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THE CRITICAL PATH METHOD AND SCHOOL BUILDING CONSTRUCTION: A CASE STUDY

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ABSTRACT

The purpose of this study was to examine the usefulness of CPM for planning and scheduling a school building construction project. The study focused on the advantages and disadvantages of using CPM. Selected literature relating to systematic planning and control techniques was reviewed and several methods were studied and compared.

This was a case study of a 30,000 square foot addition, as well as some renovations and conversions, to an existing collegiate building at Ste. Rose du Lac, Manitoba.

The contractor's progress schedule, which is included, was converted into a CPM network diagram. Although the network diagram was not used as the main schedule, it was used to compare the progress of the project based on the contractor's conventional model. The CPM diagram was also used to determine what advantages were to be gained from its use. Several interviews and discussions were held with the architect and general contractor during which their findings and opinions were sought. Both types of schedules were analyzed and evaluated.

From the study it was determined and concluded:

(1) that there are distinct advantages to be gained and benefits to be derived from the use of

CPM in planning and scheduling a school building construction project

(2) that various difficulties might have been avoided if CPM had been applied

(3) that there are various reasons why CPM is not used more widely by general contractors, and

(4) that there can be disadvantages to using CPM if it is not well planned and properly administered.

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THE PROBLEM

INTRODUCTION

School officials can experience various types of difficulties if school building construction projects are not planned carefully and adequately. These difficulties can be the result of several factors including: inaccurate information used in planning; bad breaks during a project; mishandling of responsibilities by subordinates; and unusual developments. Whatever the causes, the results are generally the same: frustrations and cost over-runs.

To deal with these frustrations and to prevent higher costs the project manager must be able to monitor a project at any stage and be able to determine progress in relation to his plan at all times. Unless he knows just how his project is progressing, he may readily find himself in a position where he may not be able to recapture lost time, even with the allocation of extra resources.

Two systematic management and control techniques have been developed which will enable the project manager to monitor the implementation of plans. They are the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM). Both have demonstrated their effectiveness.

PERT was devised to minimize production delays, interruptions and conflicts. Its purpose is to co-ordinate and synchronize the various parts of the overall job and to permit work that is orderly and controlled. It is a method of scheduling and budgeting resources so as to accomplish a job on schedule. PERT was developed with an emphasis on the control of time, and less concern for resources than CPM. It is especially suited for dealing with non-repetitive or one of a kind projects.

CPM was designed for the purpose of planning, scheduling and controlling time and resources, both of which are very important considerations to administrators. It is particularly useful when dealing with a repetitive type of project, where past experience can be an invaluable guide.

CPM can be used to deal with various types of problems. It is different from conventional project control methods in that it separates the planning and scheduling functions. The CPM involves four phases:

1. Planning: the clear identification and definition of all component activities and the arrangement of them in a logical sequence,

2. Scheduling: the development of detailed work schedules for each activity which incorporate the best allocation of resources and identifies those sequences of activities which may hinder the successful completion of the whole project,

3. Monitoring: the periodic, timely review of

the actual completion of individual activities in comparison with their scheduled completion, and

4. Forecasting and replanning: the prediction of the influence of past actual completion data on future performance in such a manner as to facilitate effective replanning of activities still to be performed.

The differences (which will be dealt with in more detail in chapter 2) between the two are important. CPM brings in cost; it also places the user on firmer ground.

This study examined the usefulness of CPM in planning and scheduling school building construction.

PURPOSE

The purpose of this study was to assess the usefulness of CPM for planning and scheduling a school building construction project. This study focused on the advantages and disadvantages of using CPM.

To determine these advantages and disadvantages the following questions were considered:

1. Can the cost of planning and implementing CPM be justified by the results of its use?

2. What benefits, if any, are there to be derived from breaking down the various activities involved in a construction project into a network diagram?

3. Can CPM assist in dealing with problems and avoiding difficulties that may arise?

4. What are the implications for the respective

parties involved in a project to which CPM is applied?

5. Can CPM enhance the setting of realistic deadline dates and length of work units? If so, is there any value to be derived from doing so?

6. Are there any decided advantages to using CPM as opposed to a conventional schedule?

7. Are there any disadvantages to be suffered by utilizing CPM?

SIGNIFICANCE

This study has both practical and theoretical value. The practical value lies in the solution School Divisions may find to the common problem experienced in school building construction.

At present, many School Divisions experience prolonged delays in construction projects. It is apparent that more effective controls must be exercised over planning and scheduling of school building construction. Unless these controls are exercised and bring about positive results, prolonged delays in construction, along with their resulting costs, will invariably continue.

School officials, architects and contractors are seeking means to improve management controls. Failure to utilize available resources properly can result not only in inconveniences caused by delays, but also in associated costs such as: preparing for and holding staggered sessions in existing schools; renting other space; administrator's time; and delays in enjoying advantages of certain programs.

In addition to the above costs, there is danger of misdirecting extra resources (extra manpower or finances) to areas of a project that may not be critical or that may not enhance the chances of completing a building within a scheduled period of time. It is only through proper planning and periodic review by means of some technique like CPM that we can ensure best utilization of extra resources. A good management technique should assist in predicting trouble spots and in alleviating problems arising from them.

The theoretical value of this study lies in the fact that few, if any, studies have assessed CPM. There are only exhortations available, but no actual case studies to see how CPM can work in particular situations.

DESIGN OF STUDY

This study was a case study designed to illustrate and assess the application of CPM to school building construction. The case dealt with a 30,000 square foot addition to the high school at Ste. Rose du Lac, in the Turtle River School Division Number 32. The addition provides three teaching areas of a semi-