metal studs, hanging drywall, and various other activities, screw guns were also identified as particularly annoying.

Demolition tasks are often a particularly disruptive element of the construction work associated with renovation, not only for involving a high level of noise, but also a great deal of dust, dirt, and debris. Building managers are quick to point out the resulting impact on a building's operation and safety concerns. Normal business operations may be severly affected in a commercial building. Computer facilities are particularly susceptible to high levels of dust and dirt. Demolition is also extremely noisy with the use of many pneumatic tools, such as chipping guns and jackhammers.

Other miscellaneous activities which are often identified as affecting tenants and a buildings operations included pipe cutting, some sawing tasks, and even the A-frame movement of dry wall through a building.

The level of disruption due to the types of activities described above may often require the tasks to be carried out after hours, as overtime, night or second shift work. Many contractors express an attitude whereby the owner will "pay now or pay later." If the most feasible option is to conduct the work after hours, to try and do so during normal crew hours only creates wasted time and in the end becomes more expensive. Methods of effectively scheduling this overtime work in a graphical network diagram are non-existent and must again become part of a new disturbance scheduling method for satisfying these restrictions.

C) DISTURBANCE IN THE ROUTING OF TRAFFIC/ACCESS TO THE BUILDING

An overriding safety concern is the maintenance of access and egress to the entire building. Periodic tenant traffic rerouting, although recognized as disruptive, is generally not as important as the categories already mentioned above. Interruption of routine and extended travel paths often are the only noticeable changes.

Elevator work is generally considered to be the most critical tenant traffic concern. Older buildings may not have adequate elevator service and when these are shut down for reconstruction, the impact may be substantial. In addition, this service disruption may also affect the movement of materials into and around the facility.

D) OTHER MISCELLANEOUS DISTURBANCE ACTIVITY CONSTRAINTS

Individual projects may introduce other activities which require special attention when conducting renovation construction. Examples might be the sensitive issues of working aroung living spaces and privacy concerns which might affect how tasks are to be scheduled.

Most types of scheduling disruptions come as a result of owner and tenant requirements. To predict them without owner input is rarely an intuitive process. What may seem to be a particularly disturbing activity from the viewpoint of a contractor may be tolerable to the tenants because of an inducement or attractiveness of the completed tasks. If the tenant can actually see or expect a tangible improvement, they might be willing to tolerate what might appear to be an extremely high level of disturbance. As an example, an aesthetic improvement (such as flooring, carpeting, windows, etc.), although very disruptive, may be more easily accepted than an electrical service upgrade in which the improvement might go unnoticed. Conventional network analysis methods offer no way of treating these differences in any objective and appropriate manner to the satisfaction of all parties involved.

5.3.4 Key Concepts to be Incorporated in Disturbance Scheduling

The scheduling constraints unnaccounted for in the steps for assembling the traditional CPM network diagram lead directly to the need for the establishment of a new, methodical, and appropriate algorithm for performing disturbance scheduling procedures. These procedures must address several categories of disturbances which surfaced in the previous sections. To summarize in review, they are:

- Coordination of project plans with owner and tenant schedules
- Construction constraints which affect the daily functioning of the building
- Activities which, for disturbance reasons, must be completed during very restrictive time frames
- Activities which are disruptive enough to require their completion after hours or on weekends
- Activities which are affected by the environmental and physical conditions of the building and thereby restrict the size of construction work space areas

Each of these key concepts thus becomes part of a new procedure, the Disturbance Scheduling Technique, which follows in the next chapter.

CHAPTER SIX

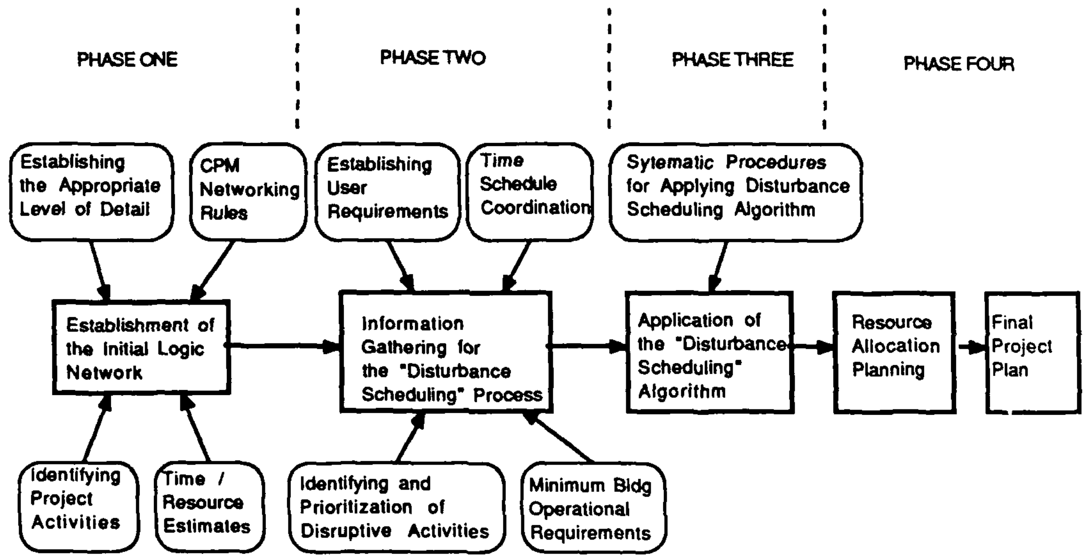
THE DISTURBANCE SCHEDULING TECHNIQUE

6.1 INTRODUCTION

The purpose of this chapter is to introduce a new, systematic scheduling method built on incorporating the principles of the previous chapter. This technique is presented as a series of specific operations, grouped into four phases, which deal with construction disturbances for scheduling purposes. It focuses on eliminating these disturbances in decreasing order of intensity and with objective procedural rules, thus arriving at an organized and better flow for the project.

The Disturbance Scheduling Technique should be recognized as an evolutionary concept which will undoubtedly undergo revisions and refinements as the knowledge and understanding of how best to accomplish renovation improves. To begin, a flowchart which outlines the general procedure is shown in Figure 6.1. This flowchart will help guide the reader in following the overall plan of assembling the project schedule.

FIGURE 6.1: **THE DISTURBANCE SCHEDULING TECHNIQUE**



Phase One of the Disturbance Scheduling process is similar to that described in Chapter 4. The initial logic network is prepared based on construction logic alone, a normal 40 hour work week calender, and with the assumption that the building is empty.

The second phase of the scheduling process is preparation for the application of a disturbance scheduling algorithm. It is an information gathering and organizational step introduced to prioritize the construction constraints associated with tenant impact concerns much the way resource constraints are accounted for with resource allocation planning.

In Phase Three, the project schedule is altered or spread out to arrive at a minimally operational level for the building. This is accomplished based on the priority system assigned to disturbance activities from Phase Two. Methodically, a series of objective steps, sequentially arranged by a ranking procedure are used to relax all disturbance constraints. It is probable that as expertise in renovation work improves, an accepted set of common algorithms may evolve for this process similar to those listed in Table 4.1 for resource scheduling.

Resource scheduling with the Disturbance Scheduling Technique becomes Phase Four of the scheduling process. The method is the same as described in Chapter 4, but this time resource constraints are applied to the network after it has been revised through disturbance scheduling. Upon completion of the fourth phase, the final network plan has been developed and is ready for use in the project management operational requirement of controlling the project and schedule through actual construction.

6.2 PHASE ONE: ESTABLISHING THE INTITIAL LOGIC NETWORK

This phase corresponds to Steps 1 through 4 described in Sections 4.3.1 through 4.3.4 of Chapter 4. It is at this point in the scheduling cycle that the first draft of networking diagram is assembled and includes all anticipated activities and estimated time and resource expenditures. The planner also performs basic scheduling computations.

6.3 PHASE TWO: INFORMATION GATHERING FOR THE DISTURBANCE SCHEDULING PROCESS

Phase Two in the application of the "disturbance scheduling" process is the collection of information relating to tenant concerns and its prioritization. This is accomplished through extensive negotiations between the project planner and the owner/tenants of the facility.

6.3.1 Owner/Tenant Negotiations: Establishing User Requirements, Time Schedule Coordination, Disturbance Activities, and Minimum Building Operational Requirements

Tenant-occupied renovations require the schedule planner to become "owner-smart" and intensely aware of client demands. This awareness can only come about as a result of effective communications with the owner and the tenants which occupy the building. The overriding concern of most owners is to keep their tenants happy. A "quiet enjoyment" clause of most lease terms allows for a tenant to conduct business without major disruption.

The owner must convey to the project planner his business concerns and any guidance for minimizing income stream disruptions to the building. This should include specific dates and periods of time when construction cannot take place at all and time periods when the construction disruption must be reduced to some predetermined level.

To assemble information regarding specific disturbance activities, the best policy is to inform owners/tenants up front about the disruption they should expect, negotiate about what time frames these tasks might best be accomplished, and determine the level of construction they can accept. Experience has shown it unwise to assume what the occupants and owners can and cannot tolerate. One of the interviewed contracting firms went as far as demonstrating activities at pre-construction meetings in order to ascertain information about specific activities which can be scheduled for different periods of time or which activities could not be tolerated at all and need to be scheduled as overtime.

These types of owner negotiations and the early establishment of complete user requirements for the renovation are critical to the successful completion of any project. This was evident in the Center Plaza study and was equally important in most of the other major projects that were studied. Changing designs, either before construction begins or, more importantly, once construction is underway can be an expensive undertaking and requires the major alteration of project schedules.

To assemble overall information on the minimum building operational requirements, the information gathering process should involve building managers and operations personnel, as these individuals are often key in identifying daily functional requirements of the facility. They also may be best able to anticipate regulatory and safety requirements which must be met during construction.

6.3.2 The Identification and Prioritization of Disruptive Activities

The information gathered in the preceding section is now formally prioritized by disruptive activities. Disruptive activities are specifically defined as those activities which significantly impact the tenants/occupants and affect the operational requirements of the building.

The project planner analytically develops a comprehensive list of activities which are arranged in decreasing order by their level of disruption. These activities are also be categorized into prominent issues which arose as key concepts at the end of Chapter Five. An example of a prioritized disruption list for a typical renovation project is shown in Figure 6.2.

FIGURE 6.2: SAMPLE PROJECT PRIORITIZED DISTURBANCE LIST
(arranged by decreasing level of disturbance)

Sample Categories	Example Activities/ Disruptive Events
1. Time Schedule Coordination: Time frames when all construction is prohibited.	(Specific Dates) -Executive Programs/Conferences -Building Conventions -Grand Opening Retail Sales/ Open House -Fiscal Year End Inventories -Graduation Excercises -Holiday Periods
2. Restrictive Time Frames: Activities which are required to be performed during a very restrictive time frame (ie. weekends only, etc.)	-Electrical Shutdowns for Service Connection -Installation of New Plumbing Connections -Utility Shutdowns required for the integration of new mechanical equipment into an operational building system -Other Utility or Service Disruption as applicable Note: These activities may affect the entire facility or just certain portions. (This information must be recorded.) -Dates for Project Approval and required documentation that cannot be changed
3. After Hours Construction: Activities which must be performed outside the normal business day (required overtime activities.)	-Coring Activities -Jackhammering operations -Assorted demolition tasks -Activities which do not meet operational building safety regulations
4. Time Frames of Reduced Construction Effort: Time Periods which require reduced construction impact due to tenant concerns.	-Quiet hours specified during a certain portion of the normal construction day. -Commercial buildings might allow full construction except for the hours of 10 a.m. to 4 p.m. with restrictions on activities during this time frame alone.

5. Minimum Building Operational Requirements: These are the activities which might impose constraints in their concurrent performance because of minimum daily functional requirements of the building.	-Elevator Renovations -Activities affecting areas of dedicated service (ie. computer facilities, etc.) -Office Space renovations which reduce space availability below minimally acceptable levels. -Global Considerations: Combinations of activities which taken together would not allow the functioning of the building.
6. Work Space and Distance Restrictions: Activities within restrictive work areas which require the proper sequencing of trades.	-Example sequencing of trades for an Interior Space: -Sheetrock -Tape and Spackling -Painting -Sprinkler -Electrical -HVAC -Millwork -Plumbing

6.4 PHASE THREE: THE DISTURBANCE SCHEDULING ALGORITHM

6.4.1 Basic Concept

The algorithm for performing "disturbance scheduling" is a sequential procedure similar to that used in resource constraining as outlined in Section 4.3.5. Rather than proceeding in a chronological manner, the disturbance sheduling algorithm examines individual tasks and activity groupings by their prioritized level of disruption.

The planner first considers the disturbance conditions which are most restrictive. These constraints are relaxed using the procedural steps which follow. Once these disturbance constraints have been met, the planner looks at the next most disruptive activity or activity grouping. In this manner, the planner continues to work his way in an orderly fashion from the most to least disturbing activities until he/she ultimately arrives at a network schedule which has been completely "disturbance scheduled."

6.4.2 Procedural Application

6.4.2.A CATEGORY 1 PROCEDURAL STEP: Time Schedule Coordination

Activity and project durations using conventional Critical Path computations are normally expressed in units of construction workdays (usually of 8 hour duration). As a result, the project planner must convert these duration times into calender dates. The procedure is simple, as the example in Figure 6.3 depicts.

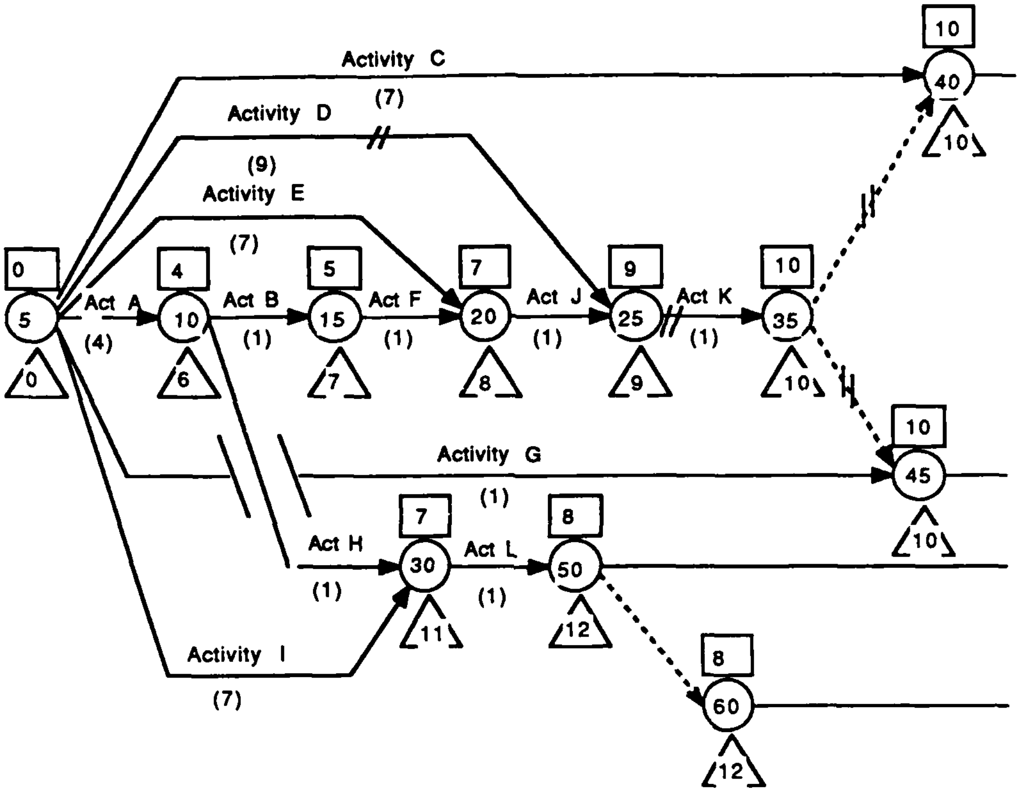
As shown in Figure 6.3, operational building renovations differ from many construction projects in that they often use weekends, in addition to normal weekdays, as prime construction time. Weekend periods offer contractors the ability to perform work in the most unconstrained fashion when tenant concerns and building operational requirements are at their lowest level.

IMPLEMENTATION

In accomplishing this step, the renovation planner considers the disturbance activity requirements which are most restrictive. These would be dates from the owner/tenant schedules that cannot be altered. They include the most critical items, constraints that cannot be worked around, and time frames when construction absolutely cannot take place. Several examples were cited in Figure 6.2.

To implement these restrictions, the planner merely blocks these dates off from the construction calender, thereby imposing an immediate extension to the overall project duration.

FIGURE 6.3: PROJECT NETWORK CALENDER INTEGRATION



SAMPLE PROJECT CALENDER

Sample Month

M	T	W	Th	F	S	Su
10	11	12	13	14	15	16
17	18	Executive	Conference		19	20
21	22	23	24	25	26	27
Holiday	28	29	30	31	32	33

Large Numbers Indicate Construction Workdays and Correspond to Duration Times on Project Network

Time Periods Prohibiting Construction are blocked out

Weekend Construction Workdays are included as available

6.4.2.B CATEGORY 2 PROCEDURAL STEP: Restrictive Time Frames

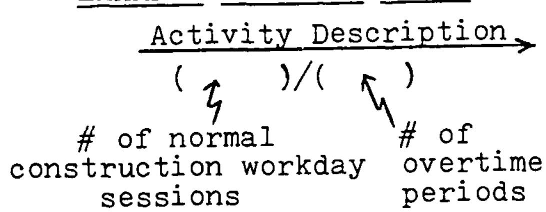
This particular category of disruptive activities (see Figure 6.2) is deferred until the last step of Phase Four of the Disturbance Scheduling Technique (after Resource Allocation Planning) and will be discussed at that time.

6.4.2.C CATEGORY 3 PROCEDURAL STEP: After Hours Construction

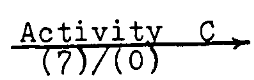
In addition to expanding the project scope to include weekend construction periods as ideal for uninterrupted work sessions, the experienced renovation planner soon realizes that after hours construction affords the same advantages and is often the only feasible alternative for particulary disruptive tasks. The conventional Critical Path Method offers no satisfactory way of graphically portraying these work sessions without modification.

The graphic symbol for individual activities must be altered to allow the planner the capability to track this after hours work. Rather than including only one duration underneath the activity arrow; two durations are recorded; one to track normal daily work sessions and one to track overtime periods.

EXAMPLE ACTIVITY ARROW



If the activity is completed only during normal crew hours, the first duration would assume the value of the task duration, while the second number recorded would be zero.



This corresponas to the case of the conventional Critical Path symbol.

Similarly, if the activity is completed only as overtime work, the symbol would appear as follows.

$$\frac{\text{Activity C}\rightarrow}{(0)/(7)}$$

If the activity is to be performed during both sessions, a combination of numbers would appear.

$$\frac{\text{Activity C}\rightarrow}{(4)/(3)}$$

In all cases, the overall activity duration used for critical path calculations would be the larger of the two numbers. In the last example above, the activity duration as computed using the Activity Estimation Sheet in Figure 4.2 would be 7 days. However, only 4 days would elapse on the construction calender. Hence, this would be the figure used and the integration procedure illustrated in Figure 6.2 still applies.

In the event it is decided to employ three work sessions during a 24-hour period, three separate durations would be recorded underneath the activity arrow; one indicating daily work sessions, one for evening shifts, and one for night shifts. Again, the overall activity duration for computational purposes would be the larger of the three numbers.

IMPLEMENTATION AND EXAMPLE

The type of disruptive activities which the renovation planner is considering at this time are those which must be performed outside the normal business day to totally preclude disturbance.

As one example, this might include certain demolition tasks on the project. It may have been decided in owner/tenant negotiations that these activities must be completed as night or second shift work. Imposing these constraints as outlined above, the planner would formally modify the original schedule to accurately reflect overtime work rather than trying to represent the accomplishment of these demolition tasks during normal crew hours.

Another application of this schedule planning process is in providing for continuity of utility service. This work may often need to be completed during system shutdowns. Examples include sprinkler system shutoffs and other essential mechanical services which may have been deemed an after hours tasks during the preplanning phase of the disturbance scheduling process. Because of the substantial impact on the facility and its occupants, the project planner must provide for a corresponding level of schedule attention. The procedural step in this section offers the planner a tool to accomplish this objective.

6.4.2.D CATEGORY 4 PROCEDURAL STEP: Time Frames of Reduced Construction Effort

The next category of disruptions are those time periods which require reduced construction impact due to disturbance concerns. Examples were again offered in Figure 6.2. The procedure to relax this constraint involves the planner splitting activities on the project into two groups;

(1) those which may be performed during the restricted time frame,

and (2) those which can not.

This information was gathered in Phase Two. Activities listed in the first grouping are not affected and remain in the network without modification.

The second group of activities must be altered to account for the disturbance constraint. Because there is a portion of each daily construction period in which work on these tasks can not be performed, the overall duration of the affected activities must be lengthened appropriately. Equipment/Manpower computations from the Activity Estimation Sheet (Figure 4.3) are re-calculated as shown in the example below, and the new durations are then recorded on activity arrows in the network diagram.

IMPLEMENTATION EXAMPLE

The following example is provided to explain the execution of the above step:

Consider a project, with normal 8-hour construction periods, requiring a quiet period each day of two hour duration which prohibits certain tasks. Also consider a representative task that has been calculated to take 6 workdays (48 hours) to complete. Because of the imposition of the quiet hour constraint, only 6-hour workdays are now allowed, reducing the effective work time each day by 25%. The overall duration for this activity is therefore increased by the same 25% to a total of 8 construction days.

Similarly, if the activity were one that was undergoing construction during both a normal and overtime period each day, its overall duration would initially be 3 workdays. By imposing the 2-hour constraint to the normal crew hour period, a reduction of 12.5% would be experienced (16 to 14 hours each full construction day). The revised overall duration would be 4 normal construction periods and 3 overtime periods ($\xrightarrow[(4)/(3)]{}$), thereby increasing the overall duration to 4 days. This procedure can easily be extended to more complex situations by adhering to the fundamental concepts above.

6.4.2.E CATEGORY 5 PROCEDURAL STEP: Minimum Building Operational Requirements

This step considers activities or activity groupings which impose constraints on their concurrent performance because of minimum daily functional requirements of the building. Even within this category, it is imperative that activities are addressed by decreasing level of disturbance.

As part of Phase Two, the planner will have already scanned the network and identified individual tasks and activity fragments which prevent the building's normal operation because of an imposed disturbance constraint. Sequentially, the planner must now analyze these activities, determine the maximum level of construction which may proceed at any one time and then spread out the activity into a number of consecutive phases, each of an allowable magnitude.

To illustrate, an activity which originally involved 10 similarly constructed components for a duration of 4 days, may only be able to be performed 2 at a time for the building to function. The task is therefore divided into 5 subactivities, each still with a duration of 4 days, for a total of 20 construction days for the entire fragment.

In spreading out the original activity grouping, the planner must also determine if there is an optimal order in which the new sub-activities should proceed. This step must involve construction expertise and is a more subjective evaluation which differs from one project to another. The examples in the implementation section which follows address this issue and are a collection of techniques from various firms interviewed on the subject.

IMPLEMENTATION AND EXAMPLES

A standard example, observed on a number of major building renovations, involves the upgrade of elevator cabs. If the building contained 8 elevators and each cab overhaul was estimated to take 4 days, the initial logic network would graphically portray their renovation as one concurrent task. No other logic constraints would exist. Assuming that the building could not operate with more than 3 cabs out of service, the planner would then be required to divide their reconstruction into 3 sub-groupings for a total duration of 12 days. The order in which these cabs were completed, and which phase would contain the overhaul of only 2 cabs, would depend on the building's configuration and the expressed interests of the owner. Whatever the decision, this determination should surely be made prior to the start of construction.

Another standard example is the disturbance imposed by minimum space requirements for individual and coorporate tenants when sequentially renovating interior office space. The planner must determine the largest number of tenant spaces that can be renovated at one time and then constrain the logic network to meet this requirement by dividing the building into allowable sections.

Considerations of the best way to break up these types of operations are complex. Conducting construction work in a facility which is to continue with tenant-occupancy throughout the operation imposes severe restrictions. Many times tenants are already at limit in space availability and therefore look unfavorably upon further hindrance to their livelihood. They obviously wish to continue their operations as normal. Hence, the scheduler should strive to minimize the amount of movement the tenants have to undergo in the course of renovation. Proper ordering of construction is the way to achieve this result.

One method of relaxing this disturbance constraint to a tolerable level is to attempt to condense the tenants to a central or convenient location early in the project, taking advantage of temporarily unoccupied space resulting from routine tenant turnover. Then, once construction is completed in other areas, the tenants might be sequentially moved back to their normal location without multiple moves. Another technique is to set up temporary property lines within occupied spaces to conform to the renovation plan as work proceeds. The construction of dust partitions and temporary barricades is a critical task in the successful execution of this type of operation.

OTHER PHASING CONSIDERATIONS

The types of location sequencing described above are important factors in modifying the original logic network to meet disturbance scheduling requirements. If feasible, working in an orderly fashion by location saves time.

The objective decision of spreading out original activity groupings is often a simple calculation. The optimal ordering of these sub-groupings, however, is much more difficult because of its subjective nature. To resolve this problem, this section discusses other common techniques which were assembled as the result of interviews conducted with scheduling experts in the field. Three major categories are presented; (a) Utility and Service Considerations, (b) Noise, Dust, Dirt, and Debris Restrictions, and (c) Traffic Considerations.

(a) Utility and Service Considerations

A key aspect of the rationale for ordering activity groupings is to understand utility service considerations and the fact that renovations can take place within a particular portion of the building a high percentage of the time without significantly affecting other parts of the building. Shutoffs, switches, and valves for utility services, if properly utilized, planned, and coordinated can be used to zone the building into specific areas of construction. This can be done on a floor-by-floor basis for multi-story buildings or by segregating the facility into quadrants or other convenient sections as required.

As examples, interruptions to the cooling system for a building may be a major concern. In planning the work procession, a planner might possibly require new connections and temporary routing of chilled water loops through the facility to minimize this disruption. Renovation work to upgrade electrical service might involve temporary zoning for the installation of new lines and conduits. Inadequate electrical service can be identified early in the planning process and provisions for new service switchovers can usually be provided without major disruption. As another example, the standard use of gravity systems in waste-water movement may dictate major plumbing alterations to adopt a vertical zoning plan and include up to three floors of the building in a particular construction segment.

(b) Noise, Dust, Dirt, and Debris Restrictions

In order to reduce noise, dust, dirt, and debris restrictions resulting from a combination of tasks, the project planner may again be required to split activities into sub-tasks that represent an allowable level of construction disturbance. This is somewhat of a subjective concern, but can be accomplished if owner/tenant negotiations have effectively identified the associated impact.

Because of noise propogation concerns, the renovation planner may wish to order the sub-activity fragments to create buffer zones between areas of current occupancy and actual construction. Sometimes a project may afford the flexibility of employing a one floor buffer between occupied areas and the construction.

(c) Traffic Considerations

Maintenance of emergency egress from the building was identified in Chapter Five as a paramount concern. In addition, restrictions imposed on equipment access around the building were also discussed. Parking regulations or local ordinances may impact the times in which the scheduler can plan to engage in certain activities. A good example might be the scheduling of crane access for loading and lifting operations in a building with inadequate or non-existent service elevators.

Once these tasks have been spread out into activity fragments which allow the building to continue to function, the techniques for ordering their accomplishment are highly dependent on the situation at individual project sites. Two thought-processes the planner should consider in these cases are (1) working on a multi-story facility in a top-down fashion thereby accomplishing the most seriously constrained work early in the project cycle, and (2) working in an orderly manner toward debris exit locations in the building in an effort to confine the disturbance and minimally impact the building's normal traffic patterns.

6.4.2.F CATEGORY 6 PROCEDURAL STEP: Work Space and Distance Restrictions

Work space and distance restrictions are often a severe constraint to the renovation planner and are the next level of disturbance constraints to be addressed. Common sense often dictates the optimum size of work crews within a particular area. This involves not only picking the right number of people to complete the job, but also proper sequencing of trades. Movement of crews must be timely and buffers between different trades becomes and issue. One technique for resolving scheduling constraints of this nature is employment of the Vertical Production Method (commonly referred to as the Line of Balance Method). [42] The concept is to use a series of stages through which the work is accomplished allowing adequate space for crews conducting independant tasks.

The renovation of a commercial building often involves the sequential completion of a number of like units (ie. individual tenant spaces, lobbies, bathroom facilities, or other appropriate sections of a building). Each unit becomes an individual project with a well-defined start and completion. However, the schedule is no longer determined simply by the length of that unit's completion. Rather, the schedule is now controlled by the time required for each of the major trades to work through the total number of units. Mapping of the progress is completed by using a series of production lines. None can go faster than the first, to any advantage, and any of the controlling lines can slow down the construction of all the units.

Critical Path Method procedures can continue to describe parallel activities which are proceeding in the logic network concurrently with the sequential completion of the like units. The Line of Balance Method starts at the event node where the project has reached the stage at which the first unit can be initiated. Establishment of this point does require the prior networking process which has been completed to this point.

Using the Line of Balance technique, the scheduler starts from this event node and projects the work progress at the anticipated rate of production on the Line of Balance Chart. The Line of Balance chart is laid out with a vertical axis divided into equal spaces, one per typical unit. The horizontal axis is a time grid. Projecting the production line for each sequential trade at their rate of progress, the end date for each typical unit can be established along with a completion date for the entire number of like units. Arithmetic computations predict the length of time for each activity and establishment of completion points. Under this approach, the production line can be drawn between the starting point and completion point. Points of intersection at each unit indicate the date at which the category of work will start on that unit. In this manner, the project planner continues by projecting all of the key subcontractors, from rough-in through to finish work.

IMPLEMENTATION EXAMPLE

To illustrate the above procedure, consider an example of typical tenant improvement work in a commercial facility. We will assume that the building contains 30 tenant spaces which will receive minor renovations while the facility remains operational. This work will include painting, electrical service upgrade and installation of new lighting fixtures, some millwork and finish work, new carpeting, and clean-up.

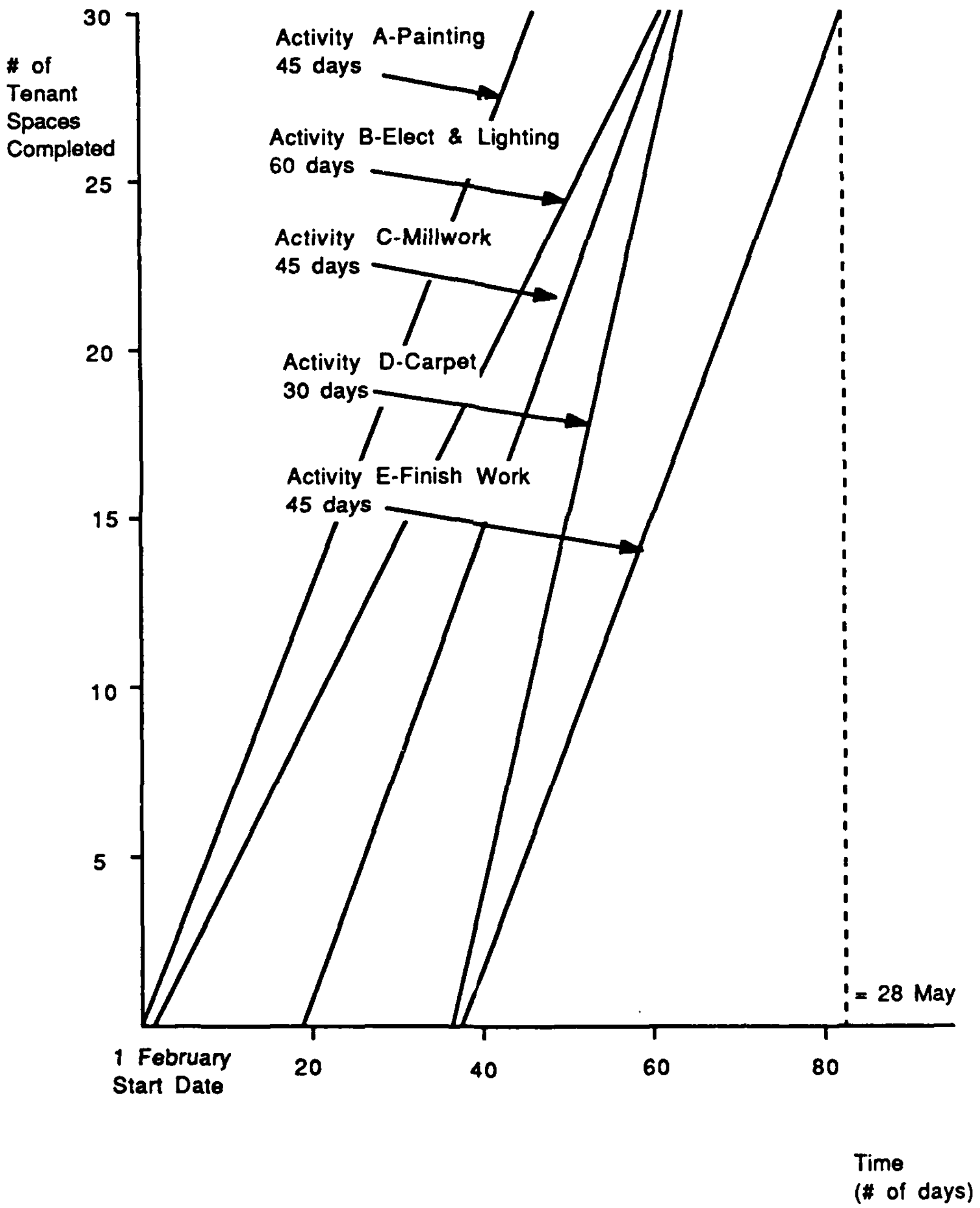
An initial analysis using the line of balance method of scheduling is shown in Figure 6.4. Durations are based on activity estimation calculations using production rates per crew for each activity and the total anticipated number of crews available, or the maximum number of crews which can be allowed due to space and distance restrictions. Figure 6.4 indicates that the current plan will meet a completion date of 28 May. This analysis is based on several assumptions. If these assumptions prove too ambitious, there may be a time overrun.

Assumptions:

1) The starting date is 1 February. This is based on the current revised logic network.

2) A 2 day buffer is allowed between activities. This may often prove adequate, but unexpected problems here could cause an overall delay. The function of the activity buffer is to delay the start of subsequent activities to an extent which will minimize the effects of these delays.

FIGURE 6.4: LINE OF BALANCE SCHEDULE



3) The estimated number of crews are available. Smaller numbers of crews would extend durations and may delay the overall completion date.

Despite the fact that the current schedule may be adequate, it is apparent that unexpected problems may cause unforeseen delays. There may be a need to decrease the scheduled duration. We next address that possible need.

Of the 5 activities on the line of balance schedule, 3 of them have a duration of 45 days. In order to isolate the subcontractors whose output may hold up the project, it would be most feasible to examine the remaining 2 activities. This type of argument will probably lead to a cost-effective revision as well. If all 5 activities were balanced to a duration of 45 days, the total duration of the tenant space operations would be 53 days or about 16 April. Any portion of this type of balancing will provide a higher probability of finishing on time and is desirable. Figure 6.5 shows this revised line of balance schedule.

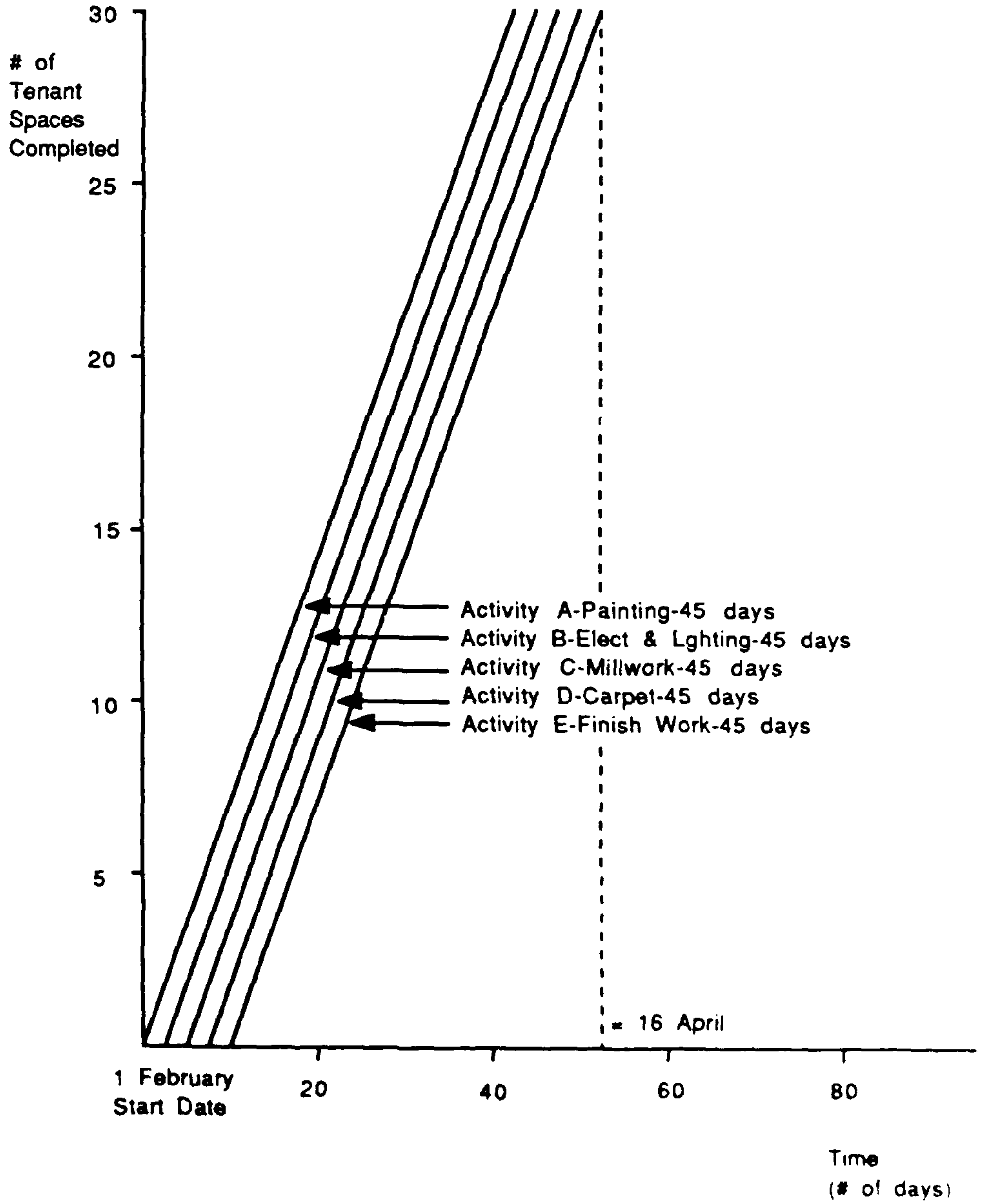
The two isolated subcontractor activities fall into two separate categories:

1. One which completes too quickly and thus must be started later to insure continuity of work. This activity still has a net effect of delaying the overall project.

Activity D - Carpet - 30 days

It is interesting to note that the overall duration of the tenant space operations could be reduced if this subcontractor

FIGURE 6.5: REVISED LINE OF BALANCE SCHEDULE



were asked to slow down their rate so that they complete all 30 tenant spaces in 45 days. Three methods of accomplishing this would be to:

(a) reduce the crew sizes on this activity.

(b) reduce the number of crews.

(c) Have the subcontractor stop and start repeatedly, in order to stay right behind the preceding subcontractor. This is usually not desirable because it adds discontinuity to the project flow.

(2) The second category is an activity which takes too long.

Activity B - Electrical and Lighting Improvements - 60 days

The following are methods by which the output of this slow subcontractor could be increased:

(a) Increase the number of crews working on that activity.

(b) Increase the number of members on the crews.

(c) Have the crews work during overtime periods.

After viewing the line of balance schedule in Figure 6.4 it is obvious that there is room for improvement by balancing all of the activities. By reducing the idle time of the tenant space renovation, while maintaining continuity of work, the overall time for interior construction can be substantially reduced, in this case by 30 days or 26 %. The ultimate goal is to have the activities run parallel to each other on the line of balance chart. It is often worth the extra costs involved to reduce the overall length of the project and thereby gain a higher probability of an earlier completion.

Rather than the common construction practice in which many like items are done in a sequential process as illustrated above, disturbance scheduling concerns may require all the work to be done in a single tenant space or a very small portion of the building prior to moving on to the next section. Despite loosing economy of scale and the advantages of completing major portions of the work by trades, this sort of scheduling restriction is commonly imposed on major tenant-occupied renovations. As such, the project planner must be prepared to modify the schedule accordingly by breaking the activity groups into these much smaller fragments.

6.5 PHASE FOUR: RESOURSE ALLOCATION PLANNING

In applying the disturbance scheduling algorithm of section 6.4, the project planner has arrived at a network that has relaxed all constraints associated with tenant impact concerns and minimum building operational requirements. The fourth phase toward a feasible and workable plan is to apply resource constraints to this schedule. The techniques for accomplishing this task were discussed in Section 4.3.5.

The only remaining task for the scheduler is to address the Category 2 disruptive activities. These were the activities which are required to be performed in a very restrictive time frame (ie. weekends only, etc.). Examples were given in Figure 6.2.

Now that the scheduler has arrived at a total network schedule, he need only move these tasks within the time frame of their performance to allow them to conform to their particular restriction. This might be accomplished by using float time as described in section 4.3.4. If not enough float is available or the activities fall along the critical path, by moving them back in the project network to meet the constraint, the overall duration of the project may be lengthened. The salient point is that these events may now be predicted to occur at a certain time with reasonable accuracy based on the network diagram, rather than arbitrarily having them chosen to be performed at a time which may not be optimal. Once completed, the project planner has developed a total project plan which will serve as an invaluable management tool as the renovation process proceeds into the construction phase.

6.6 PREPARATION FOR TEST CASE

In summary, this chapter has presented a new method and algorithm which can be employed in conjunction with the conventional Critical Path Method (CPM) for the scheduling of major tenant-occupied building renovations. The chapter which follows will now use this new technique in scheduling an actual project for the purpose of testing its applicability. The Center Plaza improvement is chosen since the reader will have gained a good background of the project from earlier chapters of the thesis.

CHAPTER SEVEN

SCHEDULING APPLICATION: The Center Plaza Improvement Project

7.1 INTRODUCTION

The purpose of this chapter is to reschedule the Center Plaza improvement project in preparation for later analysis. This rescheduling will be accomplished in two distinct ways. First, an application using the conventional Critical Path Method will be presented in Section 7.2. This will be followed directly be an application using the Disturbance Scheduling Technique in Section 7.3.

The only observations contained in this chapter are in reference to the manner in which a planner goes about applying the procedural steps of each technique. Detailed comparison and analysis of the Critical Path schedule, the Disturbance Scheduled Network, and the actual schedule (Figure 2.4) will be presented in Chapter Eight.

7.2 CONVENTIONAL CRITICAL PATH METHOD APPLICATION

7.2.1 Identification of Project Activities

Chapter 2 described the evolution of the Center Plaza project in detail. To begin, it is useful to review the reduced scope package completed during actual construction. It is shown below.

Table 7.1

FINALIZED SCOPE OF WORK

```
EXTERIOR
  Passageways-Stonework, Ceiling and Lighting
     @ 3 Center Plaza
  Storefronts and Entrances-New Doors, Glass Facades, Metal
                            Finishes, Stone Panels, Minor
                            Ceiling, Floor, and Wall Tie-ins
     @ 1,2, & 3 Center Plaza

  Public Lobbies-Ceiling,Flooring,Walls,Lighting,Directory
     @ 3 Center Plaza
  Exterior Facade Lighting

INTERIOR
  Multi-tenant Lobbies-3 each (2nd, 5th, & 8th floors; 3 CP)
                  (4th floor prototype completed in advance)
     Ceilings
     Installation of improved life safety systems
     Lighting
     Wall Finishes
     Carpeting
     Restrooms
     Floors and Partitions
  Handicap Bathrooms-3 each
     @ 2nd Floor; 1,2, & 3 Center Plaza
  Elevator Cabs
     Complete Interior Finishes
     Lighting
```

From this work description, one begins developing a comprehensive activity list exhibiting the appropriate level of detail for project management. A partial listing is shown below for the elevators. A complete activity list for the entire Center Plaza project is included in Appendix A.

Table 7.2

PARTIAL ACTIVITY LIST

Elevators
- Shop Drawings
- Remove from Service / Dismantle Cabs
- Install New Lighting and Fixtures
- Prefab Panels / Ceiling
- Install Panels / Ceiling
- Install Carpet
- Finish Work-Install Hardware/Handrails
- Reconnect Service

7.2.2 Developing the Logic Network

Next, the individual activities are connected into a network based on the logical and technical dependencies among tasks. This is accomplished in accordance with the procedure described in Section 4.3.2. Figures 7.1 through 7.9 depict the complete logic network diagram for the Center Plaza project. It is delineated into two hierarchies with Figure 7.1 showing major subnetwork fragments in an overall diagram. The remaining figures show the subnetwork fragments in complete detail.

7.2.3 Time/Resource Estimates

Time and resource estimates are now completed for each of the separate tasks. Table 7.3 below shows sample estimates for the facade lighting portion of the project. A complete listing is again found in Appendix A.

Table 7.3
PARTIAL TIME/RESOURCE ESTIMATES-CENTER PLAZA

Activity	Crew Size	Duration
FACADE LIGHTING (26 fixtures)		
Coring	2 Corers	.5 days/fixture 13 days total
Electrical Rough-in	3 Electricians	.5 days/fixture 13 days total
Framework Installation/ Fixture Attachment	4 General Laborers	.5 days/fixture 13 days total
Electrical Finish	2 Electricians	.25 days/fixture

The estimates in Appendix A were arrived at through consultation with the contractor's project manager and property project manager who controlled the construction at Center Plaza. These figures were then verified using two separate estimating sources. [57], [60]

7.2.4 Basic Scheduling Computations

After recording activity durations on the logic network, critical path scheduling computations are completed using the rules outlined in section 4.3.5. The completed network for the Center Plaza project is presented in figure 7.1 and following.

Figure 7.1 shows that i .tially the project duration is 67 construction workdays (imposing construction logic alone). The critical path for the project occurs in the 3 Center Plaza Lobby (South) network fragment.

FIGURE 7.1: INITIAL LOGIC NETWORK

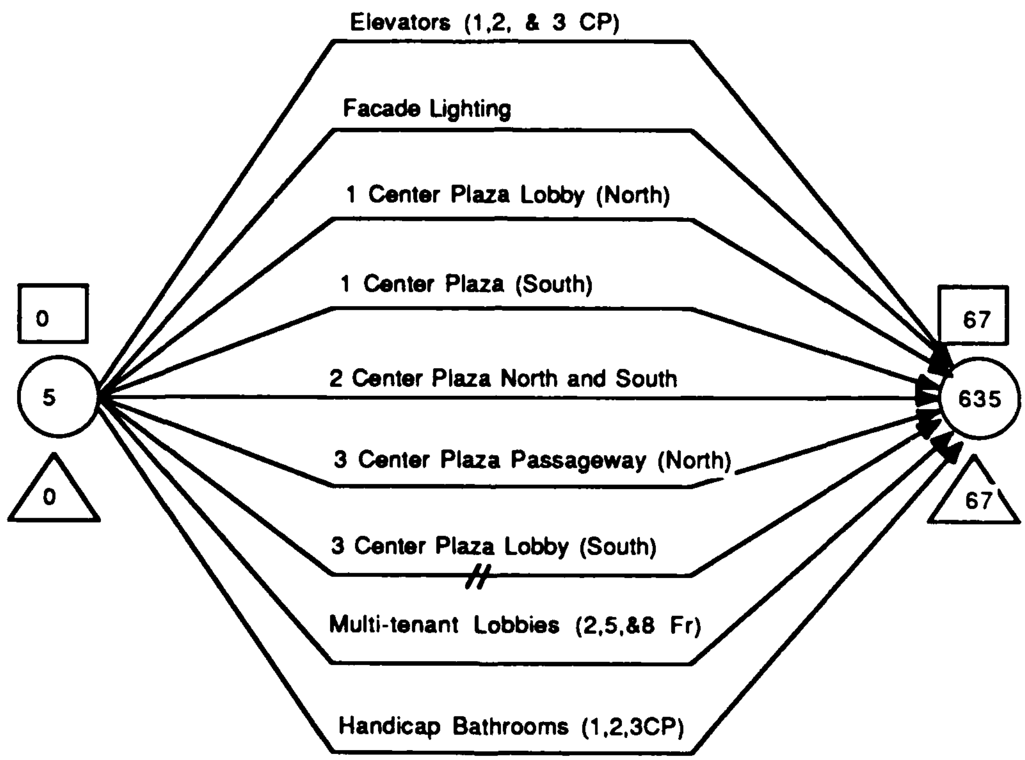


FIGURE 7.2: ELEVATORS (1,2, & 3CP)

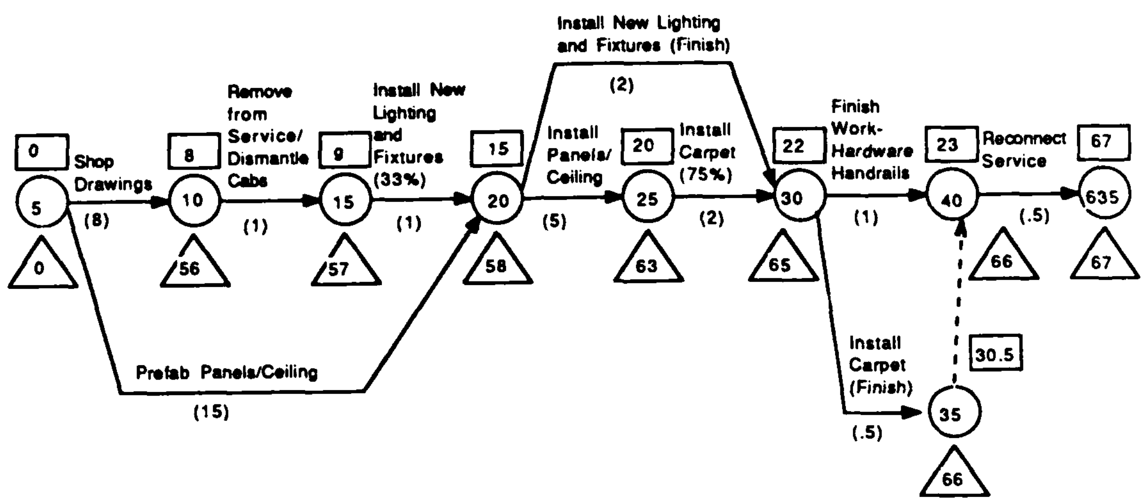


FIGURE 7.3: FACADE LIGHTING

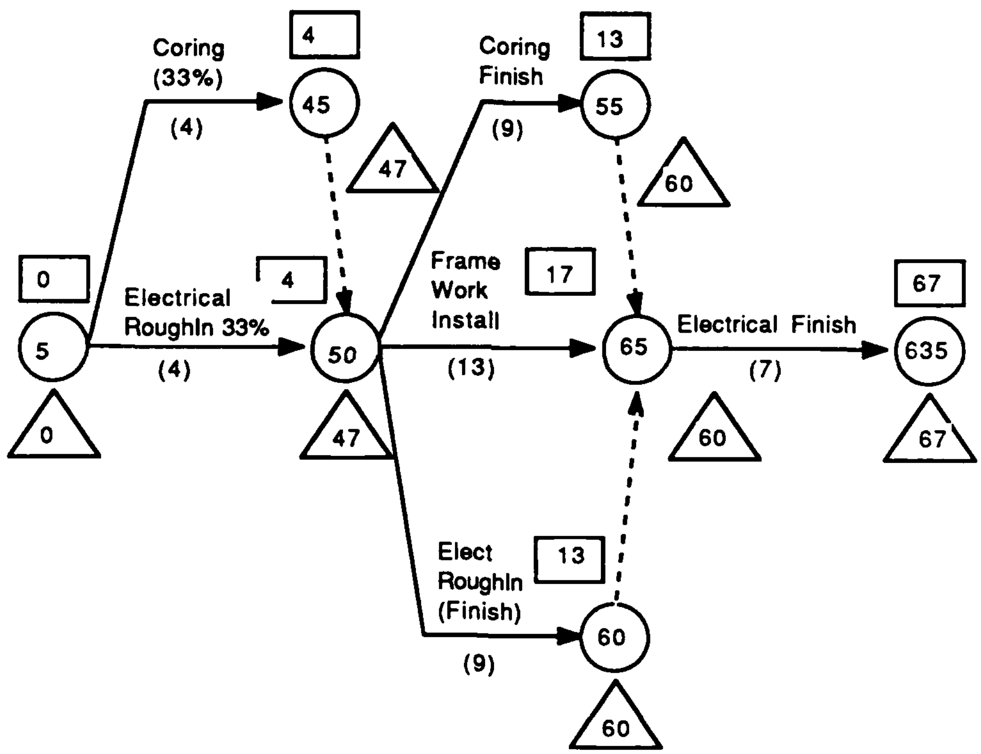
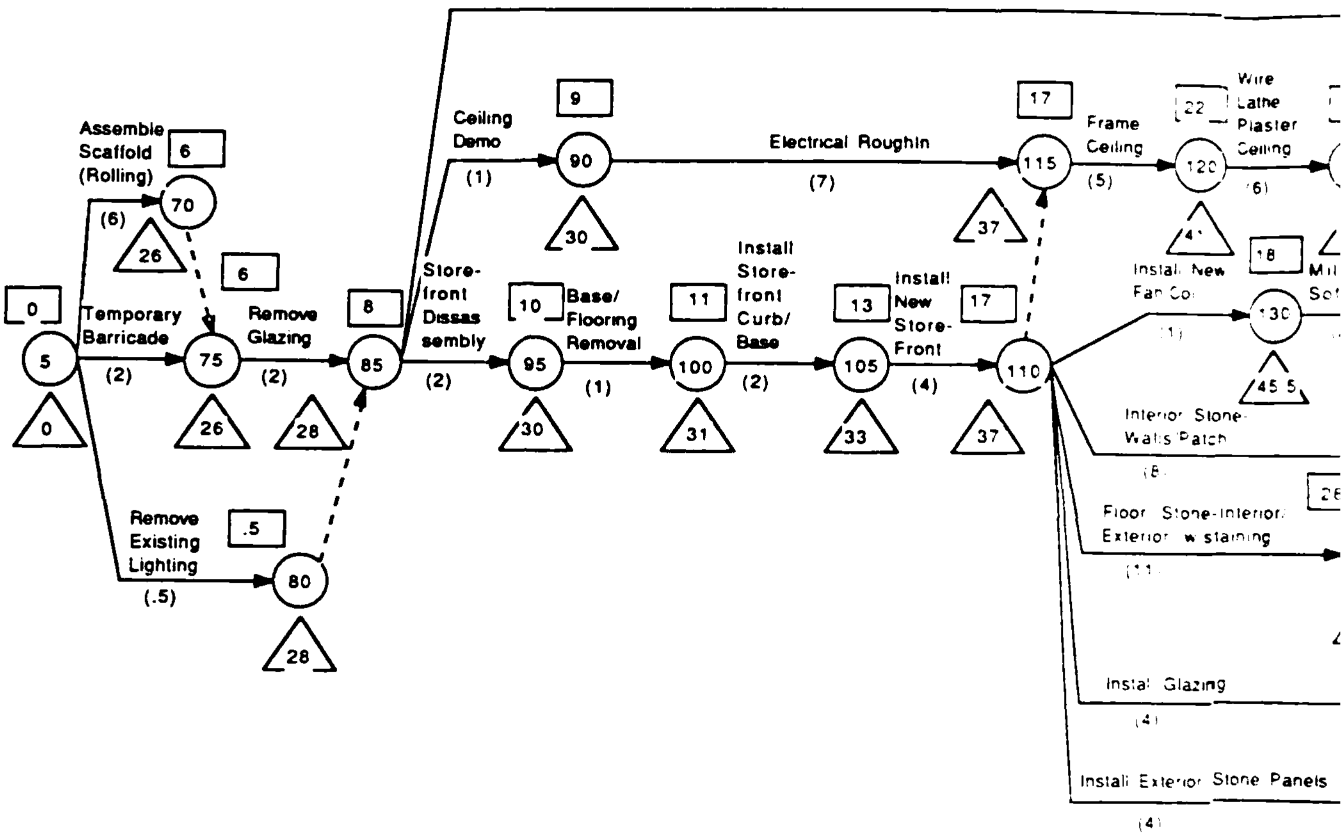
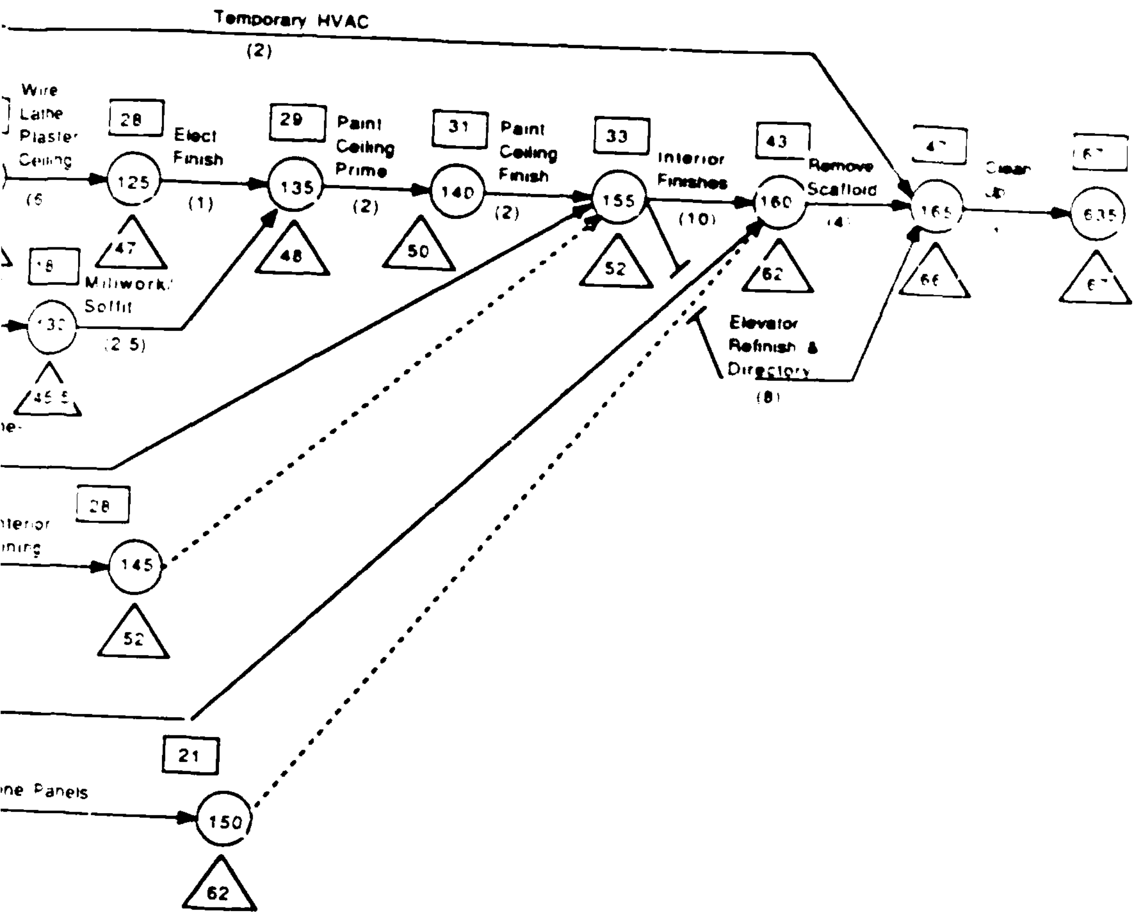


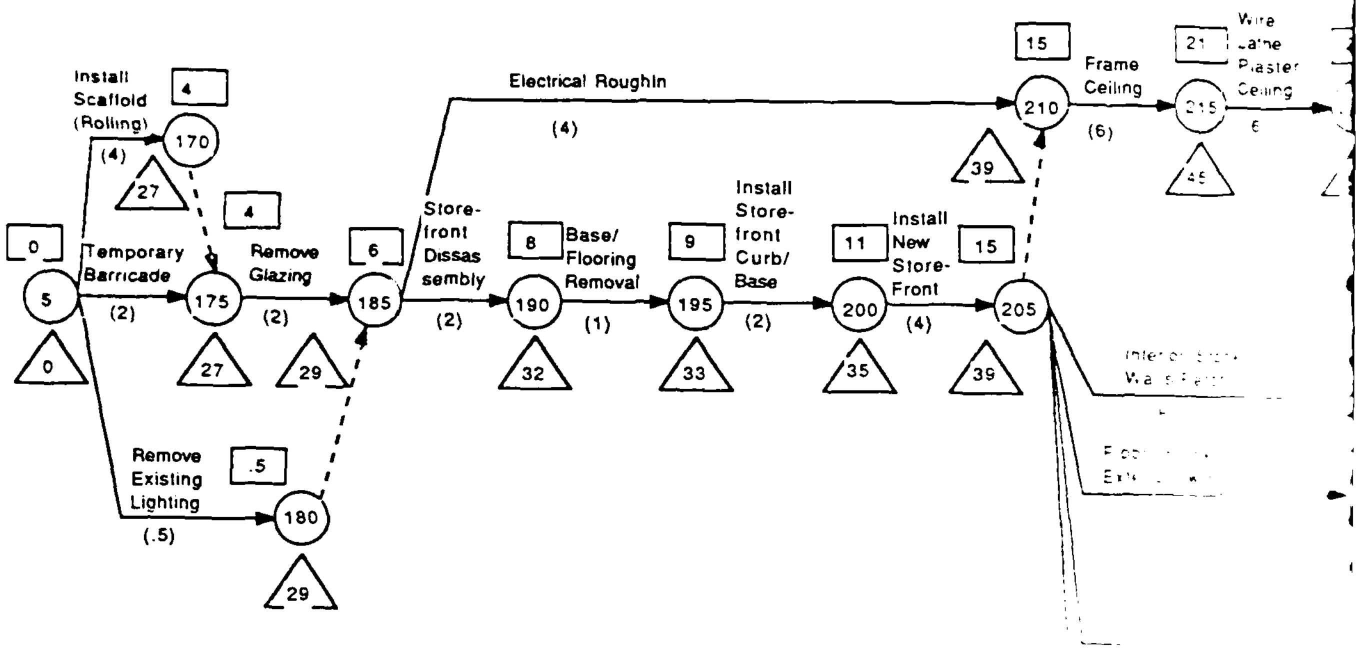
FIGURE 7.4: **1 CENTER PLAZA LOBBY (NORTH)**
(1 CENTER PLAZA SOUTH SIMILAR)





Temporary HVAC
(2)
Wire
Lathe
Plaster
Ceiling
28
Elect
Finish
(1)
29
Paint
Ceiling
Prime
(2)
31
Paint
Ceiling
Finish
(2)
33
Interior
Finishes
(10)
43
Remove
Scaffold
125
135
140
155
160
47
48
50
52
62
66
Millwork/
Soffit
(2.5)
Elevator
Refinish &
Directory
(8)
28
145
52
21
150
62
635

FIGURE 7.5: 2 CENTER PLAZA NORTH AND SOUTH



AD-A180 256   A DISTURBANCE SCHEDULING TECHNIQUE FOR MANAGING RENOVATION WORK(U) ARMY MILITARY PERSONNEL CENTER ALEXANDRIA VA W E WHITEMAN 08 MAY 87   3/4

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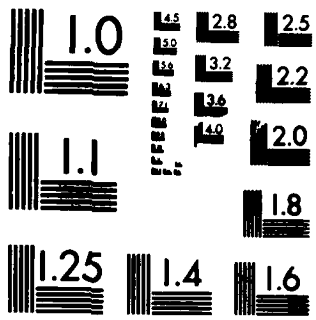
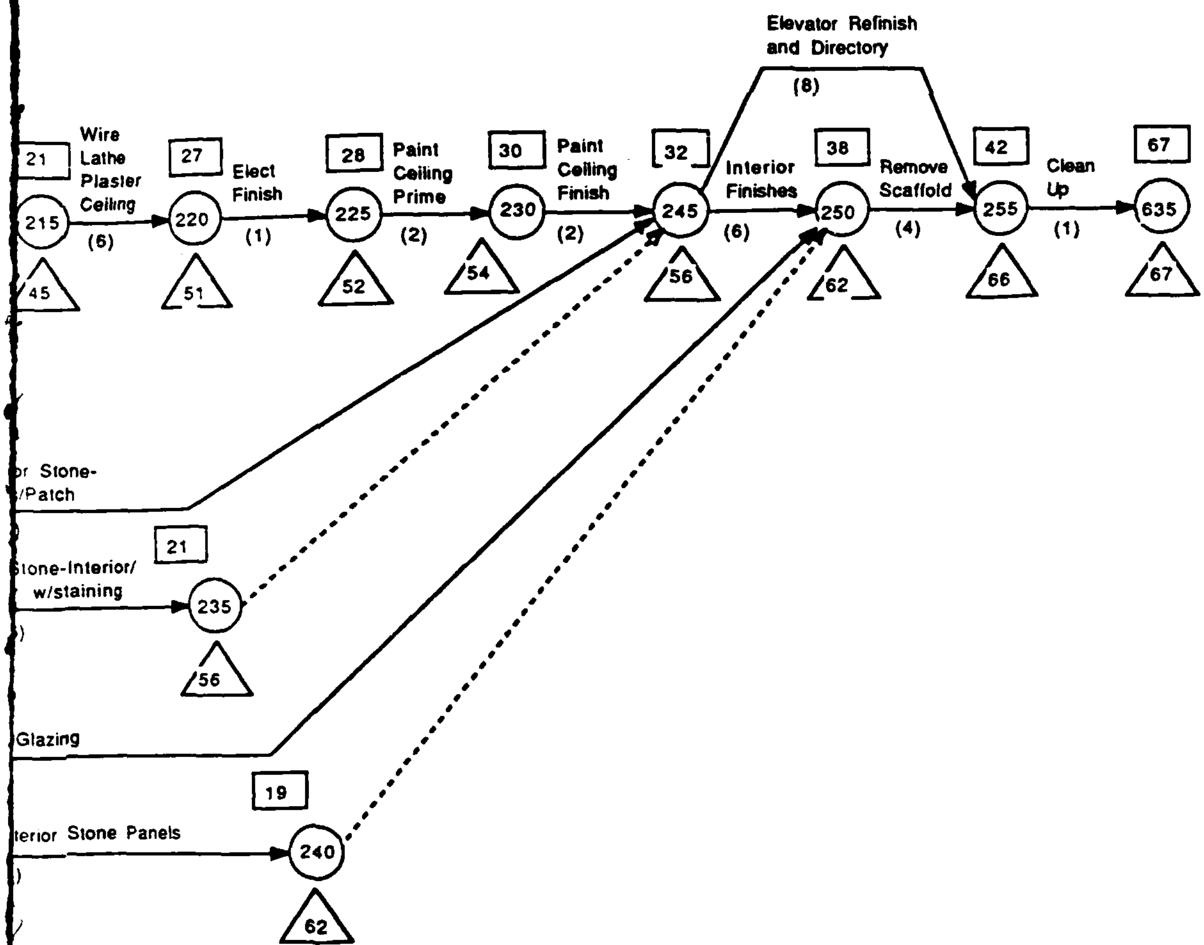
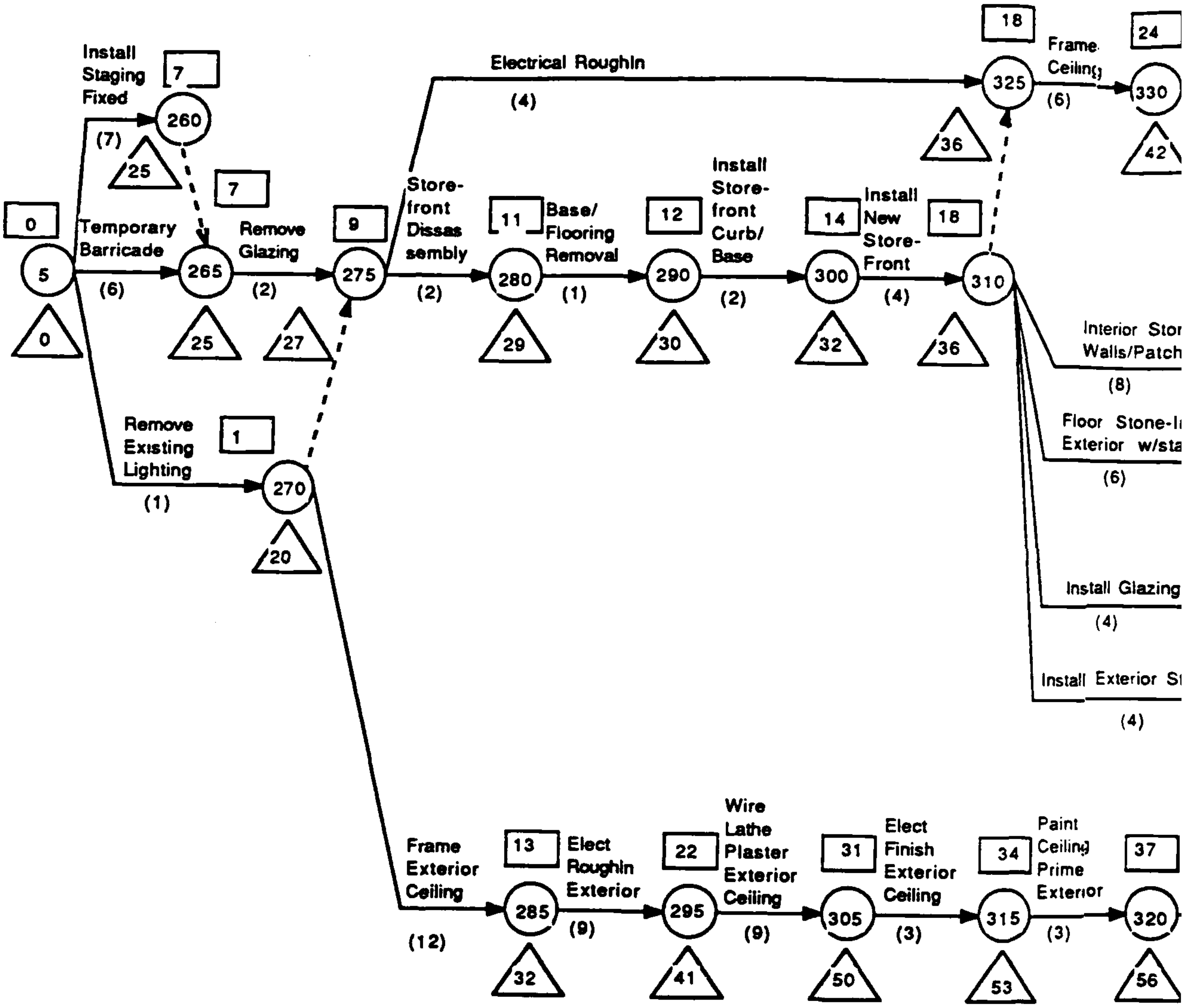


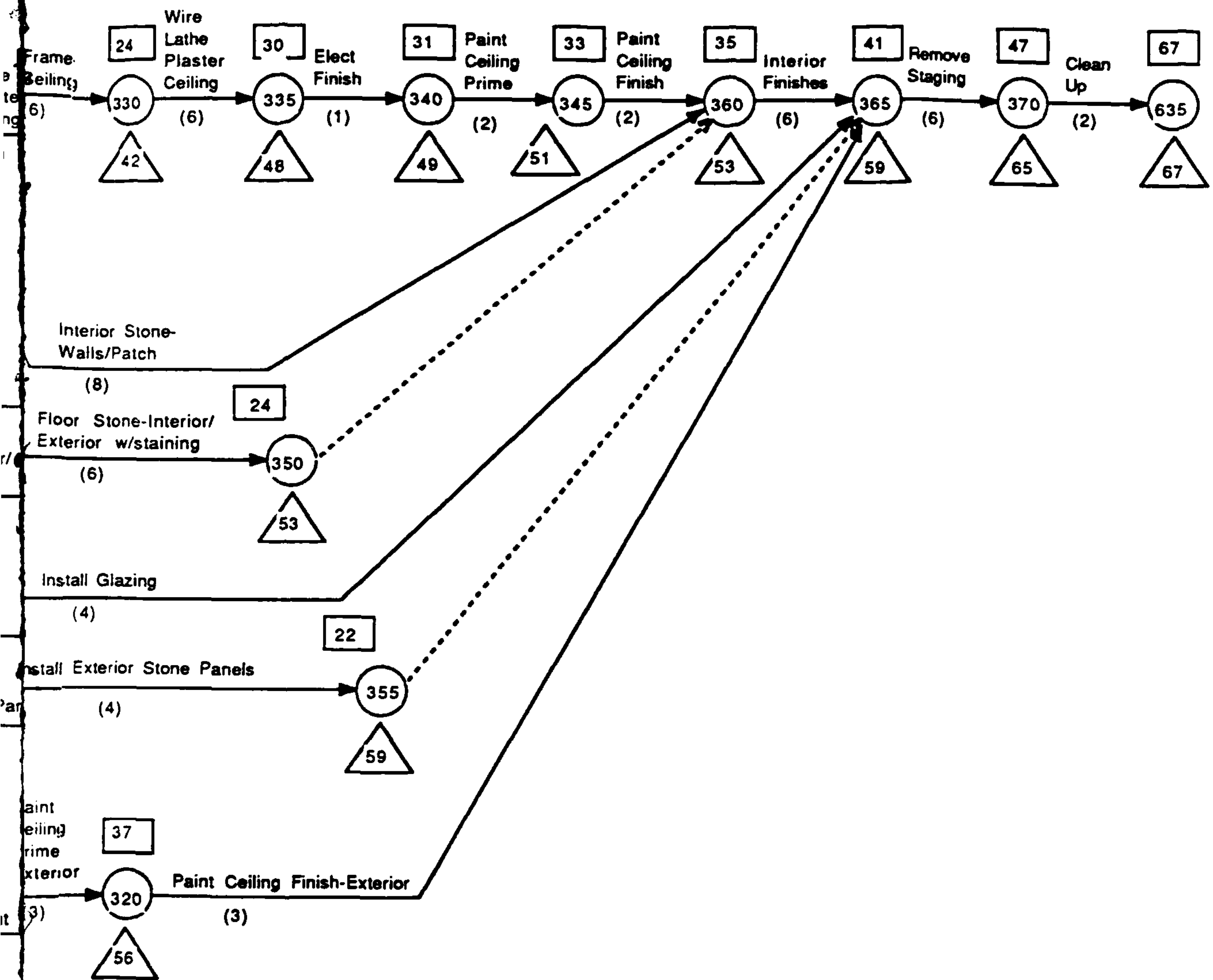
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



Elevator Refinish and Directory
(8)
21
Wire Lathe Plaster Ceiling
215
(6)
45
27
220
51
Elect Finish
(1)
28
225
52
Paint Ceiling Prime
(2)
30
230
54
Paint Ceiling Finish
(2)
32
245
56
Interior Finishes
(6)
38
250
62
Remove Scaffold
(4)
42
255
66
Clean Up
(1)
67
635
67
r Stone-
/Patch
21
tone-Interior/
w/staining
235
56
Glazing
19
terior Stone Panels
240
62

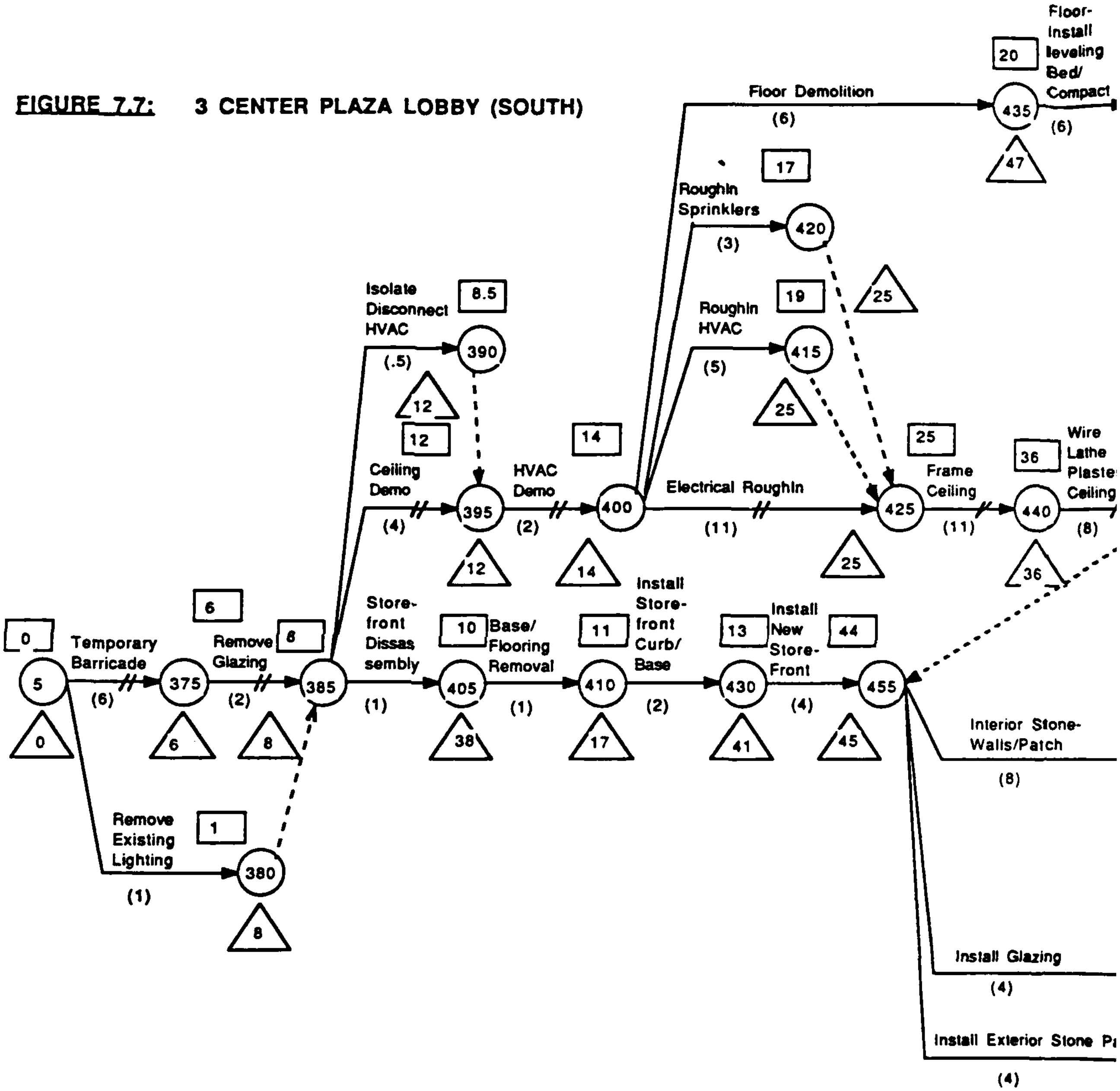
FIGURE 7.6: 3 CENTER PLAZA PASSAGEWAY (NORTH)

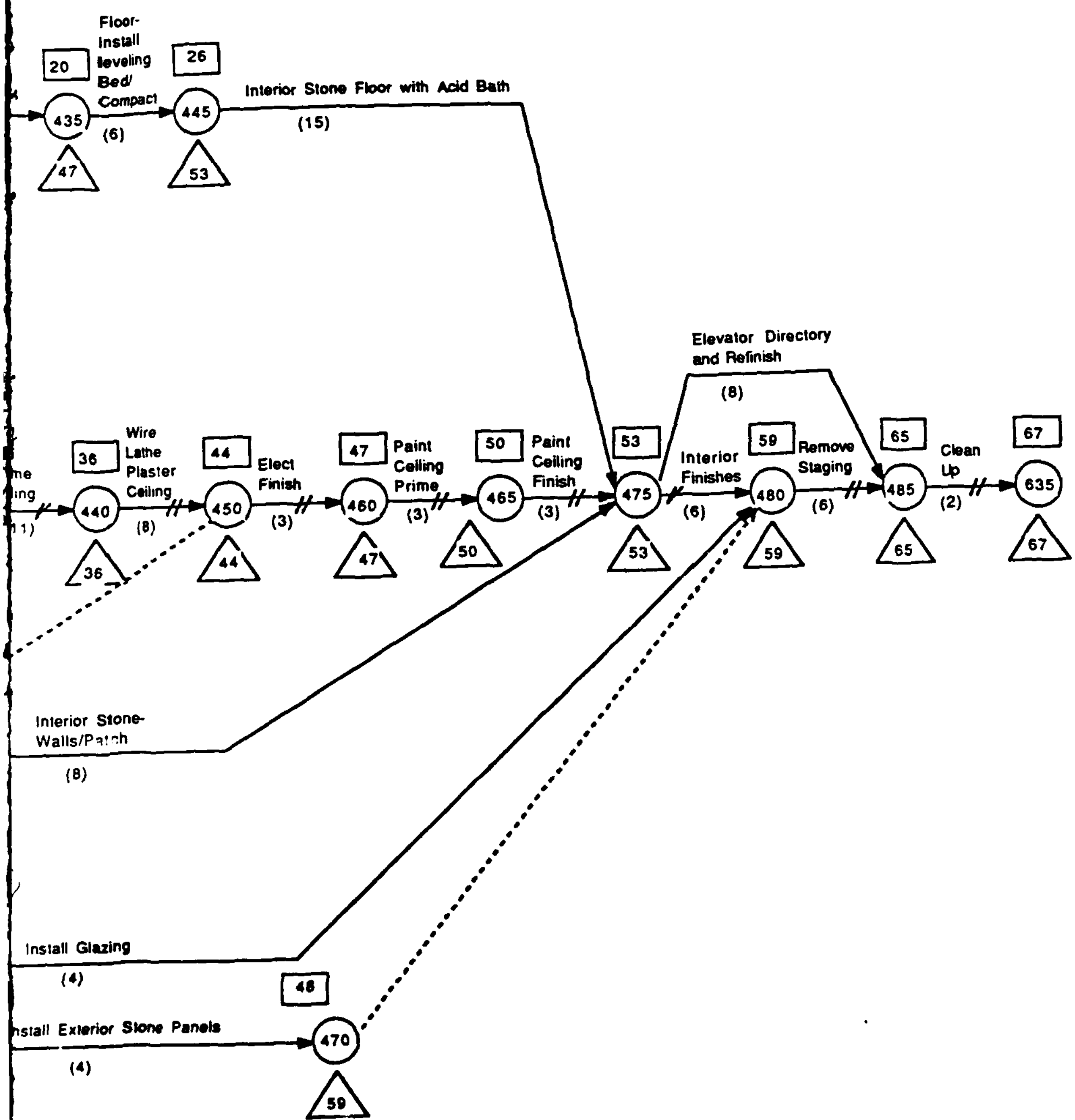




Frame Ceiling
(6)
330
24
42
Wire Lathe Plaster Ceiling
(6)
335
30
48
Elect Finish
(1)
340
31
49
Paint Ceiling Prime
(2)
345
33
51
Paint Ceiling Finish
(2)
360
35
53
Interior Finishes
(6)
365
41
59
Remove Staging
(6)
370
47
65
Clean Up
(2)
635
67
67
Interior Stone-Walls/Patch
(8)
Floor Stone-Interior/Exterior w/staining
(6)
350
24
53
Install Glazing
(4)
Install Exterior Stone Panels
(4)
355
22
59
Paint Ceiling Prime Exterior
(3)
320
37
56
Paint Ceiling Finish-Exterior
(3)

FIGURE 7.7: 3 CENTER PLAZA LOBBY (SOUTH)





Floor-Install leveling Bed/ Compact
20
435
(6)
47
26
445
53
Interior Stone Floor with Acid Bath
(15)
Elevator Directory and Refinish
(8)
36
440
Wire Lathe Plaster Ceiling
(8)
36
44
450
Elect Finish
(3)
44
47
460
Paint Ceiling Prime
(3)
47
50
465
Paint Ceiling Finish
(3)
50
53
475
53
Interior Finishes
(6)
59
480
59
Remove Staging
(6)
65
485
65
Clean Up
(2)
67
635
67
Interior Stone-Walls/Patch
(8)
Install Glazing
(4)
48
470
59
Install Exterior Stone Panels
(4)

FIGURE 7.8: HANDICAP BATHROOMS (1, 2, 3 CP)

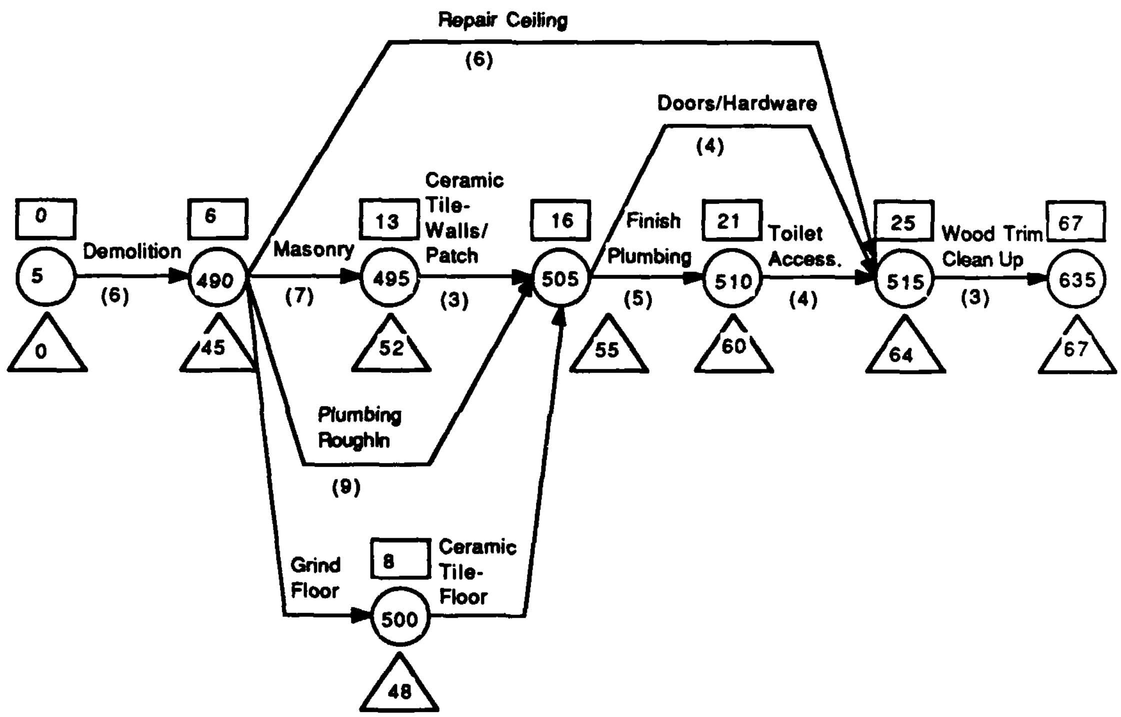
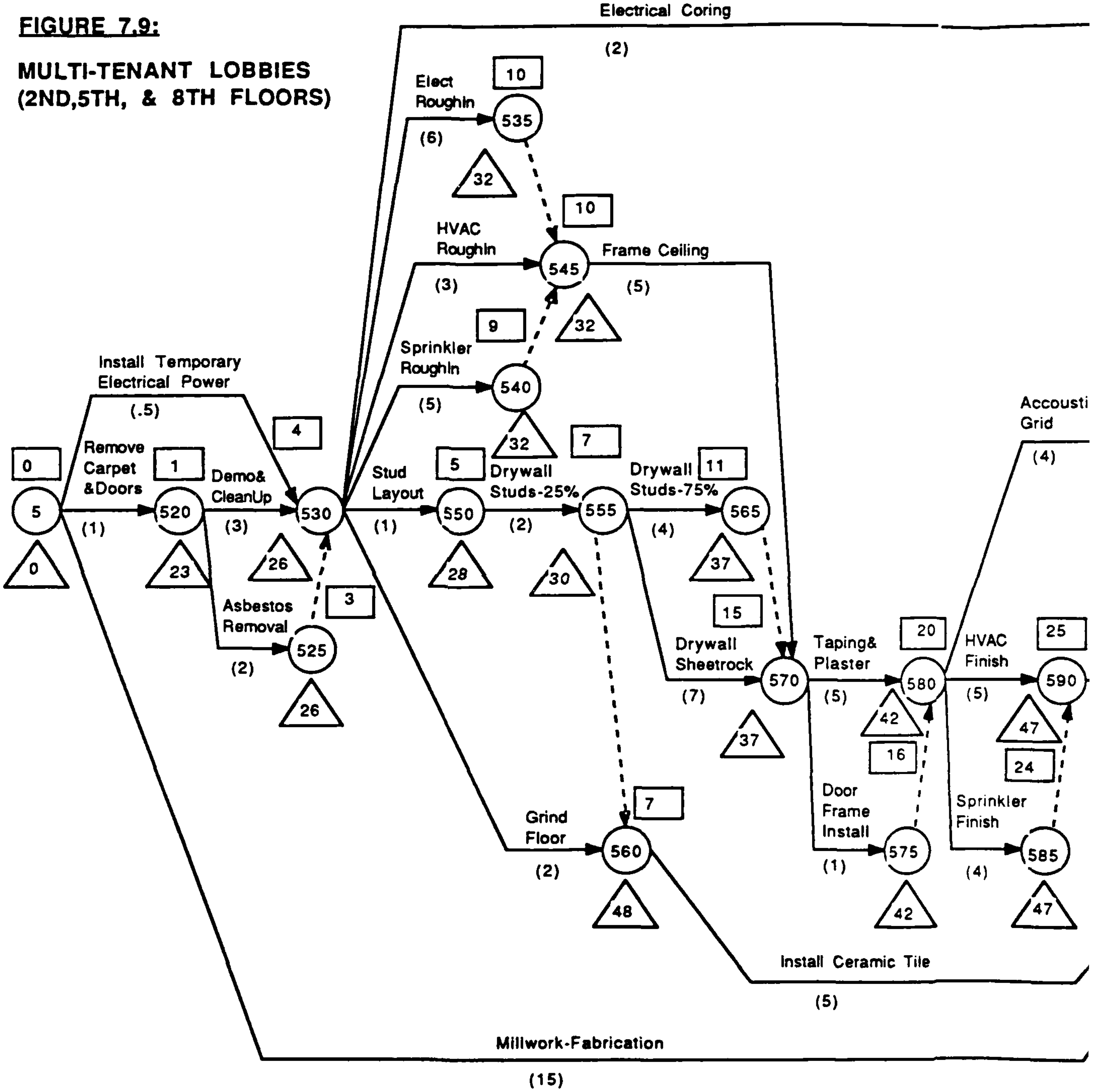
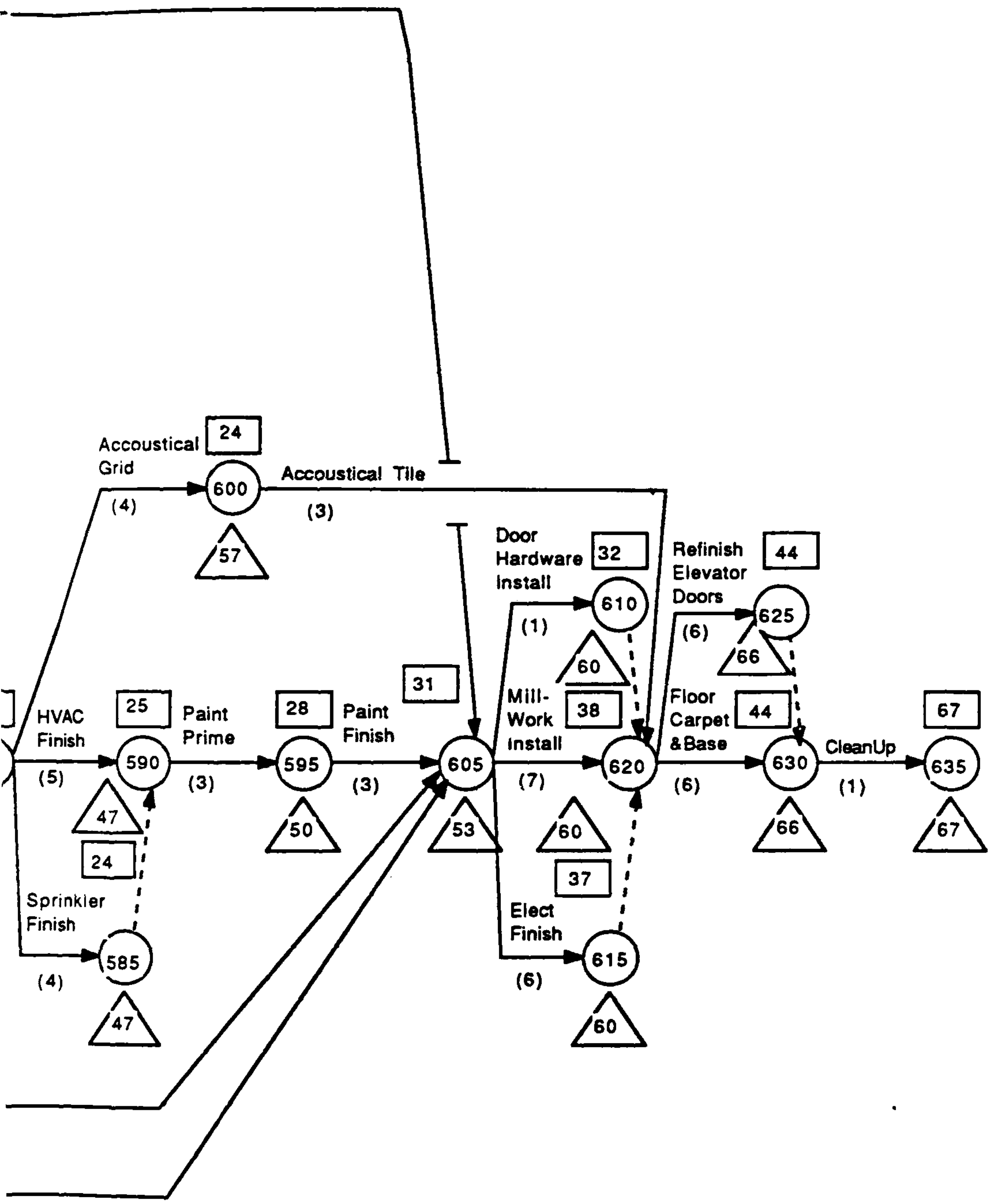


FIGURE 7.9:

MULTI-TENANT LOBBIES (2ND,5TH, & 8TH FLOORS)





Accoustical Grid
24
600
(4)
57
Accoustical Tile
(3)
Door Hardware Install
32
610
(1)
60
Refinish Elevator Doors
44
625
(6)
66
HVAC Finish
25
590
(5)
47
Paint Prime
28
595
(3)
50
Paint Finish
31
605
(3)
53
Mill-Work Install
38
620
(7)
60
Floor Carpet &Base
44
630
(6)
66
CleanUp
67
635
(1)
67
24
Sprinkler Finish
585
(4)
47
37
Elect Finish
615
(6)
60

7.2.5 Resource Constraining

In preparation for imposing resource constraints on the network diagram, an early start schedule is completed. This schedule is provided in Figure 7.10 for the first 20 construction days of the project. It depicts each of the activities with their respective resource consumption, time frame for completion, and available free and interfering float. Resource totals are also computed for each of the first 20 construction workdays.

Unconstrained, the network requires a total of approximately 100 workers on the first day of construction, including mostly general laborers. Resource totals peak out at about the 10th day of construction and tail off to a total of 67 men by day 20. Interviews with the project manager confirm that it is likely the above resource requirements could be met if the general contractor were willing to dedicate an appropriate level of management effort. Despite this fact, the building could in no way sustain a construction assault of this magnitude from an operational standpoint. As examples;

(1) For the first 24 days of the project, the elevators would need to be completely shut down.

(2) Exterior entrances and lobbies would need to be closed;

@ 1 Center Plaza - day 8 through 43
@ 2 Center Plaza - day 4 through 38
@ 3 Center Plaza - day 6 through 59

This would totally stop tenant traffic during these time frames.

FIGURE 7.10: EARLY START SCHEDULE

Activity Number	Description	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	ELEVATORS (1,2, & 3CP)																				
5-10	Shop Drawings	[1A	1A	1A	1A	1A	1A	1A	1A	X	X	X	X	X	X	X	X	X	X	X	X
5-20	Prefab Panels Ceiling	[6C	6C	6C	6C	6C	6C	6C	6C	6C	6C	6C	6C	6C	6C	6C	X	X	X	X	X
10-15	Remove from Service									[15L	X	X	X	X	X	X	X	X	X	X	X
15-20	Install New Lighting/Fixtures										[6E						X	X	X	X	X
20-25	Install Panels/Ceiling																[6C	6C	6C	6C	6C
20-30	Install New Lighting/Fixtures																[6E	6E			
	FACADE LIGHTING																				
5-45	Coring	[2R	2R	2R	2R	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5-50	Electrical Rough-In	[3E	3E	3E	3E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
50-55	Coring (Finish)					[2R	2R	2R	2R	2R	2R	2R	2R	2R					X	X	X
50-60	Electrical Rough-In (Finish)					[3E	3E	3E	3E	3E	3E	3E	3E	3E					X	X	X
50-65	Framework Install/Fixt Attach					[4L	4L	4L	4L	4L	4L	4L	4L	4L	4L	4L	4L	4L	X	X	X
65-635	Electrical Finish																		[2E	2E	2E
	1 CENTER PLAZA LOBBY (N&S)																				
5-70	Assemble/Install Scaffolding	[12L	12L	12L	12L	12L	12L	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5-75	Temporary Barricade	[4C	4C					X	X	X	X	X	X	X	X	X	X	X	X	X	X
5-80	Remove Existing Lighting	[4E								X	X	X	X	X	X	X	X	X	X	X	X
75-85	Remove Glazing							[8G	8G	X	X	X	X	X	X	X	X	X	X	X	X
85-90	Ceiling Demo									[6L	X	X	X	X	X	X	X	X	X	X	X
85-95	Alum Storefront Dissassembly									[8G	8G	X	X	X	X	X	X	X	X	X	X
90-115	Electrical Rough-In										[4E	4E	4E	4E	4E	4E	4E		X	X	X
95-100	Storefront Base/Floor Removal											[4L	X	X	X	X	X	X	X	X	X
100-105	Install Storefront Curb/Base												[4L	4L	X	X	X	X	X	X	X
105-110	Install Aluminum Storefront														[8G	8G	8G	8G	X	X	X
115-120	Frame Ceiling																		[6C	6C	6C
	2 CENTER PLAZA(North&South)																				
5-170	Assemble/Install Scaffold	[12L	12L	12L	12L	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5-175	Temporary Barricade	[4C	4C			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5-180	Remove Existing Lighting	[4E						X	X	X	X	X	X	X	X	X	X	X	X	X	X
175-185	Remove Glazing					[8G	8G	X	X	X	X	X	X	X	X	X	X	X	X	X	X
185-190	Alum Storefront Dissassembly							[8G	8G	X	X	X	X	X	X	X	X	X	X	X	X
185-210	Electrical Rough-In							[4E	4E	4E	4E						X	X	X	X	X
190-195	Storefront Base/Floor Removal									[4L	X	X	X	X	X	X	X	X	X	X	X
195-200	Install Storefront Curb/Base										[4L	4L	X	X	X	X	X	X	X	X	X
200-205	Install Aluminum Storefront												[8G	8G	8G	8G	X	X	X	X	X
205-235	Floor Stone-Int/Ext w/stain																[6T	6T	6T	6T	6T
205-240	Install Exterior Stone Panels																[4G	4G	4G	4G	
205-245	Interior Stone-Walls/Patch																[4T	4T	4T	4T	4T
205-250	Install Glazing																[4G	4G	4G	4G	
210-215	Frame New Ceiling																[6C	6C	6C	6C	6C

	3 CENTER PLAZA PASSAGEWAY																				
5-260	Install Staging (Fixed)	[6L	6L	6L	6L	6L	6L	6L	X	X	X	X	X	X	X	X	X	X	X	X	X
5-265	Temporary Barricade	[2C	2C	2C	2C	2C	2C		X	X	X	X	X	X	X	X	X	X	X	X	X
5-270	Remove Exist Lightng/Fixtures	[2E									X	X	X	X	X	X	X	X	X	X	X
265-275	Remove Glazing								[4G	4G	X	X	X	X	X	X	X	X	X	X	X
270-285	Frame Exterior Ceiling		[4C	4C	4C	4C	4C	4C	4C	4C	4C	4C	4C	4C	X	X	X	X	X	X	X
275-280	Alum Storefront Dissassembly										[4G	4G	X	X	X	X	X	X	X	X	X
275-325	Elect Rough-In (Interior)										[2E	2E	2E	2E						X	X
280-290	Storefront Base/Floor Removal												[2L	X	X	X	X	X	X	X	X
290-300	Install Storefront Curb/Base													[2L	2L	X	X	X	X	X	X
300-310	Install Aluminum Storefront															[4G	4G	4G	4G	X	X
310-350	Floor Stone-Int/Ext w/stain																			[3T	3T
310-355	Install Exterior Stone Panels																			[2G	2G
310-360	Interior Stone-Walls/Patch																			[3T	3T
310-365	Install Glazing																			[2G	2G
325-330	Frame New Ceiling (Interior)																			[3C	3C
285-295	Electrical Rough-In(Exterior)														[2E	2E	2E	2E	2E	2E	2E
	3 CENTER PLAZA LOBBY																				
5-375 *	Temporary Barricade	[2C	2C	2C	2C	2C	2C]														
5-380	Remove Exist Lightng/Fixtures	[2E							]												
375-385*	Remove Glazing							[4G	4G]												
385-390	Isolate and Disconnect HVAC									[2H			]								
385-395*	Ceiling Demo									[7L	7L	7L	7L]								
385-405	Alum Storefront Dissassembly									[4G	4G	X	X	X	X	X	X	X	X	X	X
395-400*	HVAC Demo													[2H	2H]						
400-415	Rough-In HVAC															[3H	3H	3H	3H	3H	
400-420	Rough-In Sprinklers															[2S	2S	2S			
400-425*	Electrical Rough-In															[2E	2E	2E	2E	2E	2E
400-435	Floor Demo															[5L	5L	5L	5L	5L	5L
405-410	Storefront Base/Floor Removal											[2L	X	X	X	X	X	X	X	X	X
410-430	Install Storefront Curb/Base												[2L	2L	X	X	X	X	X	X	X
430-455	Install Aluminum Storefront														[4G	4G	4G	4G			
	HANDICAP BATHROOMS																				
5-490	Demolition	[12L	12L	12L	12L	12L	12L	X	X	X	X	X	X	X	X	X	X	X	X	X	X
490-495	Masonry							[6M	6M	6M	6M	6M	6M	6M	X	X	X	X	X	X	X
490-500	Grind Floor							[3L	3L	X	X	X	X	X	X	X	X	X	X	X	X
490-505	Plumbing Rough-In							[6P	6P	6P	6P	6P	6P	6P	6P	6P		X	X	X	X
490-515	Repair Ceiling							[9B	9B	9B	9B	9B	9B								
495-505	Ceramic Tile-Walls/Patch														[6T	6T	6T	X	X	X	X
500-505	Ceramic Tile-Floors									[6T	6T	6T	6T	6T	6T	6T		X	X	X	X
505-510	Plumbing-Finish																	[6P	6P	6P	6P
505-515	Doors/Hardware																	[6C	6C	6C	6C

	MULTI-TENANT LOBBIES (3CP)																				
5-520	Remove Carpet and Doors	[9L	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5-530	Install Temporary Elect Power	[6E				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5-605	Millwork-Fabrication	[8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W					
520-525	Asbestos Removal		[9L	9L		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
530-535	Electrical Rough-In					[6E	6E	6E	6E	6E	6E	X	X	X	X	X	X	X	X	X	X
530-540	Sprinkler Rough-In					[6S	6S	6S	6S	6S		X	X	X	X	X	X	X	X	X	X
530-545	HVAC Rough-In					[9H	9H	9H				X	X	X	X	X	X	X	X	X	X
530-550	Partition and Stud Layout					[9D	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
530-560	Grind Floor					[3L	3L		X	X	X	X	X	X	X	X	X	X	X	X	X
530-605	Electrical Coring					[6R	6R														
545-570	Frame Ceiling											[9C	9C	9C	9C	9C	X	X	X	X	X
550-555	Drywall Studs (25%)						[12D	12D	X	X	X	X	X	X	X	X	X	X	X	X	X
555-565	Drywall Studs (75%)								[12D	12D	12D	12D					X	X	X	X	X
555-570	Drywall Sheetrock								[12D	12D	12D	12D	12D	12D			X	X	X	X	X
570-575	Door Frame Installation																[6C				
570-580	Taping and Plaster																[3L	3L	3L	3L	3L
560-605	Install Ceramic Tile								[9T	9T	9T	9T	9T								
	RESOURCE TOTALS	1A	1A	1A	1A	1A	1A	1A	1A												
		18C	22C	14C	14C	14C	14C	10C	10C	10C	10C	19C	19C	19C	15C	15C	18C	18C	24C	27C	27C
		2R	2R	2R	2R	8R	8R	2R	2R	2R	2R	2R	2R	2R							
		21E	3E	3E	3E	9E	9E	13E	13E	18E	25E	9E	9E	8E	6E	8E	14E	10E	6E	6E	6E
		51L	51L	51L	42L	37L	37L	13L	7L	31L	15L	21L	19L	12L	6L	9L	12L	12L	8L	8L	8L
		8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W	8W					
						8G	8G	20G	24G	16G	16G	4G	8G	8G	2CG	24G	24G	24G	12G	12G	4G
						6S	6S	6S	6S	6S						2S	2S	2S			
						9H	9H	9H						2H	2H	3H	3H	3H	3H	3H	
							12D	12D	24D	24D	24D	24D	12D	12D	12D						
								6M	6M	6M	6M	6M	6M	6M							
								6P	6P	6P	6P	6P	6P	6P	6P	6P		6P	6P	6P	6P
								9B	9B	9B	9B	9B	9B								
								9T	9T	15T	15T	15T	6T	6T	12T	12T	16T	10T	10T	16T	16T

LEGEND:

- * - Critical Path Activity
- [X] - Interfering Float
- [ ] - Free Float
- L - General Laborers
- C - Carpenters
- E - Electricians
- M - Masons
- P - Plumbers
- B - Plasterers
- R - Corers
- T - Tile Setters
- H - HVAC
- G - Glazers
- S - Sprinkler Men
- W - Millworkers
- D - Drywall
- A - Architect

(3) Work as scheduled in the multi-tenant lobbies of 3 Center Plaza would impose impacts on the tenants at a level beyond toleration between the start of the project and the 31st day of construction.

Thus, the question turns to one of how the planner would spread the project out to meet constraints, whether they be resource related or imposed because of restrictions required in keeping the building functional.

First, resource leveling algorithms fail because they can not distinguish or recognize the ordering of major subnetwork fragments. The concept for their implementation is to move individual activities without regard to the total flow of the project.

As an example, refer to Figure 7.10. Let us consider the imposition of a constraint of only 14 carpenters available on the first day of construction. The current requirement is for 18 carpenters. Thus, we need to relax the network by pushing back a combination of activitie(s) that total 4 carpenters. Four alternatives exist:

<u>Alternative 1</u>
Move Activity 5-20:
Prefab Panels/Ceiling - ELEVATORS (6 carpenters)

<u>Alternative 2</u>
Move Activity 5-75:
Temporary Barricade - 1 CENTER PLAZA (4 carpenters)

<u>Alternative 3</u>
Move Activity 5-175:
Temporary Barricade - 2 CENTER PLAZA (4 carpenters)

Alternative 4
Move Activity 5-265
    Temporary Barricade - 3 CENTER PLAZA PASSAGEWAY
  AND
    Activity 5-375
    Temporary Barricade - 3 CENTER PLAZA LOBBY (total of 4 carpenters)

Each of these four alternatives come from a different major subnetwork fragment. The planner has no objective rules to guide him as to which alternative is appropriate to choose first. As one continues to try and impose other resource constraints, one quickly becomes overwhelmed.

A completely analogous situation arises when one tries to address the restrictions associated with the minimum operational requirements for the building. Again, because of the proliferation of feasible alternatives available in relaxing the network, coupled with the lack of a formal way of addressing their application, the planner has no way of objectively prioritizing the order in which portions of the work are to be accomplished. Thus, the traditional network planning model has failed.

7.3 APPLCATION OF THE DISTURBANCE SCHEDULING TECHNIQUE

In this section we embark upon a scheduling application on the same project, this time using the Disturbance Scheduling Technique.

7.3.1 Phase One: Establishing the Initial Logic Network

This phase is accomplished exactly as shown in Sections 7.2.1 through 7.2.4 with the results presented in Figure 7.1 through 7.9.

7.3.2 Phase Two: Information Gathering for the Disturbance Scheduling Process

Owner/tenant negotiations were carried out through interviews by the author to attain information establishing user requirements, time schedule coordination, and minimum building operational requirements at Center Plaza. As a result, a prioritized disturbance list was assembled and is illustrated in Figure 7.11.

FIGURE 7.11 CENTER PLAZA PROJECT PRIORITIZED DISTURBANCE LIST

Category 1: Time Schedule Coordination

31 August - 2 September: Labor Day Holiday Weekend
21 November - 24 November: Thanksgiving (Reserved for Float)
5 September - 10 September: Visit, Irish Ambassador-5th floor, 3CP

Category 2: Restrictive Time Frames

Activity Grouping-Multi-Tenant Lobby Demolitions
2nd, 5th, & 8th floors, 3 CP
Weekends Only

includes activities:

5-520 Remove Carpet and Doors
5-530 Install Temporary Electrical Power
520-525 Asbestos Removal
520-530 Demolition and Clean-Up

Category 3: After Hours Construction Only

85-90 Ceiling Demo (1CPN & 1CPS)
385-395 Ceiling Demo (3CP Lobby)

95-100 Storefront Base/Flooring Removal (1CPN & 1CPS)
190-195 Storefront Base/Flooring Removal (2CPN & 2CPS)
280-290 Storefront Base/Flooring Removal (3CP Passageway)
405-410 Storefront Base/Flooring Removal (3CP Lobby)

5-45 & 50-55 Coring (Facade Lighting)
5-50 & 50-60 Electrical Rough-in (Facade Lighting)
50-65 Frmwk Install/Fixture Attach (Facade Lighting)
65-635 Electrical Finish (Facade Lighting)

490-500 Grind Floor (Handicap Bathrooms)
530-560 Grind Floor (Multi-tenant Lobbies)

530-605 Electrical Coring (Multi-tenant Lobbies)

140-155 Paint Ceiling-Finish (1CPN & 1CPS)
230-245 Paint Ceiling-Finish (2CPN & 2CPS)
320-365 Paint Ceiling-Finish Exterior (3CP Passageway)
345-360 Paint Ceiling-Finish Interior (3CP Passageway)
465-475 Paint Ceiling-Finish (3CP Lobby)
595-605 Paint-Finish (Multi-tenant Lobbies)

Category 4: Time Frames of Reduced Construction

Normal Crew Hours: 7:00 am to 4:00 pm
Building Business Hours: 9:00 am to 5:00 pm

400-435 Floor Demo (3CP Lobby)

435-445 Floor-Install Leveling Bed / Compaction (3CP Lobby)

400-415 Rough-In HVAC (3CP Lobby)
530-545 HVAC Rough-in (Multi-tenant Lobbies)

85-95 Alum Storefront Dissassembly (1CPN & 1CPS)
185-190 Alum Storefront Dissassembly (2CPN & 2CPS)
275-280 Alum Storefront Dissassembly (3CP Passageway)
385-405 Alum Storefront Dissassembly (3CP Lobby)

545-570 Frame Ceiling (Multi-tenant Lobbies)

Category 5: Minimum Building Operational Requirements

Elevators (1,2, & 3CP)
Each Entrance has a bank of 5 Elevators
1 and 3 CP have one freight elevator each
A maximum of 2 elevators may be shut down at one time in each entrance.

Multi-tenant Lobbies, Handicap Bathrooms and Elevators
All 5 elevators in each lobby bank must be operational during Multi-tenant lobby and Handicap Bathroom Construction to accomodate debris removal and material handling.

3 Center Plaza Lobby (South)
Floor Demolition and Installation must be phased to accomodate tenant traffic

1 Center Plaza North
Lobby entrance can not be shut down completely for tenant traffic reasons.

2 Center Plaza North and South
Only one lobby entrance can be shut down at one time for tenant traffic reasons

Category 6: Work Space and Distance Restrictions

Handicap Bathrooms
Facade Lighting

7.3.3 Phase Three: Application of the Disturbance Scheduling Algorithm

A. CATEGORY 1 PROCEDURAL STEP: TIME SCHEDULE COORDINATION

The Center Plaza project calendar relating construction work days to calendar dates is provided in Figure 7.12. It was determined through owner negotiations that the Labor Day Weekend would be a period of non construction for two reasons: First, to avoid disruption to the holiday retail sales during that period; and second, to allow the project managers a break in the construction to fully assess progress to date and adjust schedules and work procession as appropriate to maintain control of the project.

The Thanksgiving day weekend is also blocked out from construction. This four day period will be used as float time, as necessary, to make up any lost construction time on the project and bring the schedule back in line with projected completion dates, if required.

A visit by the Ambassador of Ireland is scheduled for a tenant located on the 5th floor of 3 Center Plaza from 5 through 10 September. These dates are also noted on the project calender for use during later stages of disturbance scheduling.

FIGURE 7.12: CENTER PLAZA PROJECT CALENDER

AUGUST

Su	M	T	W	Th	F	S
				1	2	3
4	5 1	6 2	7 3	8 4	9 5	10 6
11 7	12 8	13 9	14 10	15 11	16 12	17 13
18 14	19 15	20 16	21 17	22 18	23 19	24 20
25 21	26 22	27 23	28 24	29 25	30 26	31 Labor Day

SEPTEMBER

Su	M	T	W	Th	F	S
1 Labor	2 Day	3 27	4 28	5 29	6 30 Irish Ambassador	7 31
8 32 Visit-5th	9 33 floor, 3 CF	10 34	11 35	12 36	13 37	14 38
15 39	16 40	17 41	18 42	19 43	20 44	21 45
22 46	23 47	24 48	25 49	26 50	27 51	28 52
29 53	30 54					

OCTOBER

Su	M	T	W	Th	F	S
		1 55	2 56	3 57	4 58	5 59
6 60	7 61	8 62	9 63	10 64	11 65	12 66
13 67	14 68	15 69	16 70	17 71	18 72	19 73
20 74	21 75	22 76	23 77	24 78	25 79	26 80
27 81	28 82	29 83	30 84	31 85		

NOVEMBER

Su	M	T	W	Th	F	S
					1 86	2 87
3 88	4 89	5 90	6 91	7 92	8 93	9 94
10 95	11 96	12 97	13 98	14 99	15 100	16 101
17 102	18 103	19 104	20 105	21 Thanksgiving Holiday	22 Thanksgiving Holiday	23 Thanksgiving Holiday
24 Thanksgiving	25 106	26 107	27 108	28 109	29 110	30 111

B. CATEGORY 2 PROCEDURAL STEP: RESTRICTIVE TIME FRAMES

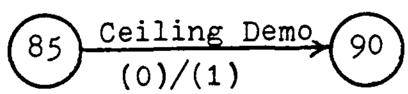
In accordance with the Disturbance Scheduling Technique, the imposition of these constraints are deferred until the last step of Phase Four.

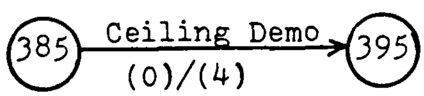
C. CATEGORY 3 PROCEDURAL STEP: AFTER HOURS CONSTRUCTION

The tasks listed in this category are highly disruptive and must be performed only during non-business hours of the building. (Refer to Figure 7.11) It was decided that the scheduling of overtime periods would occur with one 8-hour evening shift alloted during each weekday. Night shifts on weekdays and second shifts on weekends would only occur if dictated in maintaining and controlling deadlines required by the project schedule.

1) Ceiling Demolition

It was felt that these activities would introduce hazards to the tenants because of falling plaster due to demolition and possible exposure during asbestos removal. Their logic network symbols are altered as shown below to accurately reflect their overtime requirements.





With this understanding (and barring future constraint requirements), the planner could now plan and cost these activities to be completed by overtime crews during the time frame 13 August through 16 August (construction workdays 9 through 12). This information is invaluable, allowing subcontractors notice of the need to provide overtime crews far in advance of the scheduled construction dates.

Each of the activities listed below are altered in a completely analogous manner and are recorded on the logic network:

2) Storefront Base/Flooring Removal

The noise associated with jackhammers and other pneumatic tools used in completing this task prohibit its accomplishment between the hours of 8 a.m. and 5 p.m.

3) Facade Lighting Subgroup

The tasks in this grouping all require the use of a pole truck adjacent to the exterior facade around Center Plaza. Parking regulations during normal business hours prohibit access of this equipment to these areas and therefore require their completion after hours. This type of constraint is an example of the issue of surrounding environmental conditions discussed in Section 5.2.1.

4) Grind Floor & Electrical Coring (interior tenant space)

The level of noise and its proximity in relation to tenant space deem these after hours tasks.

5) Paint Ceiling - Finish

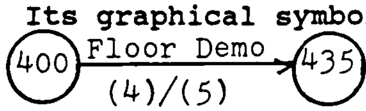
The toxic fumes associated with spray painting pose a hazard to individuals in the vicinity of the work area.

D. CATEGORY 4 PROCEDURAL STEP: TIME FRAMES OF REDUCED CONSTRUCTION EFFORT

As indicated above, the routine business hours are from 9:00 am to 5:00 pm, Monday through Friday. Normal contractor crew hours are from 7:00 am to 4:00 pm. This allows a two-hour period from 7:00 am to 9:00 am when a higher level of disturbance can be tolerated by tenants arriving at work. The activities in this category can be conducted during this period in addition to scheduled overtime periods.

1) Floor Demolition (3 Center Plaza Lobby)

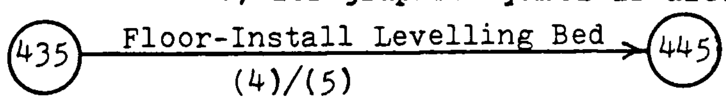
The original estimated duration of this activity was 6 construction workdays (48 hours). Revising this task as outlined in Section 6.4.2.D, it is now scheduled for 4-2 hour daily periods and 5-8 hour overtime periods for a total of 48 hours. Its graphical symbol is altered as such.



Thus, the overall duration for the activity is now reduced from 6 to 5 total work days, and this figure will be used in recomputing critical path calculations.

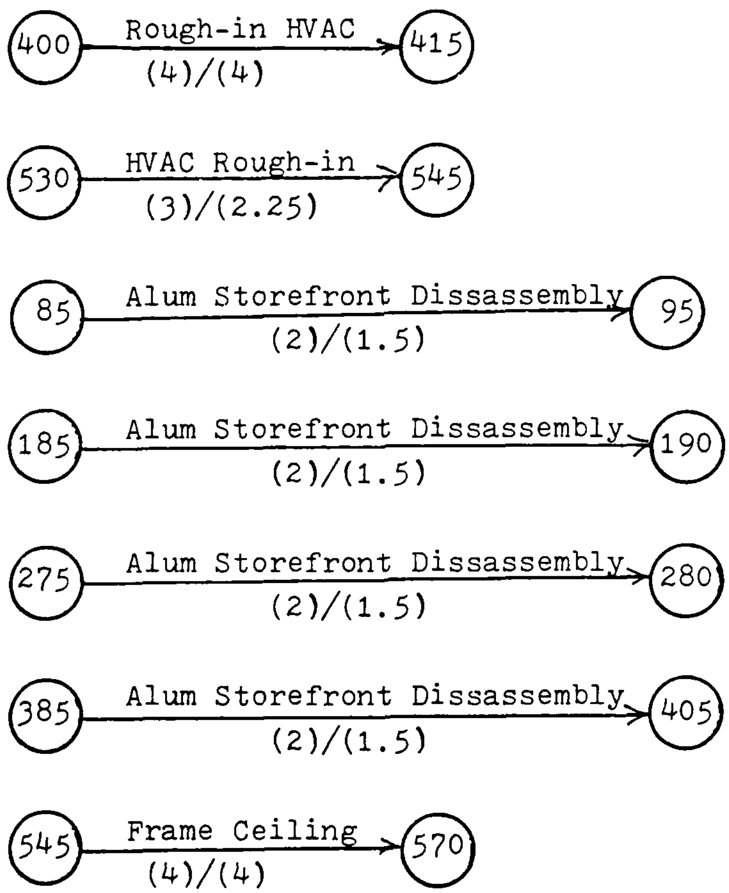
2) Floor-Install Leveling Bed/Compaction (3 Center Plaza)

The noise associated with compaction tools used for this task require it to be performed during time frames of reduced construction effort. Again, consistent with the procedure outlined above, its graphic symbol is altered to reflect:



3) HVAC Work, Alum Storefront Dissassembly, and Frame Ceiling Tasks

Each of these activities introduce disruptions at a level requiring their completion outside normal building business hours; the HVAC work and Storefront Dissassemblies because of metal to metal noise impact, and the framing of ceilings in the tenant areas because of the use of screw guns. Their altered graphic symbols are shown below and can now be recorded on the logic network.

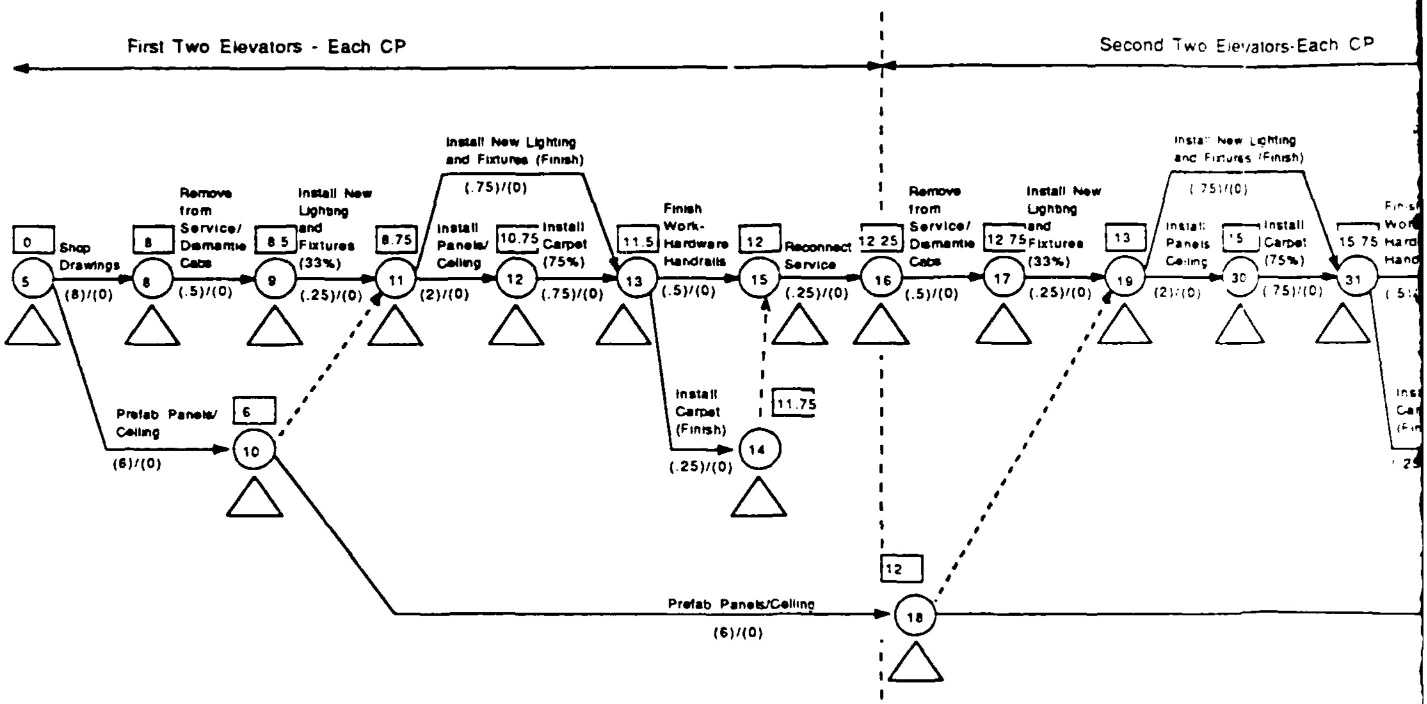


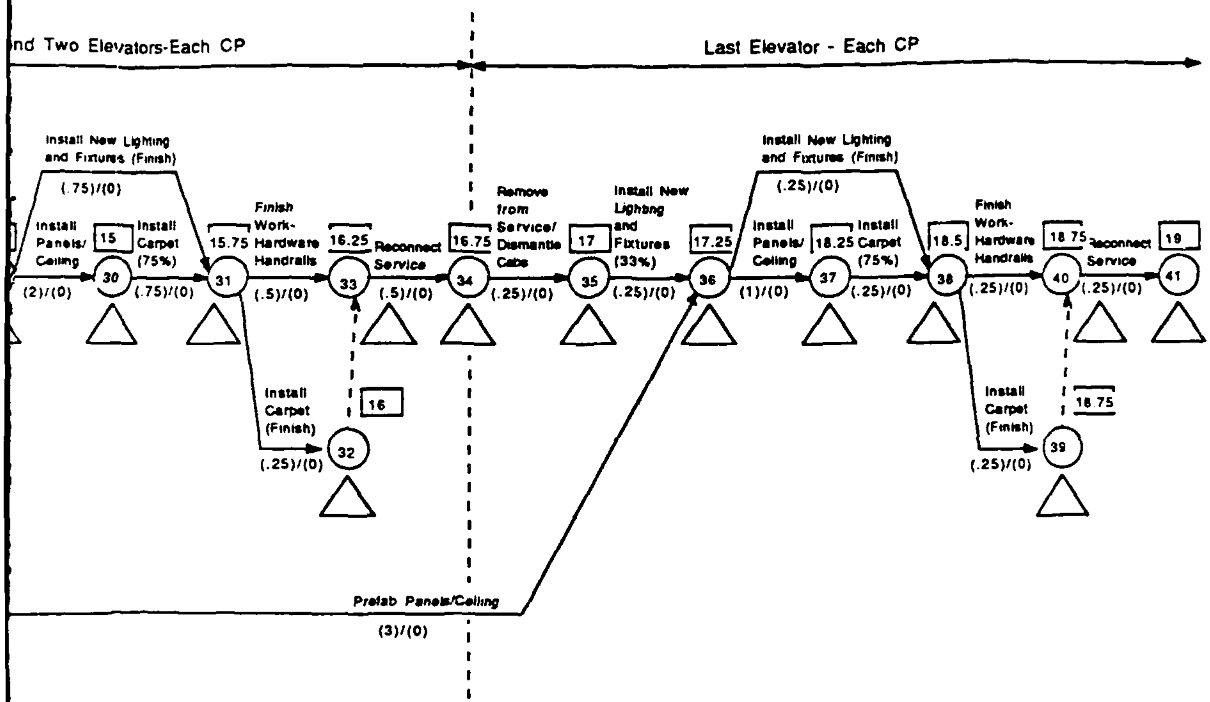
E. CATEGORY 5 PROCEDURAL STEP: MINIMUM BUILDING OPERATIONAL REQUIREMENTS

1) Elevators (1,2, and 3 Center Plaza)

Each of the three entrances at Center Plaza have a bank of five passenger elevators, one of which is for garage use only. In addition, 1 and 3 Center Plaza have freight elevators which can be used for passengers, if desired. It was determined that a maximum of two elevators may be shut down at one time in each of the entrances. Thus, this task is broken into 3 sub-groups, two of which will include the reconstruction of 2 elevators, and one which will include the remaining elevator. The alteration of this elevator subnetwork fragment is shown in Figure 7.13.

FIGURE 7.13: ELEVATORS (1,2, & 3 CP)



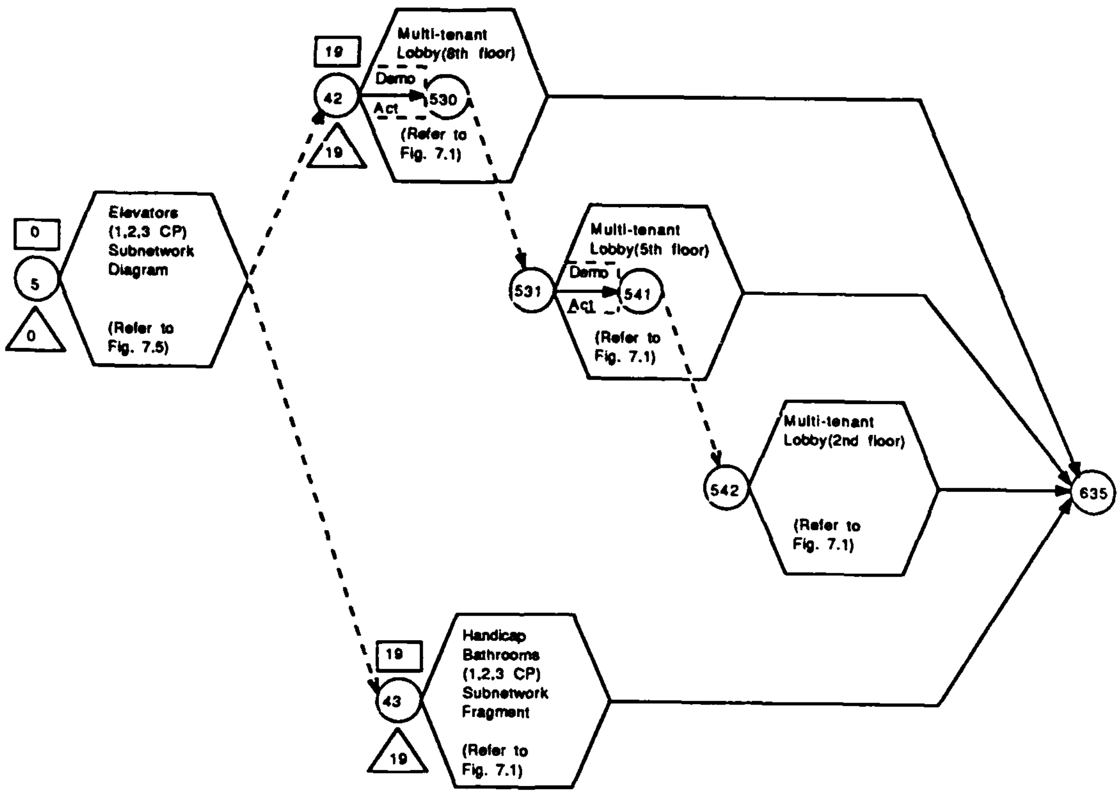


nd Two Elevators-Each CP
Last Elevator - Each CP
Install New Lighting and Fixtures (Finish)
(.75)/(0)
Install Panels/ Ceiling
(2)/(0)
15
Install Carpet (75%)
(.75)/(0)
15.75
Finish Work-Hardware Handrails
(.5)/(0)
16.25
Reconnect Service
(.5)/(0)
16.75
Remove from Service/ Dismantle Cabs
(.25)/(0)
17
Install New Lighting and Fixtures (33%)
(.25)/(0)
17.25
Install New Lighting and Fixtures (Finish)
(.25)/(0)
Install Panels/ Ceiling
(1)/(0)
18.25
Install Carpet (75%)
(.25)/(0)
18.5
Finish Work-Hardware Handrails
(.25)/(0)
18.75
Reconnect Service
(.25)/(0)
19
30
31
32
33
34
35
36
37
38
39
40
41
Install Carpet (Finish)
(.25)/(0)
16
Install Carpet (Finish)
(.25)/(0)
18.75
Prefab Panels/Ceiling
(3)/(0)

2) Multi-tenant Lobbies, Handicap Bathrooms, and Elevators

All five elevators in each lobby bank must be operational during multi-tenant lobby and handicap bathroom construction to accomodate debris removal and material handling using the freight elevators. In addition, the service elevator system and building access points can only accomodate demolition and debris removal in one multi-tenant lobby at a time. These disturbance constraints are now imposed on the logic network and are shown in Figure 7.14.

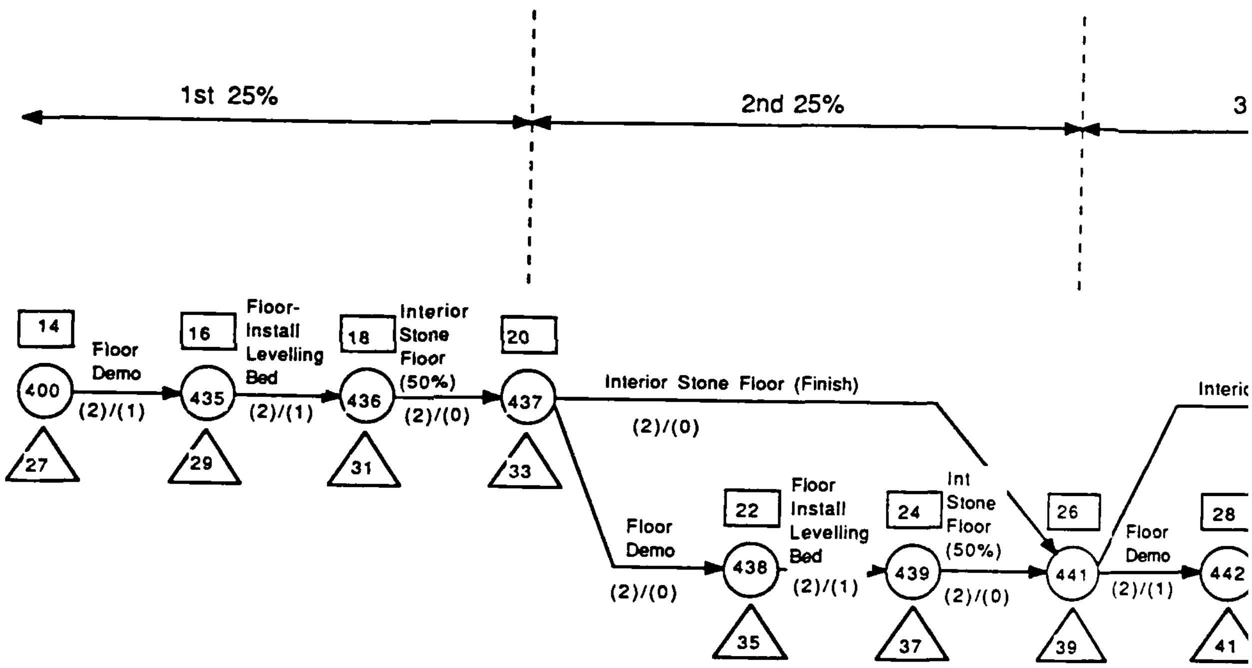
FIGURE 7.14: ELEVATORS,MULTI-TENANT LOBBIES, AND HANDICAP BATHROOMS

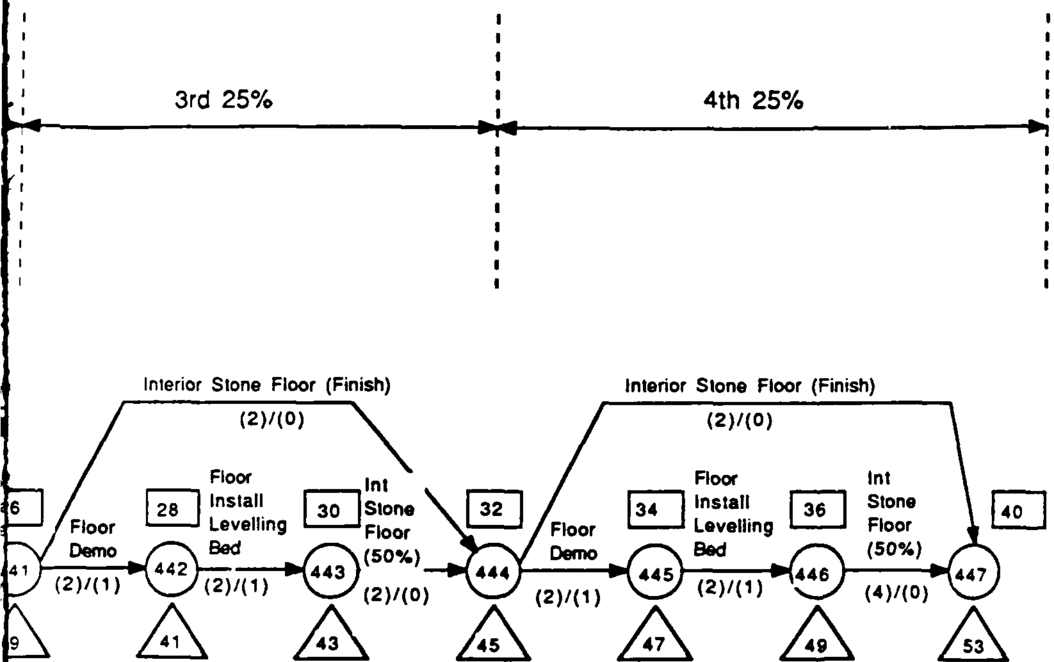


3) 3 Center Plaza Lobby (South)

Because of the configuration of the lobby at 3 Center Plaza, and the need to allow continued tenant traffic routes through this entrance, it was decided to conduct the floor demolition and installation in four sections. The revised portion of this network diagram is shown in Figure 7.15 to illustrate the process of spreading out this task into these 4 consecutive phases.

FIGURE 7.15: FLOOR INSTALLATION - 3 CENTER PLAZA LOBBY





3rd 25%
4th 25%
Interior Stone Floor (Finish)
(2)/(0)
Interior Stone Floor (Finish)
(2)/(0)
Floor Demo
(2)/(1)
Floor Install Levelling Bed
(2)/(1)
Int Stone Floor (50%)
(2)/(0)
Floor Demo
(2)/(1)
Floor Install Levelling Bed
(2)/(1)
Int Stone Floor (50%)
(4)/(0)
28
30
32
34
36
40
442
443
444
445
446
447
41
43
45
47
49
53

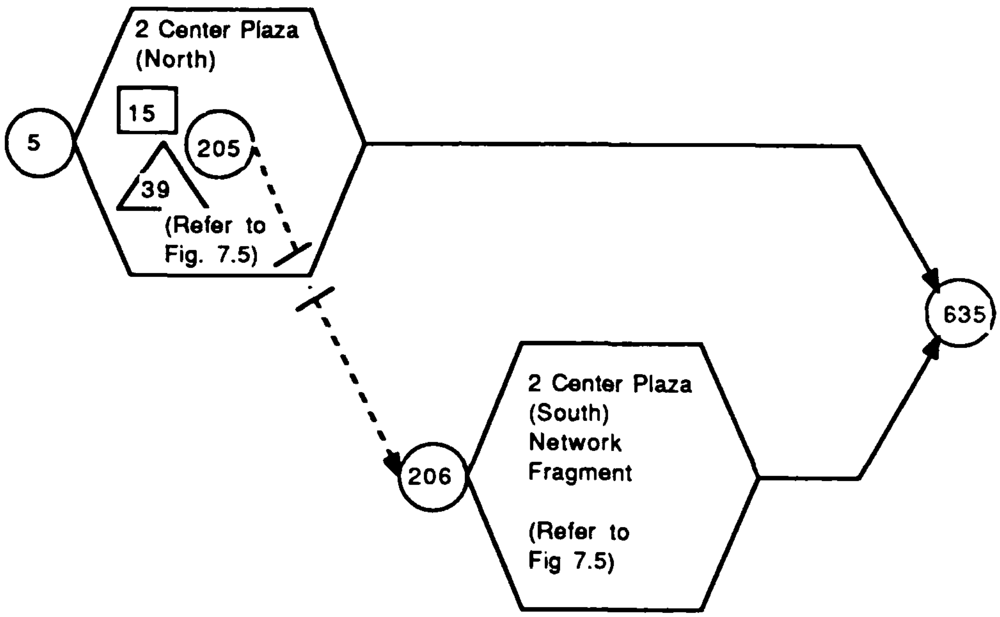
4) 1 Center Plaza Lobby (North)

For tenant traffic reasons, the lobby entrance at 1 Center Plaza (North) can not be completely shut down. As such, the storefront must be completed in 2 consecutive phases, 50% at a time, along with the use of temporary walkways to facilitate continuous entrance and egress. This is accomplished in a manner completely analogous to the floor demolition and installation at 3 Center Plaza described in the previous section. The only change is the introduction of two rather than four phases.

5) 2 Center Plaza North and South

In this section of the building, both storefronts provide access to a common lobby. Consequently, only one lobby entrance can be shut down at a time to maintain tenant traffic lanes. It was decided by the contractor that the first entrance could be re-opened for tenant traffic at the conclusion of Activity 200-205: Installation Aluminum Storefront with Revolving Door. The altered network fragments to accomplish this overlap is shown in Figure 7.16.

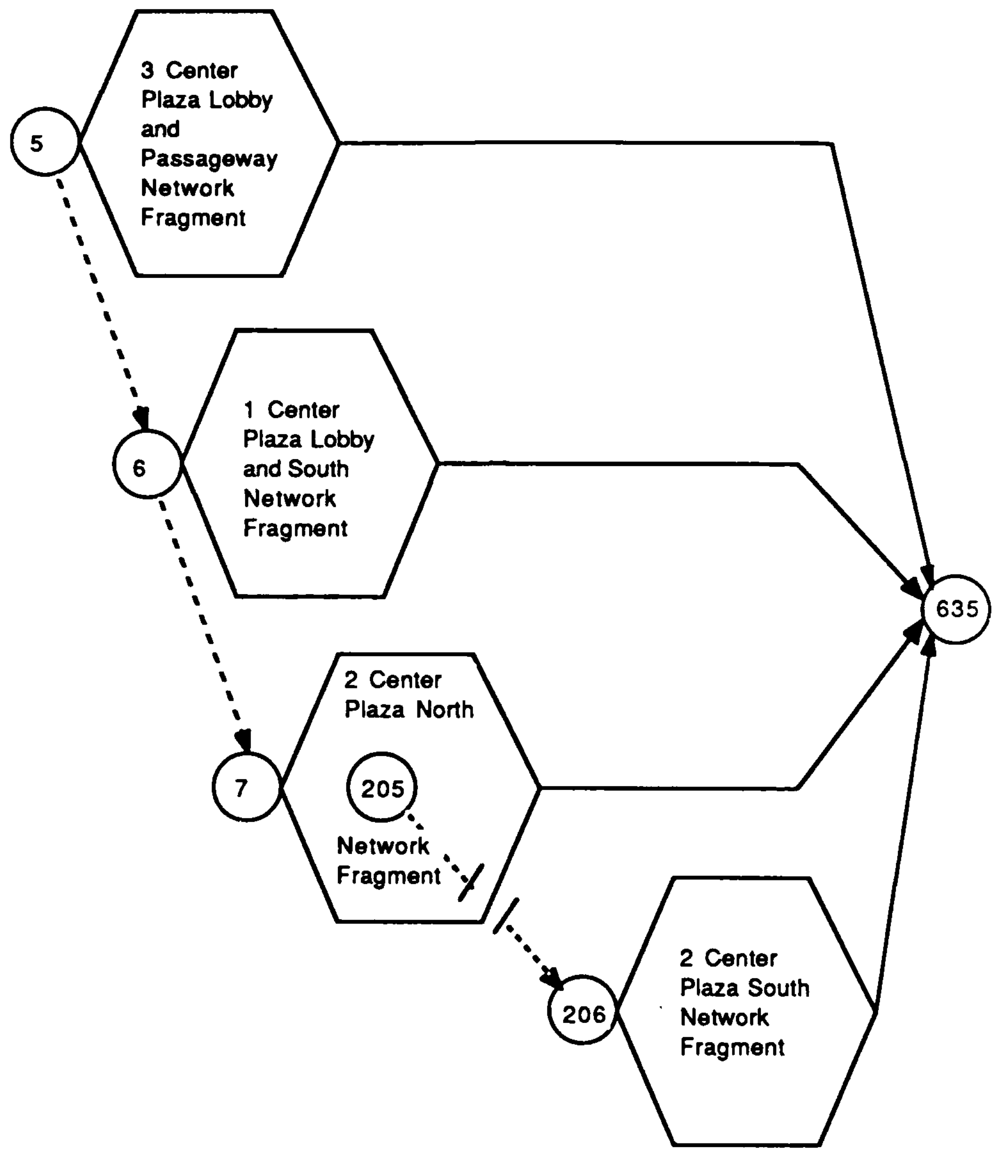
FIGURE 7.16: **2 CENTER PLAZA**



6) Disturbance Priority for 1, 2, and 3 Center Plaza Storefronts and Lobbies

In the course of resource or further disturbance constraining, a priority is also assigned to the ordering of the major subnetwork fragments for 1, 2, and 3 Center Plaza storefront and lobbies as noted in the Priority Disturbance List (Figure 7.11). 3 Center Plaza is to recieve priority because of the extensive work to be accomplished and the fact that its level of disturbance is the highest. 1 Center Plaza receives the next priority because the work on the storefronts directly affect tenant spaces on the 2nd floor. 2 Center Plaza receives last priority as the storefronts are not adjacent to occupied tenant space. To introduce this precedence, the logic network is depicted in Figure 7.17.

FIGURE 7.17: **LOBBY ENTRANCE SEQUENCING**



F. CATEGORY 6 PROCEDURAL STEP: WORK SPACE AND DISTANCE RESTRICTIONS

1) Handicap Bathrooms (2nd Floor; 1,2,& 3 Center Plaza)

The renovation of the handicap bathrooms involves space and distance restrictions because of the physical size of the work areas. It also involves the sequential completion of a number of activities in 3 like-units. This type of operation lends itself to line of balance scheduling. Completion of this technique, in accordance with the procedure described at the end of Chapter Six is shown in Figure 7.18.

2) Facade Lighting

This activity fragment also lends itself to the advantages offered in a line of balance approach. This revised schedule is also shown in Figure 7.19.

FIGURE 7.18: LINE OF BALANCE: HANDICAP BATHROOMS

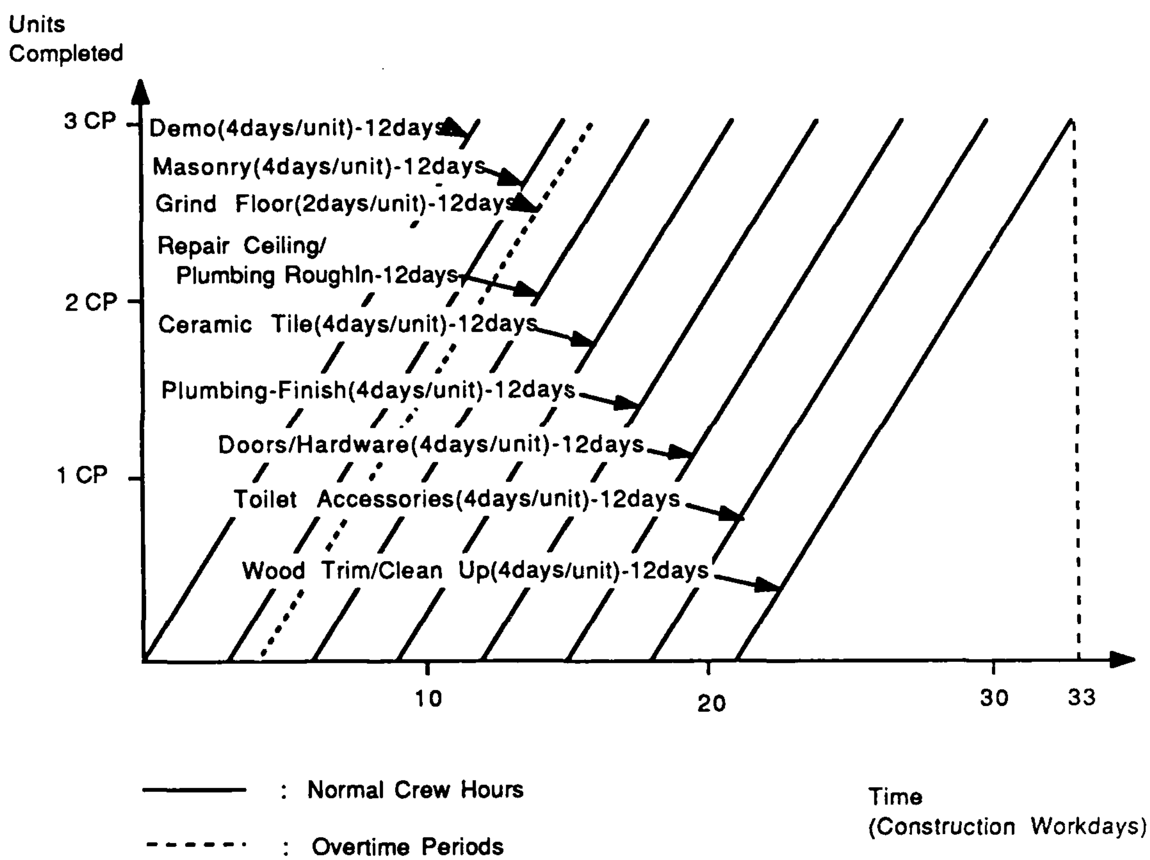
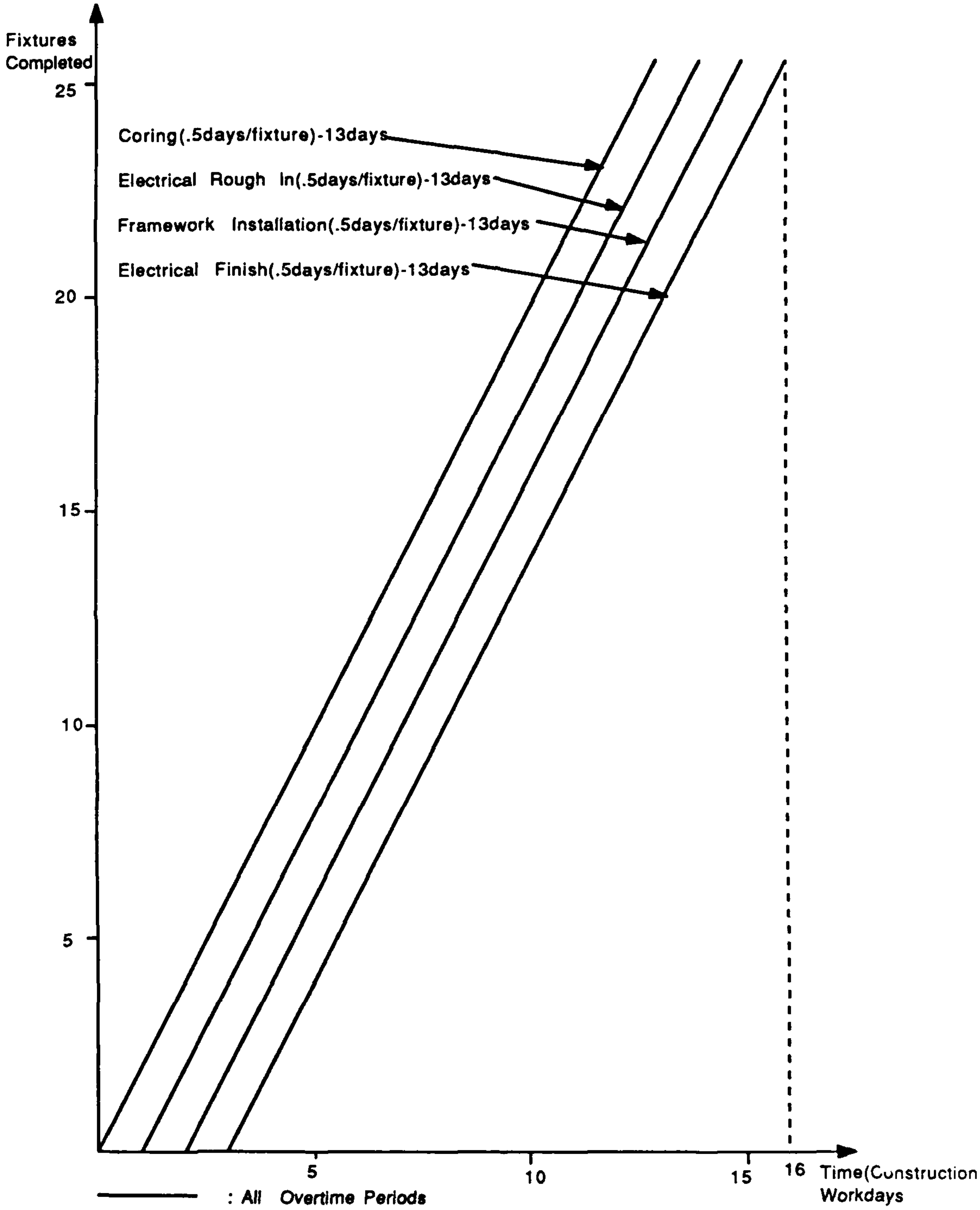


FIGURE 7.19: LINE OF BALANCE: FACADE LIGHTING



7.3.4 Phase Four: Resource Allocation Planning

In completing phase three, we have arrived at a network that has relaxed all constraints associated with tenant impact concerns and minimum building operational requirements except Category 2 activities. The fourth phase is to apply any possible resource constraints to the updated schedule.

An early start schedule, completely similar to that shown in Figure 7.10, is prepared for the Disturbance Scheduled Network. Resource leveling algorithms, discussed in Section 4.3.5, are applied with minor modifications. The choice of activities to be pushed back within a common subnetwork fragment follow strict conventional rules. However, if the planner is faced with a decision of pushing back activities which belong to separate subnetwork fragments, the priorities assigned by the Disturbance Scheduling algorithm must be followed. This provides the planner with an objective rationale for making these decisions which he/she was lacking in the traditional network planning model.

A. CATEGORY 2 PROCEDURAL STEP: RESTRICTIVE TIME FRAMES

As the last step in phase four, the planner must address the Category 2 disruptive activities. Because the activity groupings for the multi-tenant lobby demolition include asbestos removal and the complete shut down of the lobby for tenant use, they must be scheduled to occur on weekends only. This is now easily done by moving back the first lobby for completion on a weekend and introducing a 7 day buffer between the start of each of the remaining lobby renovations. These changes are noted in the final project plan presented in the succeeding section.

7.3.5 Total Project Plan

Consolidating all of the aforementioned steps of the Disturbance Scheduling Process, the plannner has developed a total project plan. This completed schedule is presented in Figures 7.20 through 7.25.

FIGURE 7.20: DISTURBANCE SCHEDULED NETWORK

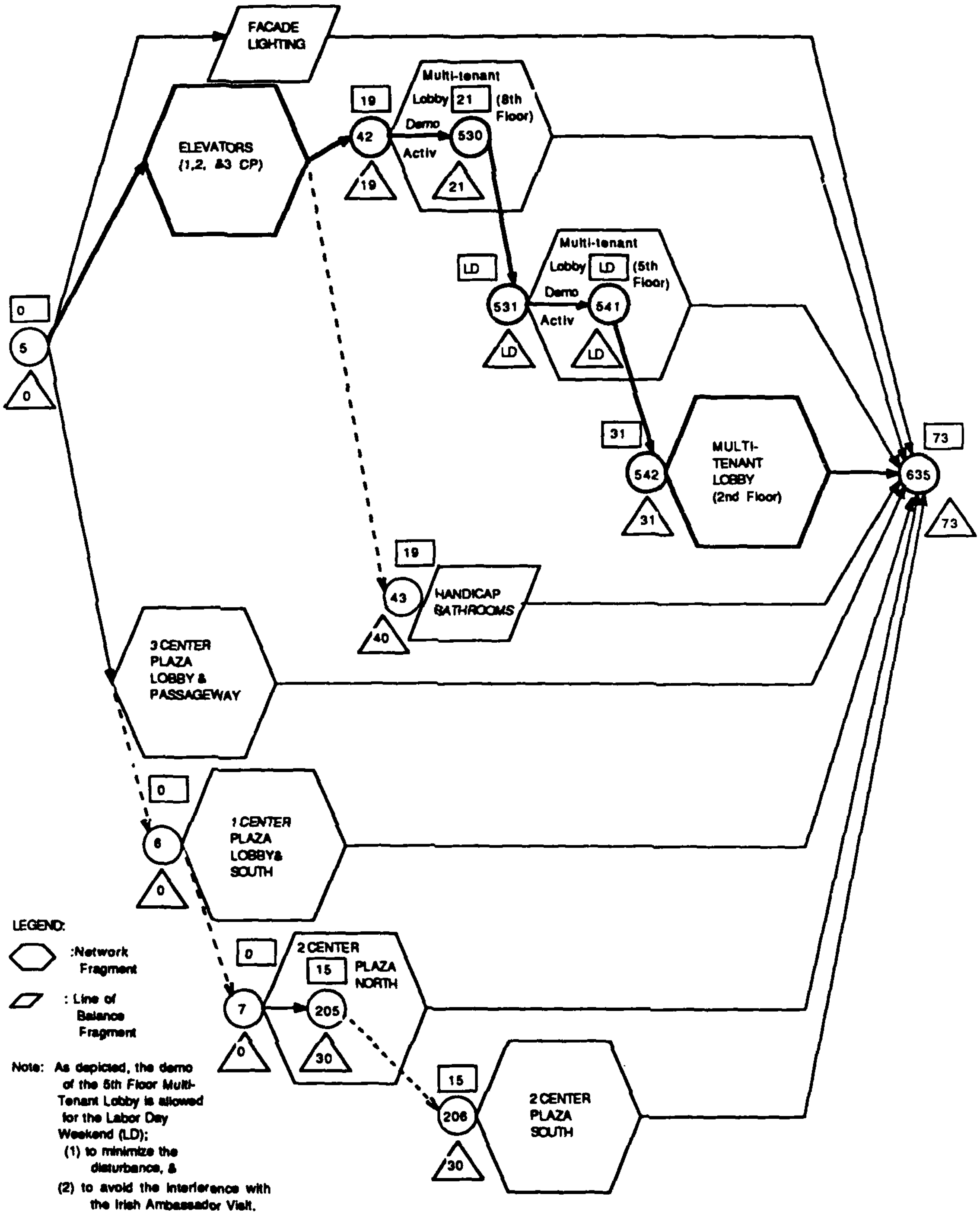


FIGURE 7.21: FACADE LIGHTING

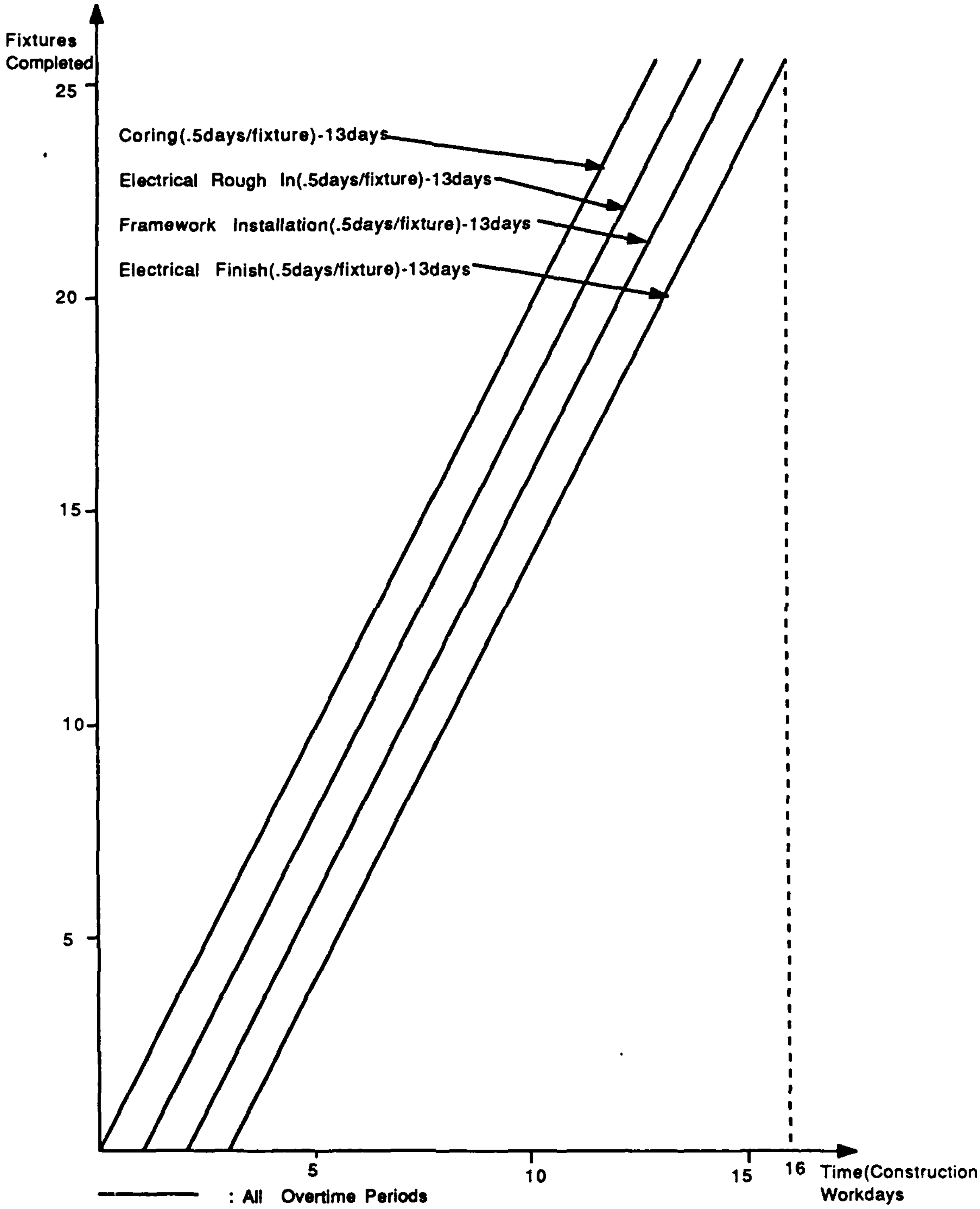


FIGURE 7.22: HANDICAP BATHROOMS

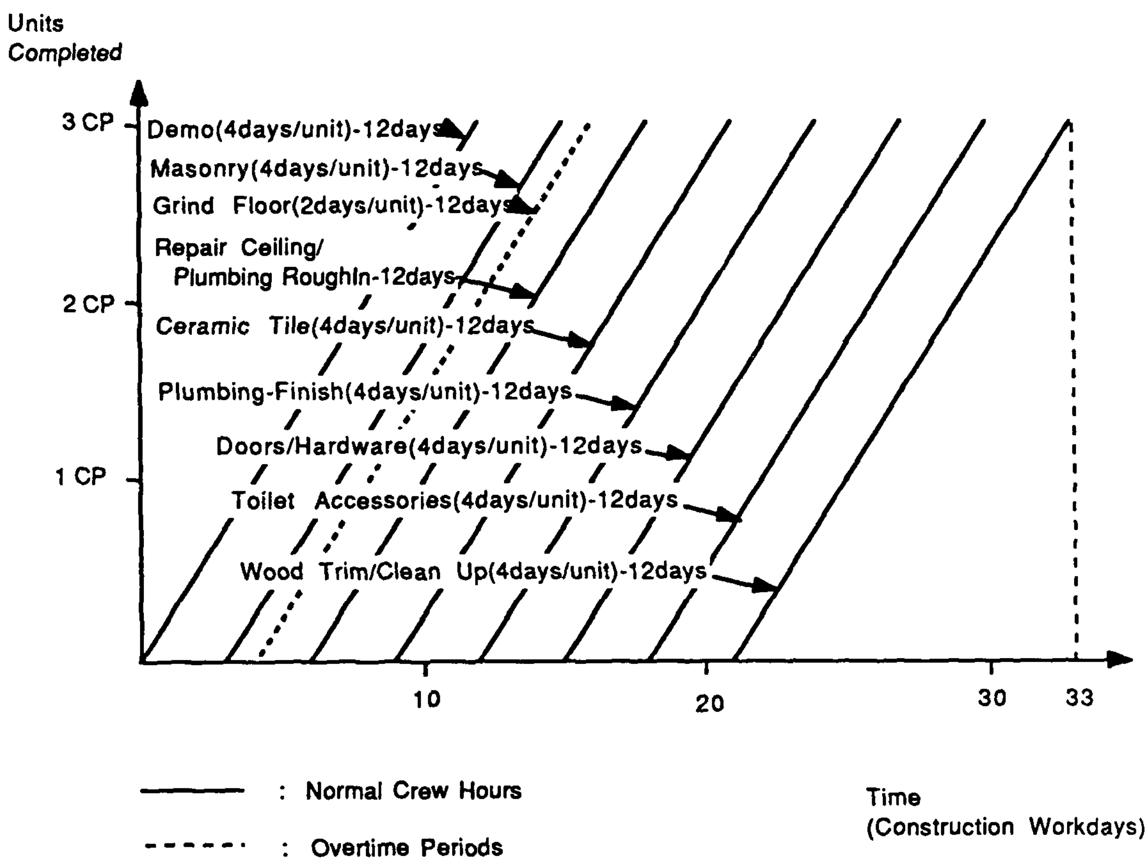
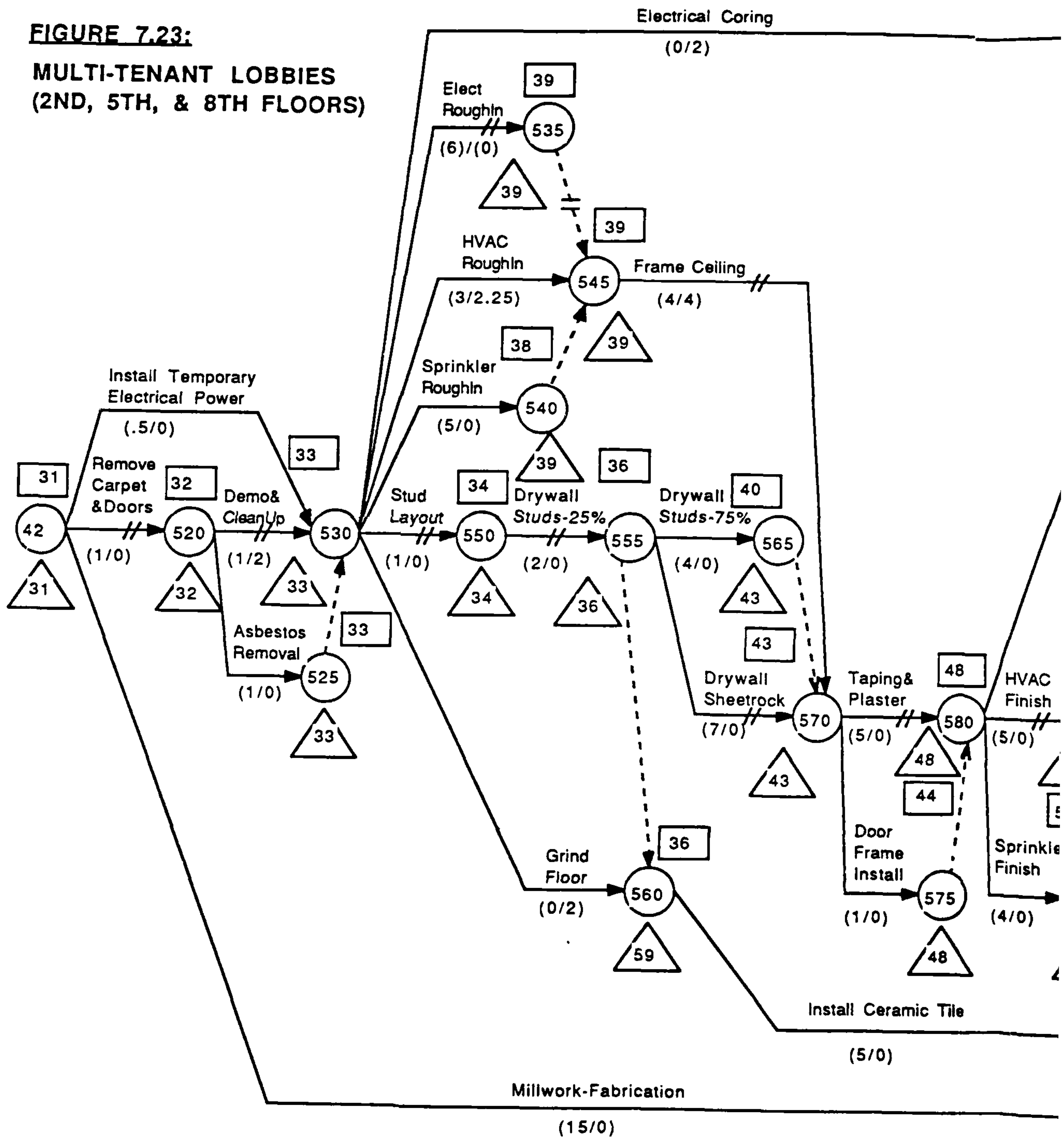
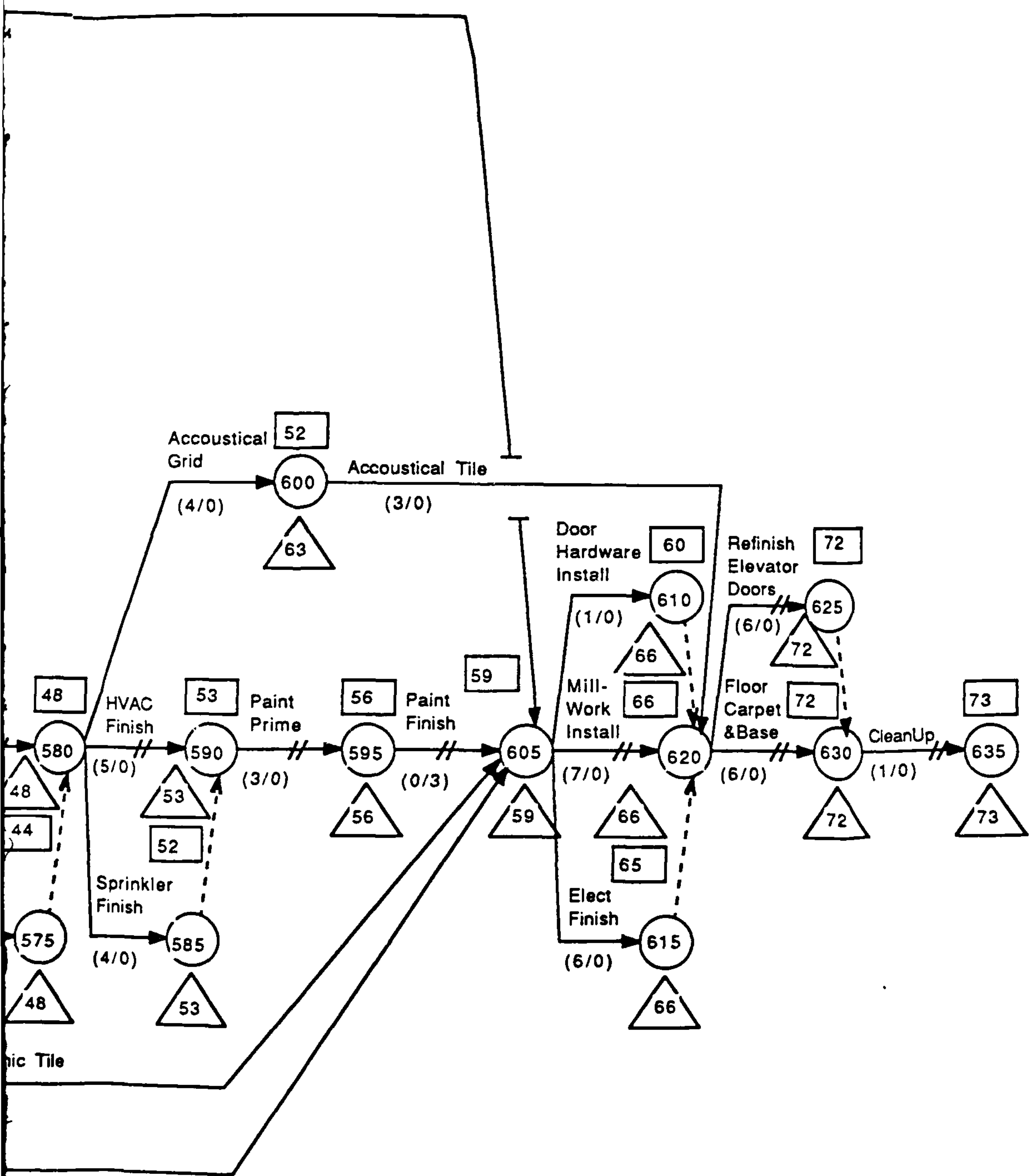


FIGURE 7.23:

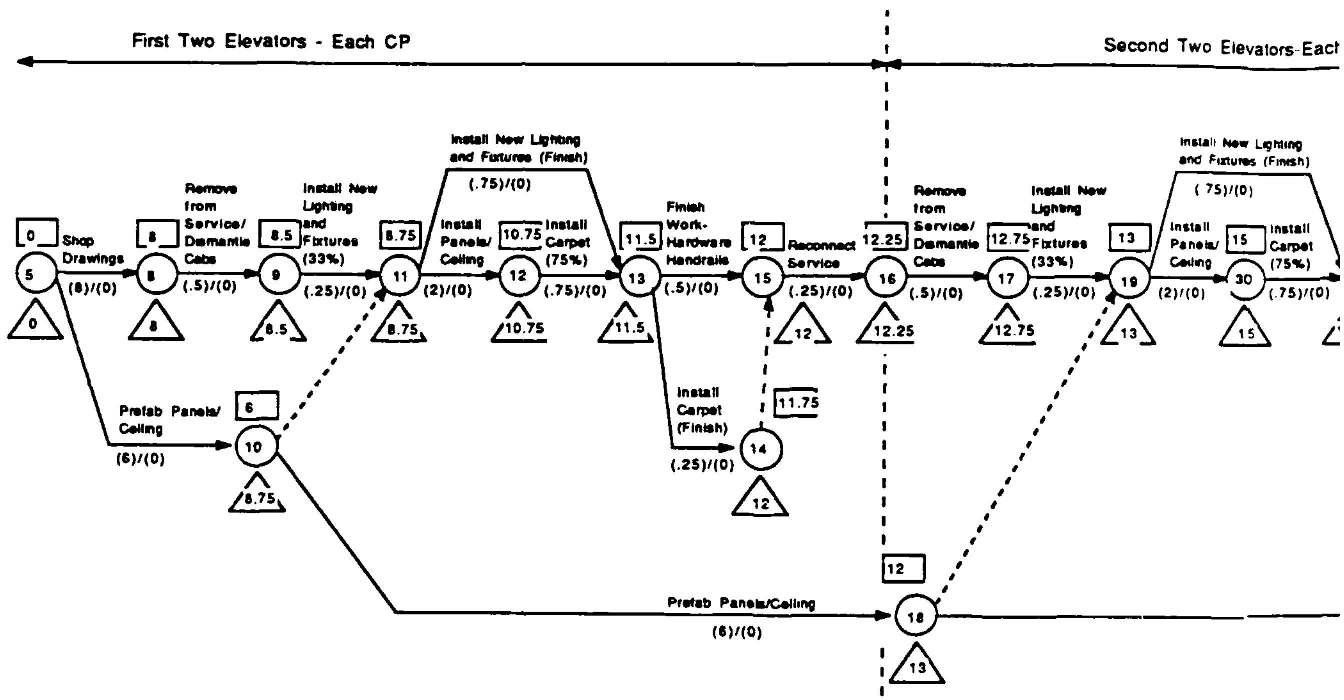
MULTI-TENANT LOBBIES (2ND, 5TH, & 8TH FLOORS)

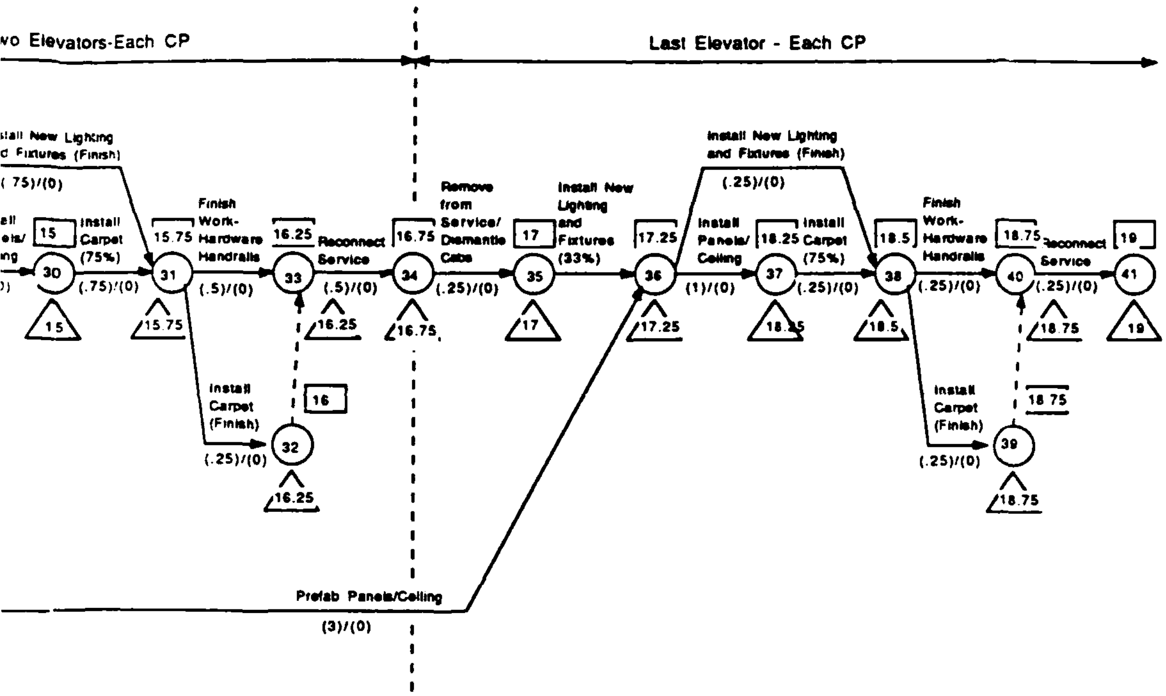




Accoustical Grid
52
600
(4/0)
63
Accoustical Tile
(3/0)
Door Hardware Install
60
610
(1/0)
66
Refinish Elevator Doors
72
625
(6/0)
72
48
580
48
44
HVAC Finish
(5/0)
53
590
53
52
Paint Prime
(3/0)
56
595
56
Paint Finish
(0/3)
59
605
59
Mill-Work Install
66
620
(7/0)
66
65
Elect Finish
615
(6/0)
66
Floor Carpet &Base
72
630
(6/0)
72
CleanUp
(1/0)
73
635
73
Sprinkler Finish
575
(4/0)
585
48
53
ic Tile

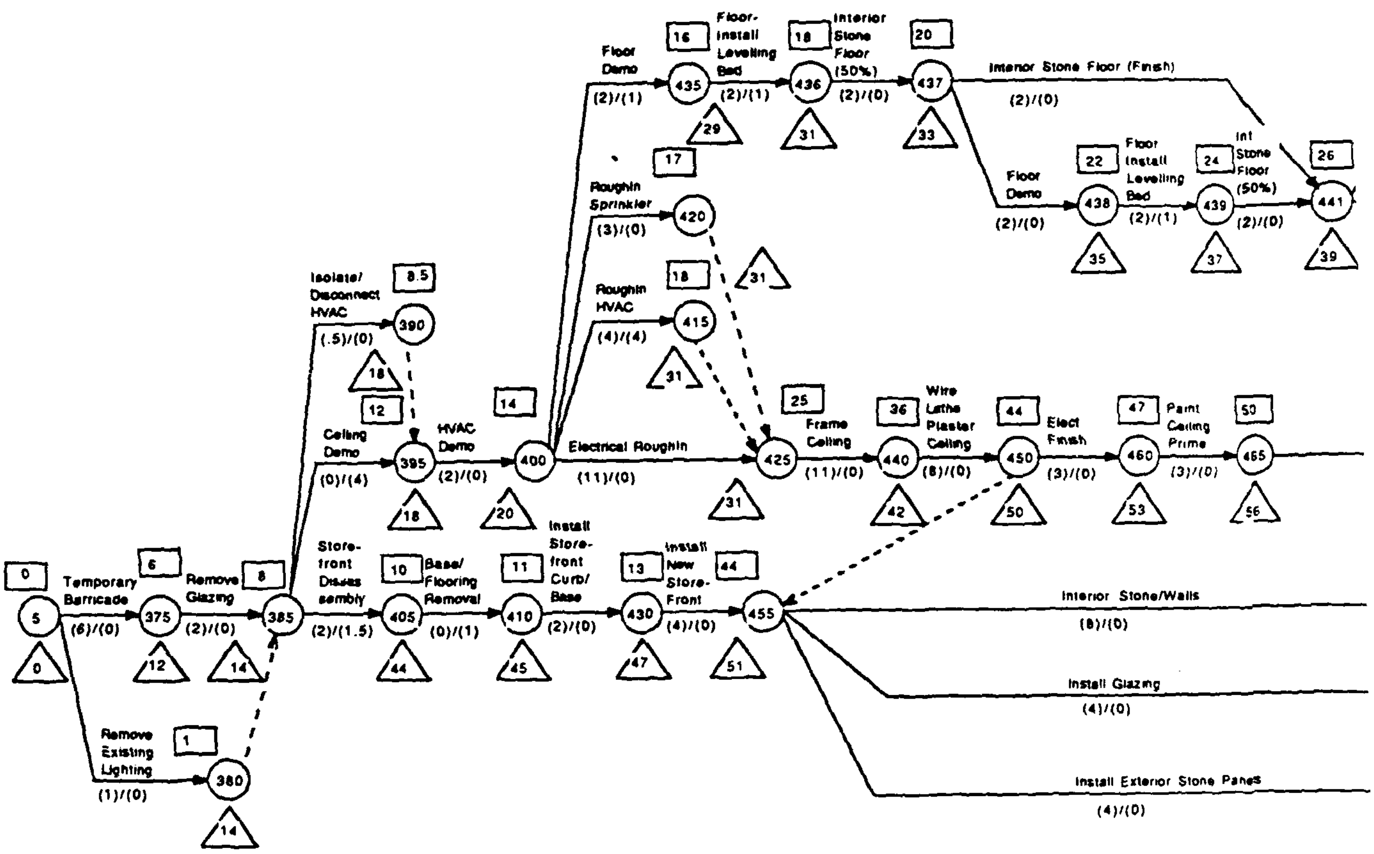
FIGURE 7.24: ELEVATORS (1,2, & 3 CP)

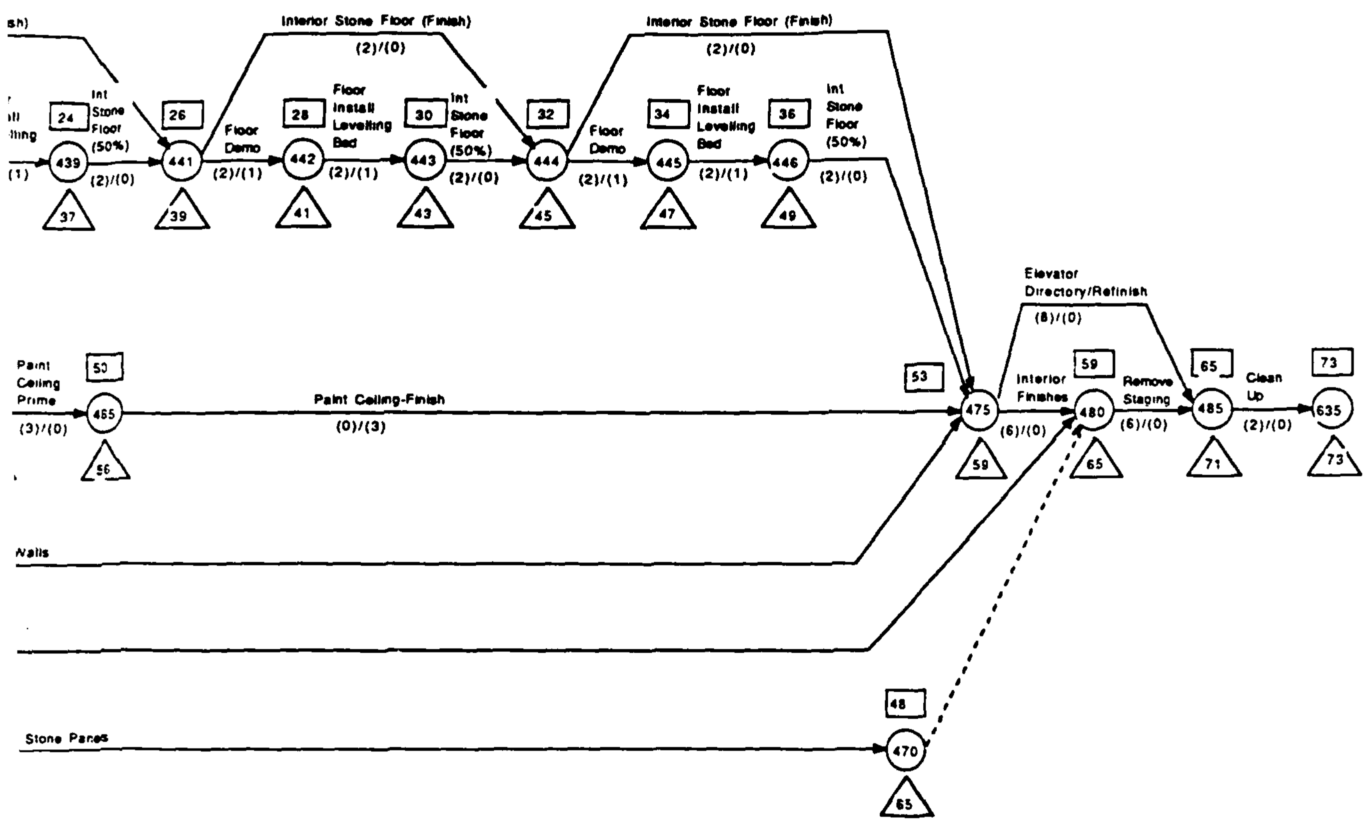




wo Elevators-Each CP
Last Elevator - Each CP
Install New Lighting and Fixtures (Finish)
(.75)/(0)
Install Carpet (75%)
(.75)/(0)
Finish Work-Hardware Handrails
(.5)/(0)
Reconnect Service
(.5)/(0)
Install Carpet (Finish)
(.25)/(0)
Remove from Service/ Dismantle Cabs
(.25)/(0)
Install New Lighting and Fixtures (33%)
Install New Lighting and Fixtures (Finish)
(.25)/(0)
Install Panels/ Ceiling
(1)/(0)
Install Carpet (75%)
(.25)/(0)
Finish Work-Hardware Handrails
(.25)/(0)
Reconnect Service
(.25)/(0)
Install Carpet (Finish)
(.25)/(0)
Prefab Panels/Ceiling
(3)/(0)

FIGURE 7.25: 3 CENTER PLAZA LOBBY (SOUTH)





Interior Stone Floor (Finish)
(2)/(0)
Interior Stone Floor (Finish)
(2)/(0)
Int Stone Floor (50%)
Floor Demo
Floor Install Levelling Bed
Int Stone Floor (50%)
Floor Demo
Floor Install Levelling Bed
Int Stone Floor (50%)
Elevator Directory/Refinish
(8)/(0)
Paint Ceiling Prime
(3)/(0)
Paint Ceiling-Finish
(0)/(3)
Interior Finishes
(6)/(0)
Remove Staging
(6)/(0)
Clean Up
(2)/(0)
Stone Panes

From these figures we see that the start date is scheduled for 5 August. The total duration of the constrained schedule is 73 days. The project completion date is projected on 19 October. The multi-tenant lobbies are scheduled to start on the weekends of 24 August, 31 August, and 7 September. These fragments, along with the completion of the elevators, lie along the new critical path. The lobbies and entrances at 1 and 3 Center Plaza are to begin at the initiation of construction. The 2 Center Plaza lobby entrance is a phased operation with the southern portion commencing on 20 August.

The last step is now to analyze this Disturbance Scheduled Network in Chapter Eight and highlight any significant observations which can be drawn as a result of the preceding application.

CHAPTER EIGHT

COMPARISON AND ANALYSIS OF THE DISTURBANCE SCHEDULED NETWORK TO THE SCHEDULE USED DURING ACTUAL CONSTRUCTION

8.1 INTRODUCTION

The preceding chapter applied both the Critical Path Method and the Disturbance Scheduling Technique to the Center Plaza improvement. In the latter case we were able to arrive at a total plan showing the complete flow of the project. The purpose of this chapter is to further analyze this Disturbance Scheduled Network and compare it with the schedule which was used by the contractor at Center Plaza for actual construction. Conclusions are then drawn concerning the efficacy of the new technique.

The chapter begins with a brief discussion of the CPM application in Section 8.2. Section 8.3 is the analysis with the actual schedule. Section 8.4 summarizes the chapter and reiterates the major issues which emerged from the comparison.

8.2 COMPARISON AND ANALYSIS WITH CONVENTIONAL CPM

Initially it was the intention of the author to compare the conventional Critical Path Method with the Disturbance Scheduled Network. Section 7.2 showed that the CPM application failed, however. This result is born out in practice as well. The procedure, based on construction logic alone, produced a schedule which dictated the simultaneous completion of a number of activities which could not allow minimum daily operations of the building. In addition, this conventional method offered no rules or guidance in proceeding in an acceptable manner when introducing resource and disturbance constraints.

8.3 COMPARISON AND ANALYSIS WITH THE ACTUAL SCHEDULE

The schedule used for construction at Center Plaza was provided in Figure 2.4. For means of comparison, it was shown in the form of a network diagram, depicting construction logic precedence among activities when possible. The procedure of converting the original barchart to the network diagram was done in consultation with the construction project manager and did not in any way alter the time frames for completion of activities on the original schedules.

Major subnetwork fragments were identified and outlined by dashed lines. The critical path of activities and late event times were not shown because of the absence of many of the precedence relationships. Known or implied precedence, overlapping of tasks, and integration of activities were shown wherever viable. In many cases this was not possible, however, even after consultation with the managers on the project.

This actual schedule will now be compared to the Disturbance Scheduled Network as depicted in Figures 7.20 through 7.25. Prior to this analysis, it is important to re-emphasize that the actual productivity rates for both schedules are the same. The time estimates shown in the original schedule in Figure 2.4 were taken off of the actual barcharts used on the project. These same productivity rates were also used in the preparation of the Disturbance

Scheduled Network through consultation with the project managers.

Four types of comparisons will be conducted. First, milestone comparisons will be made between the two schedules. Five critical events on the project will be selected and analyzed to determine when they occurred in the project cycle and the length of their construction. This type of comparison will help the reader understand how the Disturbance Scheduled Network significantly changed the flow of the project and how it was able to reduce the length of construction impact to which the occupants of the building would be exposed.

A second type of comparison will then be undertaken which vertically slices the respective schedules at 3 specific dates and analyzes all the activities that are taking place on that particular day. For each schedule one day is chosen for the beginning of the project, one in the middle of construction, and a final date near the completion of the work. This type of analysis provides the reader with a feeling for the total construction effort and impact on the building at particular points during construction. As an extension of this comparison, manpower utilization for the two schedules will be compared.

Finally, float time for the two respective schedules will be analyzed to assess the ordering of critical parts of the project. Calculations from the Disturbance Scheduled Network will be compared to a ranking of these portions of the project as determined by the property project manager. This will hopefully provide some insight into why the original phasing of the project took so long.

8.3.1 Milestone Comparisons

A. COMPLETION OF THE ELEVATOR CAB RENOVATIONS

Because of the tremendous impact on tenant traffic in the building as indicated earlier, completion of the elevator tasks was a paramount concern. The actual schedule shows these tasks ending on day 112 of the project after a duration of 42 days of construction.

The Disturbance Scheduled Network places this activity fragment at the start of the project with completion in 19 days. A time savings of 23 days is realized. An illustration of the time savings and occurence of this critical events are found in Figures 8.1 and 8.2.

B. CLOSING OF THE 3 CENTER PLAZA LOBBY

The actual schedule started the 3 Center Plaza lobby construction on day 89, after the tenants had undergone a lengthy disruption during renovation of the interior multi-tenant lobbies in the same section of the building.

The Disturbance Scheduled Network arranges for this shutdown to take place on day 6 of the project and overlaps this construction with the work taking place in the multi-tenant lobbies at the same location. This overlap still allows the building to function, but only exposes the tenants to construction at 3 Center Plaza for a duration of 73 days, whereas during the actual construction the tenants were subject to this renovation effort for a total of 153 construction days, doubling the length of the disturbance impact. A graphical portrayal of this reduction is shown in Figure 8.1.

FIGURE 8.1: MILESTONE COMPARISONS: TIME SAVINGS

ELEVATOR CAB RENOVATIONS

Original Schedule:

40 days

Disturbance Scheduled Network:

19 days

3 CENTER PLAZA RENOVATIONS

Original Schedule:

153 days

Disturbance Scheduled Network:

73 days

MULTI-TENANT LOBBY CONSTRUCTION

Original Schedule:

92 days

Disturbance Scheduled Network:

54 days

OVERALL PROJECT DURATION

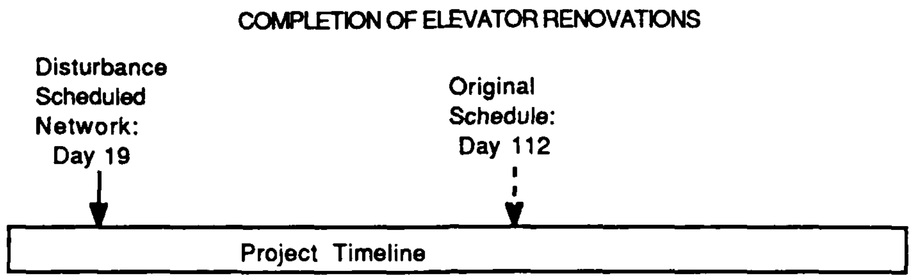
Original Schedule:

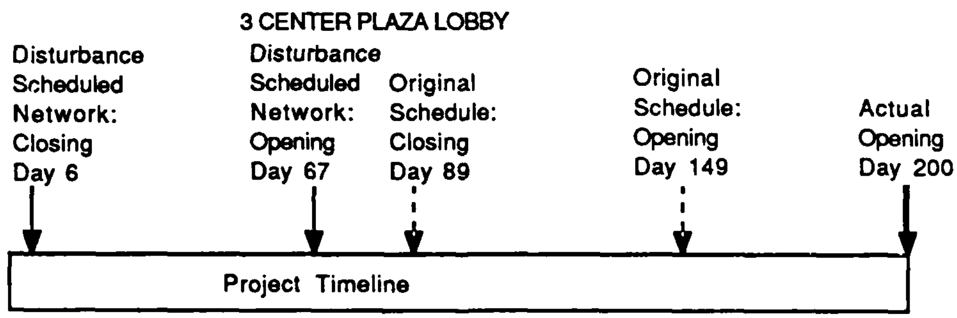
198 days

Disturbance Scheduled Network:

73 days

FIGURE 8.2: MILESTONE COMPARISONS: CRITICAL EVENTS





C. OPENING OF THE 3 CENTER PLAZA LOBBY

During actual construction, the lobby at 3 Center Plaza was scheduled to open on day 149 but ended up being delayed until near the end of construction, or approximately day 200.

The Disturbance Scheduled Network predicts this opening to take place on day 67. The length of this construction is only slightly reduced; the salient point is that this disturbing segment is completed much earlier in the project cycle. Figure 8.2 shows the relative position of these critical events on the project timeline.

D. LENGTH OF MULTI-TENNANT LOBBY CONSTRUCTION

The multi-tenant lobbies were found to be particularly disturbing during actual construction because of their close proximity to occupied tenant spaces. The original schedule estimated the length of this construction to be 92 days.

By efficiently employing a line of balance approach, the Disturbance Scheduled Network shows the duration to be 54 days. This is a reduction of 41% in construction time, as shown in Figure 8.1, which is even more important because of the fact that these segments also lie along the calculated critical path.

E. OVERALL PROJECT DURATION

By far, the most prominent difference between the actual schedule and the Disturbance Scheduled Network is in the total project duration. The actual project anticipated completion in 198 construction workdays while the Disturbance Scheduled Network predicts completion in 73 days, or 37% of the original estimate, again shown in Figure 8.1.

This total reduction in construction time on each of the project segments and in the overall length of the project is very favorable. In addition, a key advantage of the Disturbance Scheduling Technique was in its ability to schedule the most disturbing parts of the project very early in the project cycle and complete them in an expeditious manner thereby minimizing the corresponding impact on the occupants and operational considerations of the building. The milestone comparison above illustrates this concept very well for several of the most disturbing segments of the project, in particular, the elevator rehab and in the 3 Center Plaza section of the building where the majority of renovation effort was expended.

8.3.2 Vertical Construction Date Comparison

A. BEGINNING OF CONSTRUCTION

To begin, for this comparison, day 10 of both schedules is chosen. On the original schedule only the 8th floor multi-tenant lobby is under construction. Specific activities are shown in Table 8.1. Surely other tasks could have been overlapped with this event, but this was not done.

Table 8.1 Day 10 - Original Schedule

8th Floor Multi-tenant Lobby, 3 Center Plaza	
Demolition	10 Laborers
	2 Electricians
	3 HVAC
	2 Carpenters
Millwork Shop Drawings	2 Men

For day 10 on the Disturbance Scheduled Network, the elevators are under construction. In addition, aluminum storefront dissassemblies, electrical, and ceiling work is taking place at each of the lobby entrances. Table 8.2 below illustrates the complete listing of activities that are taking place.

Table 8.2 Day 10 - Disturbance Scheduled Network

Elevators	
Prefab Panels/Ceiling	6 Carpenters
Install Panels/Ceiling	6 Carpenters
3 Center Plaza Lobby	
Storefront Base/Flooring Removal	2 Laborers
Ceiling Demo	7 Laborers
3 Center Plaza Passageway	
Electrical Rough In	2 Electricians
Aluminum Storefront Dissassembly	4 Glazers
Frame Exterior Ceiling	4 Carpenters
1 Center Plaza	
Temporary HVAC	2 HVAC
Electrical Rough In	2 Electricians
Storefront Dissassembly	4 Laborers
2 Center Plaza	
Install New Storefront Curb/Base	2 Laborers
Electrical Rough In	2 Electricians

These events can take place at the same time and doing so is certainly advantageous, not only because it tends to group disruptive events and get them completed early, but also because better coordination is allowed for the subcontractors working to prepare each of the storefront entrances for new installations.

B. MIDDLE OF CONSTRUCTION

Day 80 is chosen on the actual schedule. Table 8.3 below shows work on the elevators and completion of the multi-tenant lobbies in 3 Center Plaza to be occuring at this time. These, in fact, are competing events since the freight elevator was to be used to temporarily carry passengers during elevator renovations and also used to transport materials and debris for the multi-tenant lobby work. Therefore, these activities should not have been overlapped, and the schedule is incorrect.

Table 8.3 Day 80 - Original Schedule

Elevators	
Elevator Renovations	6 General Laborers 6 Carpenters
1 Center Plaza	
Glazing-Factory Fabricate	4 Glazers
2nd Floor Multi-tenant Lobby, 3 Center Plaza	
Complete Plaster	1 Plasterer
Millwork Fabrication and Installation	4 Millworkers

For the Disturbance Scheduled Network, day 25 is chosen during peak construction and is depicted in Table 8.4.

Table 8.4 Day 25 - Disturbance Scheduled Network

8th Floor Multi-tenant Lobby, 3 Center Plaza	
Electrical Rough In	2 Electricians
Sprinkler Rough In	2 Sprinkler
Drywall-Studs and Sheetrock	4 Drywall
Install Ceramic Tile	3 Tile Setters
Millwork Fabrication	4 Millworkers
Handicap Bathrooms	
Masonry	2 Masons
Grind Floor	1 Laborer
Plumbing Rough In	2 Plumbers
3 Center Plaza Lobby	
Frame Ceiling/Walls	3 Carpenters
Interior Stone Floor	4 Tile Setters
3 Center Plaza Passageway	
Wire Lathe and Plaster Ceilings	3 Plasterers
Interior Stone Walls-Patch	3 Tile Setters
Floor Stone-Interior/Exterior	3 Men
1 Center Plaza	
Wire Lathe and Plaster Ceiling	3 Plasterers
Interior Stone Walls-Patch	2 Tile Setters
Floor Stone-Interior/Exterior	3 Men
2 Center Plaza	
Wire Lathe and Plaster	3 Plasterers

As shown, on this particular day, interior crews are sequentially working through the multi-tenant lobbies. The handicap bathrooms are sequentially undergoing masonry and plumbing tasks, while the lobby entrances at 1,2, and 3 Center Plaza are undergoing plastering, stonework, ceiling and floor installation operations.

The simultaneous completion of these tasks in no way impedes the operational requirements of the building because of the location sequencing and the fact that all the disturbance constraints had already been relaxed. Resource constraints may arise but can be easily imposed by adhering to the precedence assigned in the prioritized disturbance list prepared in Figure 7.11. In addition, there may be an increased management requirement. To address this issue, it might be recommended to employ 2 superintendants during the conduct of this phase of the work, one to supervise the interior work on the multi-tenant lobbies and handicap bathrooms, and one to watch over the construction on the exterior lobby entrances.

C. END OF CONSTRUCTION

Day 150 of the original network shows only the scheduling of the 2 Center Plaza lobby with clean up at 3 Center Plaza.

Table 8.5 Day 150 - Original Schedule

3 Center Plaza Passageway	
Remove Scaffolding	6 Laborers
2 Center Plaza South	
Install Storefront (North)	8 Glazers
	9 Laborers

The 2 Center Plaza work shown was not a critical event, as confirmed by both the Construction and Property project managers, and probably should have been scheduled for completion much earlier in the project cycle.

Day 70 is chosen at the end of the Disturbance Scheduled Network.

Table 8.6 Day 70 - Disturbance Scheduled Network

2nd Floor Multi-tenant Lobby, 3 Center Plaza	
Refinish Elevator Doors	2 Men
Flooring-Carpet and Baseboard	2 Carpet Layers

Here we see only the completion of the last multi-tenant lobby taking place with clean as we near completion of the critical path activities. All construction and disturbances have been completed by this time at 1, 2, and 3 Center Plaza.

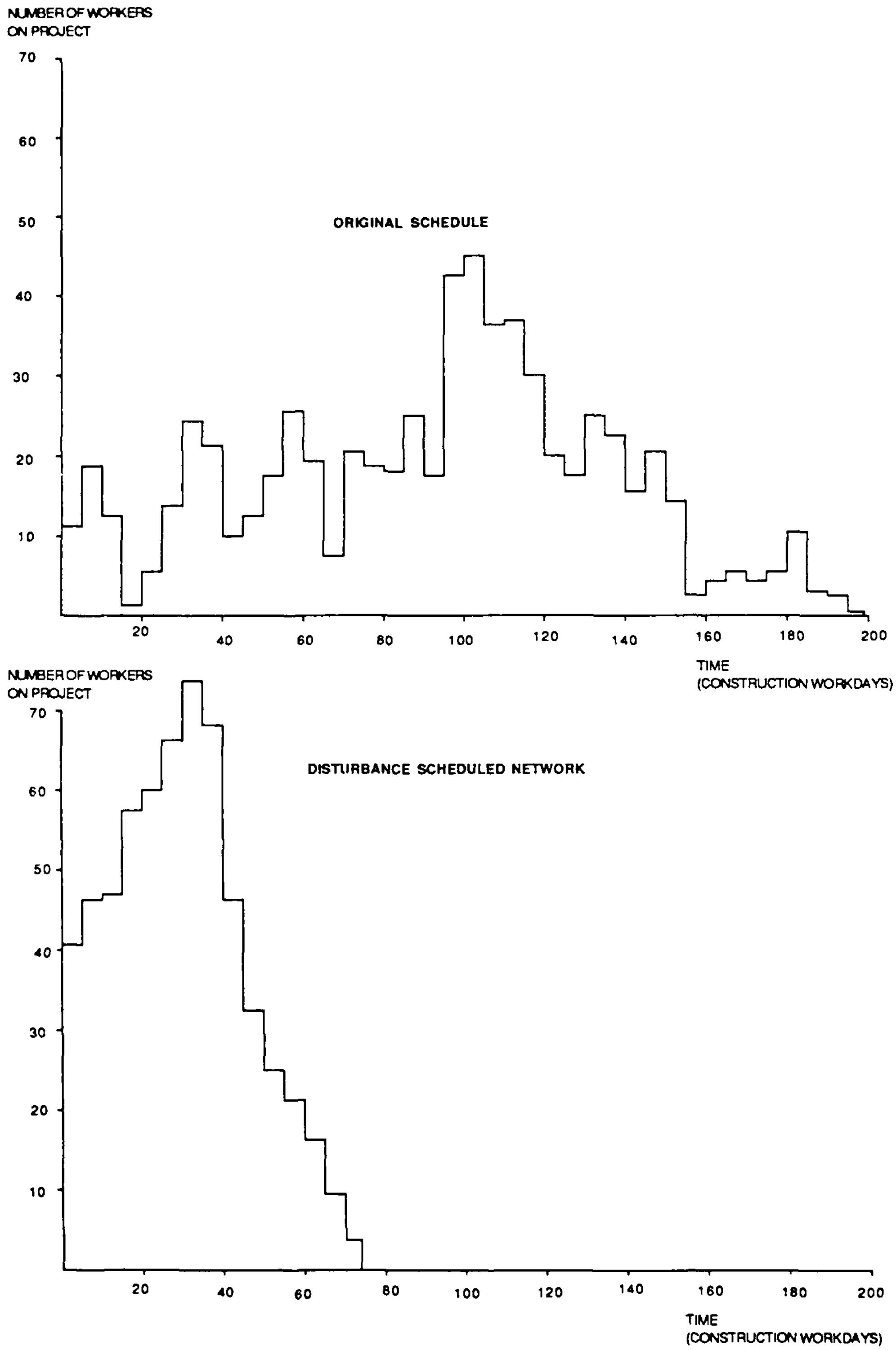
8.3.3 Manpower Utilization Comparison

The preceding vertical comparison was very revealing in the amount of construction effort that was scheduled to take place at certain time frames on the project. Another interesting comparison in this respect is to look at the manpower utilization required by each of the project schedules over the entire course of construction. Histograms for the original schedule and the Disturbance Scheduled Network are shown in Figure 8.3.

Analysis of this figure clearly shows that the original schedule was a conglomeration of a number of individual segments or phases of the project. (These are evident as peaks in the upper graph of Figure 8.3.) Although, some overlap was achieved, the project is still very lengthy in duration and shows distinctive breaks where integration and a total project flow is not achieved.

In comparison, the lower graph in Figure 8.3 shows that the Disturbance Scheduled Network arrived at a schedule that was more condensed and better overlapped construction at different locations in the project. It is interesting to note that rather than starting with a gradual buildup of manpower, the Disturbance Scheduled Network dictates that the project start very rapidly. There is little time to mobilize assets once the project begins and the construction team must be prepared to push forward very early with a substantial work effort. It is also interesting to note that although the peak utilization requirements are higher

FIGURE 8.3: MANPOWER UTILIZATION



for the Disturbance Scheduled Network versus the original schedule, it is only be an increase of approximately 40%. The management requirements due to this increased work force could easily be handled by the project management personnel as long as they were prepared to address these additional needs early in the project cycle.

At no time does the Disturbance Scheduled Network require the concurrent accomplishment of tasks which would impede the building's operation. This was avoided by proper location sequencing and the systematic relaxation of disturbance constraints only to a level which allowed the building to remain functional. In addition, the relative size of the Disturbance Scheduled lists to the Actual Schedule activities from Section 8.3.2 shows how the Disturbance Scheduled Network was able to complete a large number of the most disturbing activities early in the project cycle and thereby reduce the amount and length of construction impacts that the tenants at the site would experience.

8.3.4 Float Comparisons

Float calculations can be computed from the Disturbance Scheduled Network to assess the critical nature of individual network fragments. Six typical fragments are chosen below as an illustration:

Level of Importance of Timely Completion	Network Fragment	Total Float
1	Elevators (1,2,& 3CP)	0
1	Multi-tenant Lobbies	0
3	3 Center Plaza Lobby and Passageway	6 days
4	2 Center Plaza	15 days
5	Handicap Bathrooms	21 days
6	1 Center Plaza	25 days

Because of the lack of network analysis calculations on the original schedule, float times could not be computed. As an alternative, the project manager of the actual project was asked to rank the level of importance as objectively as possible. The result is shown below:

Level of Importance of Timely Completion	Network Fragment
1	3 Center Plaza Lobby and Passageway
2	1 Center Plaza
3	2 Center Plaza
4	Multi-tenant Lobbies
5	Handicap Bathrooms
6	Elevators (1,2,& 3CP)

This comparison is very revealing and provides some answers to why the actual project took so long. Some of the events, which were most critical using an objective disturbance scheduling approach, were not realized as being critical at all from the standpoint of the project manager's experience. This can be attributed to the lack of an appropriate scheduling tool for the manager to use in determining a logical flow to the project which meets all constraints in the least possible amount of construction time.

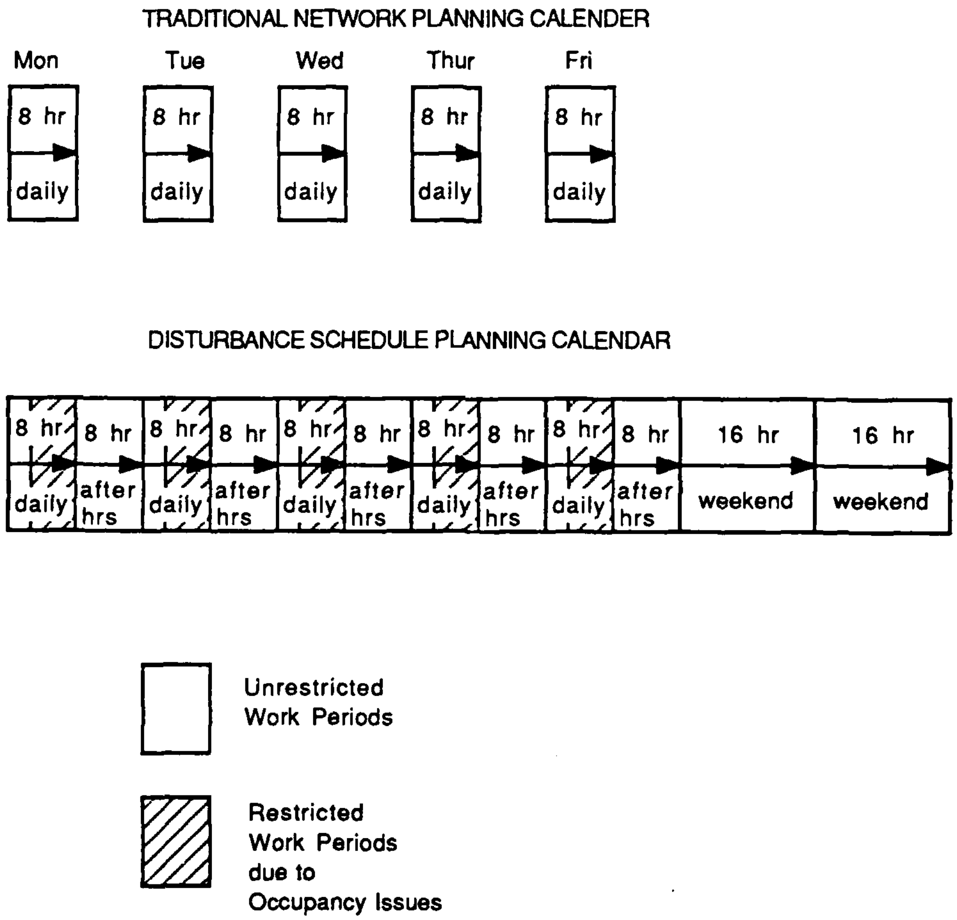
8.3.5 Expanded Scope of Available Construction Time Frames

The whole concept of traditional construction scheduling centers around the efficient use of normal crew workdays. Overtime and weekend work periods are almost never scheduled far in advance, and then only by exception and viewed primarily as a control tool to make up lost time on the project if required.

The actual Center Plaza schedule exhibited this characteristic. A project calender was correlated with the construction workday schedule. It included only 5 workdays a week, each of 8-hour duration. Activities known in advance to require completion outside this schedule were still placed within the boundaries of the 40-hour work week.

In correcting this conceptual error, the Disturbance Scheduled Network led directly to a scaling adjustment of the project calender. It recognized the scheduling and control of available overtime and weekend periods to be as important as daily sessions. Figure 8.4 graphically represents this scale adjustment concept.

FIGURE 8.4: **EXPANDED SCOPE OF CONSTRUCTION TIME FRAMES**



8.3.6 Precedence Relationships and Phasing Issues

It is apparent on the original schedule that the project managers, somewhat subjectively aware of impact concerns, introduced arbitrary phases to the project. Interviews with both the construction and property project managers, and careful review of the schedule indicate that this phasing operation was not based on any type of formal rules, but merely what they felt might best work for the flow of the project. The graphical barchart they prepared was simply a means to conceive of the time scale of the project.

The actual schedule was separated into two distinct parts, the interior tenant space areas and the exterior and lobby entrances. No apparent connection was made between these entities. Subnetwork fragments were identified but were treated as completely separate and discrete units. Only later was an attempt made to overlap their completion, but again without formal precedence relationships.

Figure 2.4 shows that the 1 Center Plaza lobby was arbitrarily chosen to be scheduled first in the succession of exterior entrances. Using a concept of hierarchy among disruptive groupings, this would be questionable logic. This oversight is not nearly as critical, however, as the fact that the schedule next implies logic jumps alternating between this lobby entrance at 1 Center Plaza and the work to be completed at the 3 Center Plaza entrance. There is no connection between these two subnetwork fragments and this excessive phasing only served to prolong the disruption that was experienced in each of the work areas rather than completing each fragment as quickly as possible. The Disturbance Scheduling Network shows it to be far more efficient and productive to maintain the project flow in one area rather than impose severe construction impacts at two different locations when it is not necessary and only serves to force the leapfrog movement of men, materials, and equipment.

8.4 COMPARISON RESULTS

In conclusion, the key point which accounted for the major differences between the actual and Disturbance Scheduled Network is that characteristically, as was done at Center Plaza, planners tend to overphase major renovations because of their complexity and building operation concerns. They then attempt to overlap these phases only as a second thought.

The Disturbance Scheduling Process offers a more rational approach. It begins with the assumption of no phasing on the project and then sequentially applies constraints to the network only to the extent which meets all disturbance and resource restrictions. In this manner, the planner is assured of arriving at the minimum duration for the project while continuing to keep the facility functional throughout construction. While the actual schedule also met most of the disturbance requirements, it did so in a suboptimal manner by extending the total duration of the project to an excessive degree and creating further hardships to the building and its occupants.

In its systematic application, the Disturbance Scheduling Process encourages the completion of the most disruptive segments of the project at the earliest possible time in the cycle. It also provides a procedural way of grouping the most disruptive tasks and completing them together, thereby decreasing the overall length of disturbance, saving time, money and imposing much less aggravation on the tenants and the owner. In addition, these disruptive tasks are often the ones that cause the greatest problems in project control, and can now be addressed early to avoid excessive delays later in the project.

CHAPTER NINE

CONCLUSIONS

9.1 SUMMARY

The purpose of this thesis was to investigate objective and systematic means of addressing the unique issues and problems that are faced in renovation work. This evolved into the development of a new Disturbance Scheduling Technique which alters traditional network analysis models to better address the considerations of construction in operational facilities and thereby advance the way the renovation process is currently managed.

Chapter One began with a statement of the problem and a methodology of research for fielding solutions to overcome these deficiencies. Chapter Two was a case study that served the purpose of identifying many issues, factors, and pitfalls which habitually plague the renovation process. The findings of this study highlighted the need for early establishment and prioritization of objectives and goals on renovation projects. This fulfills the purpose of deriving a cohesive and coherent plan which provides for the ability to physically implement design goals.

It was also recognized that because of the small-scale, low budget nature of renovation work, a focal point (such as a design competition, a specific predetermined desired outcome, or a master plan) is needed to provide direction to the renovation process. Key players must be selected to participate based on their ability to commit to what sometimes can be a relatively small financial, yet complex venture. Experience and expertise in renovation work was cited as a key ingredient for all participants and should command heavy influence in the assemblage of the construction team. All told, despite being small compared to new construction ventures, it was found that renovation projects require at least as much, and often more, construction management attention.

In the area of technical planning and control, the results of the study stressed the importance of reviewing existing building conditions and minimizing the risk associated with unforeseen conditions. An issue was raised about limiting the design to practical, standard applications to avoid lengthy construction periods which could seriously affect the operation of the building and morale of the occupants who are subject to the inconvenience. In addition, the need to avoid excessive material delays was cited for similar reasons. The most salient technical deficiency was found to occur in the area of scheduling the actual construction. This issue provided impetus for the development of a new technique which would better serve project managers in planning complex renovations.

Chapter Three extended the findings of the Center Plaza study into a generic model of the renovation process which addressed the topics of project procurement, project management, organizational issues, a flowchart of the global phases of the project delivery process, and a support system composed of adjustment factors, grouped into managerial and technical issues, which aid managers in making timely decisions on renovation projects.

In developing this model, the conclusion was drawn that the Construction Management approach for procurement had distinct advantages in the delivery of the renovation product. In light of this observation, it was recommended that the CM's function emphasize early preparation as part of the preplanning or preconstruction phase of a project and include heavy owner involvement in early decision-making. It was deemed important to develop a critical overview of the project, firmly establish roles of the various key players as quickly as possible, and formulate the management plan which would become a driving force on the project toward completion.

A sample project management organizational structure was presented which graphically depicted the complex interrelationships of the various participants typically involved in the renovation process. In analyzing this type of a matrix structure, emphasis was placed on the ability to ascend the concept of management of a simple project to the management of a larger upgrade and improvement program which might involve several individual renovation ventures.

A global flowchart of the renovation process was developed based on existing management control system models. This flowchart highlighted the cyclical establishment and realization of control and success variables in performance tracking to attain overall plan accomplishment. Several specific examples were cited and related directly to actual renovation projects studied.

The chapter ended with the presentation of management adjustment factors in the form of a decision support system to help project managers by improving their understanding of issues critical to the completion of the renovation process. These generic factors were a direct extension and application of the findings of the Center Plaza report and the other renovation project studies performed by the author.

The traditional network analysis technique of CPM was reviewed in Chapter Four. Chapter Five identified considerations in renovation which can in no way be addressed by these conventional scheduling methods. A new Disturbance Scheduling Technique for use in scheduling renovation work was presented in Chapter Six. This new method and algorithm was offered for employment in conjunction with the conventional Critical Path Method. It was the result of extensive research and development and provided a systematic means of improving schedule preparation in the construction renovation field.

The Disturbance Scheduling Technique was presented in the form of a four phase operation. Phase One was the establishment of an initial, unconstrained logic network using conventional CPM. This was followed by an information gathering process which resulted in a prioritized list of disturbance activities. Phase Three was the application of the new algorithm to relax these disturbance cnstraints in sequential order, from most to least disruptive. Time scaling of the project calender was accomplished by introducing networking tools for scheduling overtime and weekend work periods. Computational procedures were presented for altering time estimates when scheduling periods of reduced construction. Objective rules for relaxing constraints to allow a facility to function at a pre-determined minimally operational level during renovation were offered. Work space and distance restrictions were resolved by integrating the use of the line of balance scheduling technique. Finally, under the new method, resource allocation was applied as a tertiary consideration in arriving at a total project plan.

Chapter Seven was an application of both CPM and the Disturbance Scheduling Technique to the Center Plaza improvement project. Finally, Chapter Eight was an analysis and comparison of this Disturbance Scheduled Network with the schedule used at Center Plaza during actual construction.

9.2 CONCLUSIONS

The final application and analysis of the Disturbance Scheduling Technique yielded exciting results. It was able to reduce the scheduled overall duration of the Center Plaza project to nearly one-third of the original estimate and substantially reduced several of the very critical and disturbing segments of the project. In addition, it accomplished the objective of scheduling completion of the most disruptive parts of the work very early in the construction cycle and in a concurrent fashion which resulted in a minimum length of duration. The Disturbance Scheduling Technique also provided an objective rationale for applying resource constraints to this complex project, something that was unattainable with conventional methods short of assigning arbitrary phases to the work performance.

The Disturbance Scheduling Algorithm is an innovative concept which results in an improved project flow and attains results that would be desirable on any major renovation effort, namely accomplishment of the work in the shortest amount of time while imposing an assault on the facility only to a level which allows daily functions to continue.

In many ways the Disturbance Scheduling Algorithm is similar to resource constraining algorithms in its objectivity in the choice of activity movement within the overall network. It also includes specific techniques and examples that were gathered from scheduling experts in the field and have been proven through actual experience.

A desirable characteristic of the Disturbance Scheduling Technique is in its relative simplicity and ease with which it was applied to an actual test case. Anyone who understands fundamental CPM scheduling can learn and apply the Disturbance Scheduling Technique to their particular renovation situation. Actual employment of the disturbance scheduling rules only require about 25% more time in schedule preparation. This increased planning time is more than offset by the advantages afforded by the final Disturbance Scheduled Network in better managing the project through construction.

Many of the issues which were presented as part of the Disturbance Scheduling Technique are often recognized but not thoroughly understood in the construction industry. This thesis often criticized planners in the field for not using more advanced network analysis techniques, when in fact, most of the time the reason they were not using them was because they did not work and provided no structure for imposing disturbance constraints upon an overall network logic plan. By providing this much needed format, "disturbance scheduling" encourages the project planner to be more mobile, yet systematic in his thinking and examine all of the factors which play a part in the course of a project. In a global sense, the Disturbance Scheduling Technique provides for an assessment of the situation, followed by a formulated plan of attack.

It is interesting to note that the steps of the Disturbance Scheduling Technique are in no way limited to applications in the occupied building renovation field alone. The process is generic enough for application in a number of disciplines and could substantially improve scheduling in a wide variety of areas. Two striking examples might include the renovation of highway and transit systems which must operate throughout construction, and water distribution systems and sewage network upgrades which must continue to provide a needed service throughout any infrastructure improvement program.

9.3 AREAS OF FUTURE RESEARCH

The preceding conclusions lead directly to a few areas where additional or future research is required in refining and extending the Disturbance Scheduling Technique. These areas include:

- Further application of the Disturbance Scheduling Technique to other renovation projects for testing purposes and to refine the way the procedure is applied. As noted above, this should include renovations in areas much broader than simply occupied commercial building facilities.

- Development of an automated scheduling system for incorporating the Disturbance Scheduling Technique. The systematic procedure of the new algorithm lends itself to this type of an automated application. This could be in the form of a completely new project management software package, or the integration of the Disturbance Scheduling Technique with current project management software programs with an option of imposing disturbance constraints on particular projects when desired.

- Development of a knowledge based expert system that captures the engineering judgement of renovation project managers and the information assembled in this thesis concerning (1) the managerial and technical issues identified as critical to the renovation process, (2) generic adjustment factors which aid in the management decision making process, and (3) scheduling rules which provide for a more efficient flow of the overall renovation project plan.

The renovation and improvement of civil facilities is an exciting and rapidly growing part of the construction industry. It is intended that this thesis add substantial insight into the undertaking of these projects and hopefully significantly improve the scheduling and completion of this work.

APPENDIX A

ACTIVITY LIST WITH TIME/RESOURCE ESTIMATES

Activity	Crew Size	Duration
ELEVATORS (1,2,&3CP)		
Shop Drawings	1 Architect	8 days total
Remove from Service/ Dismantle Cabs	5 Crews-1 Electr/ 2 Gen'l Labor each	.25 day/cab/crew 1 day total
Install New Lighting and Fixtures	3 Crews- 2 Electricians each	.5 day/cab/crew 2.5 days total
Prefab Panels/Ceiling	3 Crews- 2 Carpenters each	3 days/cab/crew 15 days total
Install Panels/Ceiling	3 Crews- 2 Carpenters each	1 day/cab/crew 5 days total
Install Carpet	3 Carpet Layers	.5 days/cab/lyer 2.5 days total
Finish Work-Install Hardware/Handrails	3 Crews- 2 Finishers each	.2 days per cab 1 day total
Reconnect Service	5 Electricians	.1 day/cab/elect 1 day total
FACADE LIGHTING		
Coring	2 Corers	.5 days/fixture 13 days total
Electrical Rough-in	3 Electricians	.5 days/fixture 13 days total
Framework Installation/ Fixture Attachment	4 General Laborers	.5 days/fixture 13 days total
Electrical Finish	2 Electricians	.25 days/fixture 7 days total
1 CENTER PLAZA LOBBY (NORTH)		
Assemble/Install Scaffold	6 General Laborers	6 days
Temporary Barricade	2 Carpenters	2 days
Temporary HVAC	2 HVAC	2 days
Remove Glazing	4 Glazers	2 days
Aluminum Storefront Dissassembly	4 Glazers	2 days
Storefront Base/Flooring Removal	2 General Laborers	1 day
Ceiling Demo (w/asbestos removal)	3 Men	1 day
Remove Existing Lighting	2 Electricians	.5 days
Install New Storefront Curb/Base	2 Laborers	2 days
Install Alum Storefront	4 Glazers	4 days
Install Glazing	2 Glazers	4 days
Install Ext Stone Panels	2 Glazers	4 days
Electrical Rough-in	2 Electricians	7 days
Frame Ceiling	3 Carpenters	5 days
Wire Lathe and Plaster Ceiling	3 Plasterers	6 days

1 CENTER PLAZA LOBBY (NORTH) (cont.)

Electrical Finish/ Lighting Fixtures	2 Electricians	1 day
Paint Ceiling-Prime	2 Painters	2 days
Paint Ceiling-Finish	2 Painters	2 days
Interior Stone-Walls/Patch	2 Tile Setters	8 days
Floor Stone-Int/Ext w/staining	3 Men	11 days
Install New Fan Coil	2 HVAC	1 day
Millwork/Ceiling Soffit	2 Millworkers	2.5 days
Interior Finishes	4 Finishers	10 days
Elevator Refinish and Directory	2 Men	8 days
Remove Scaffolding	6 General Laborers	4 days
Clean Up	6 General Laborers	1 day

2 CENTER PLAZA NORTH AND SOUTH

Assemble/Install Scaffold	6 General Laborers	4 days
Temporary Barricade	2 Carpenters	2 days
Remove Glazing	4 Glazers	2 days
Aluminum Storefront Dissassembly	4 Glazers	2 days
Storefront Base/Flooring Removal	2 General Laborers	1 day
Remove Existing Lighting	2 Electricians	.5 days
Frame New Ceiling	3 Carpenters	6 days
Install New Storefront Curb/Base	2 Laborers	2 days
Install Alum Storefront	4 Glazers	4 days
Install Glazing	2 Glazers	4 days
Install Ext Stone Panels	2 Glazers	4 days
Electrical Rough-in	2 Electricians	4 days
Wire Lathe and Plaster Ceiling	3 Plasterers	6 days
Electrical Finish/ Lighting Fixtures	2 Electricians	1 day
Paint Ceiling-Prime	2 Painters	2 days
Paint Ceiling-Finish	2 Painters	2 days
Interior Stone-Walls/Patch	2 Tile Setters	8 days
Floor Stone-Int/Ext w/staining	3 Men	6 days
Interior Finishes	4 Finishers	6 days
Elevator Refinish and Directory	2 Men	8 days
Remove Scaffolding	6 General Laborers	4 days
Clean Up	6 General Laborers	1 day

3 CENTER PLAZA PASSAGEWAY (NORTH)		
Install Staging (Fixed)	6 General Laborers	7 days
Temporary Barricades	2 Carpenters	6 days
Remove Existing Lighting Fixtures	2 Electricians	1 day
Frame Ceiling (Exterior)	4 Carpenters	12 days
Electrical Rough-in (Ext)	2 Electricians	9 days
Wire Lathe and Plaster	5 Plasterers	9 days
Electrical Finish/Lighting Fixtures (Exterior)	2 Electricians	3 days
Paint Ceiling-Prime (Ext)	3 Painters	3 days
Paint Ceiling-Finish (Ext)	3 Painters	3 days
Remove Glazing	4 Glazers	2 days
Aluminum Storefront Dissassembly	4 Glazers	2 days
Storefront Base/Flooring Removal	2 General Laborers	1 day
Install New Storefront Curb/Base	2 General Laborers	2 days
Install Alum Storefront	4 Glazers	4 days
Install Glazing	2 Glazers	4 days
Install Ext Stone Panels	2 Glazers	4 days
Electrical Rough-in (Int)	2 Electricians	4 days
Frame Ceiling (Interior)	3 Carpenters	6 days
Wire Lathe & Plaster(Int)	3 Plasterers	6 days
Electrical Finish/Lighting Fixtures (Interior)	2 Electricians	1 day
Paint Ceiling-Prime (Int)	2 Painters	2 days
Paint Ceiling-Finish (Int)	2 Painters	2 days
Interior Stone-Walls/Patch	3 Tile Setters	8 days
Floor Stone-Int/Ext	3 Men	6 days
Interior Finishes	4 Finishers	6 days
Remove Staging	6 Laborers	6 days
Clean Up	6 Laborers	2 days
3 CENTER PLAZA LOBBY (SOUTH)		
Temporary Barricades	2 Carpenters	6 days
Remove Existing Lighting/ Fixtures	2 Electricians	1 day
Ceiling Demo	7 Laborers	4 days
Isolate and Disconnect HVAC	2 HVAC	.5 days
HVAC Demolition	2 HVAC	2 days
Rough-in HVAC	3 HVAC	5 days
Floor Demolition	5 Laborers	6 days
Rough-in Electrical	2 Electricians	11 days
Floor-Install Leveling Bed/Compaction	4 Tile Setters	6 days
Interior Stone-Floor w/acid bath	4 Tile Setters	15 days
Rough-in Sprinkler	2 Sprinkler Cont	3 days
Frame Ceiling/Walls	3 Carpenters	11 days
Wire Lathe and Plaster Ceiling	5 Plasterers	8 days
Remove Glazing	4 Glazers	2 days

3 CENTER PLAZA LOBBY (SOUTH) (cont.)

Aluminum Storefront Dissassembly	4 Glazers	2 days
Storefront Base/Flooring Removal	2 Laborers	1 day
Install New Storefront Curb/Base	2 Laborers	2 days
Install Alum Storefront	4 Glazers	4 days
Install Glazing	2 Glazers	4 days
Install Ext Stone Panels	2 Glazers	4 days
Electrical Finish/ Lighting Fixtures	2 Electricians	3 days
Paint Ceiling-Prime	3 Painters	3 days
Paint Ceiling-Finish	3 Painters	3 days
Interior Stone-Walls	3 Tile Setters	8 days
Interior Finishes/Millwork	2 Millworkers	6 days
Elevator Refinish and Directory	2 Men	8 days
Remove Staging	6 Laborers	6 days
Clean Up	6 Laborers	2 days

HANDICAP BATHROOMS (1,2, & 3 CP)

Demolition	4 Laborers	6 days
Masonry	2 Masons	7 days
Repair Ceiling	3 Plasterers	6 days
Plumbing Rough-in	2 Plumbers	9 days
Grind Floor	1 Man	2 days
Ceramic Tile-Walls/Patch	2 Tile Setters	3 days
Ceramic Tile-Floors	2 Tile Setters	7 days
Plumbing Finish	2 Plumbers	5 days
Toilet Partitions/Access	2 Plumbers	4 days
Doors/Hardware	2 Carpenters	4 days
Wood Trim/Clean Up	2 Men	3 days

MULTI-TENANT LOBBIES (2nd, 5th, and 8th floors)

Remove Carpet/Doors	3 Laborers	1 day
Asbestos Removal	3 Men	2 days
Install Temporary Electrical Power	2 Electricians	.5 day
Demolition and Clean Up (to include HVAC & Elect)	4 Laborers	3 days
Partition and Stud Layout w/approval	3 Drywall	1 day
Drywall-Studs	4 Drywall	6 days
Drywall-Sheetrock	4 Drywall	7 days
Frame Ceiling	3 Carpenters	5 days
Taping and Plaster	1 Man	5 days
Door Frame Installation	2 Carpenters	1 day
Door Hardware Install	2 Carpenters	1 day
Accoustical-Grid	1 Man	4 days
Accoustical-Tile	1 Man	3 days
Paint-Prime	2 Painters	3 days
Paint-Finish	2 Painters	3 days
Grind Floor	1 Man	2 days
Install Ceramic Tile	3 Tile Setters	5 days

MULTI-TENANT LOBBIES (2nd,5th, & 8th floors)

HVAC Rough-In	3 HVAC	3 days
HVAC Finish	3 HVAC	5 days
Millwork Fabrication	4 Millworkers	15 days
Millwork Install	4 Millworkers	7 days
Electrical Coring	2 Corers	2 days
Electrical Rough-in	2 Electricians	6 days
Electrical Lighting and Finish	2 Electricians	6 days
Flooring Carpet and Baseboard	2 Carpet Layers	6 days
Sprinkler Rough-in	2 Sprinkler Cont	5 days
Sprinkler Finish	2 Sprinkler Cont	4 days
Refinish Elevator Doors	2 Men	6 days
Clean Up	6 Laborers	1 day

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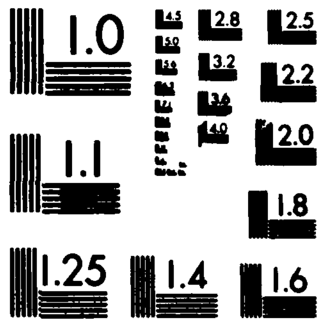

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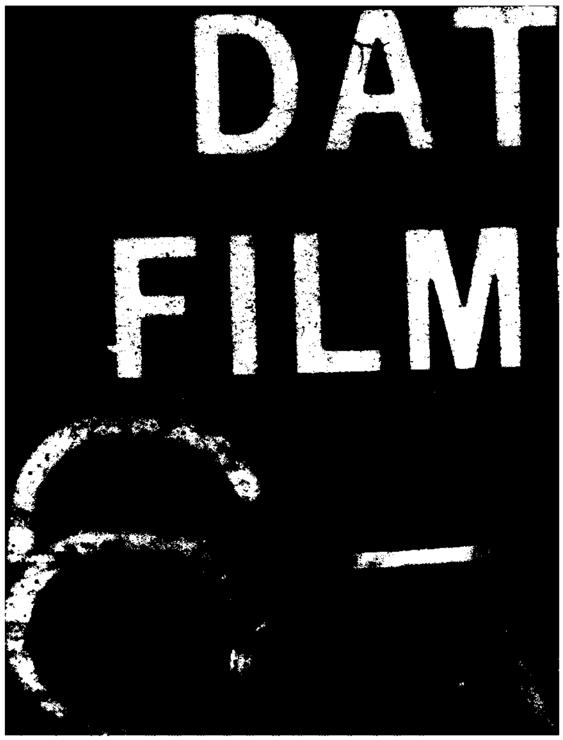
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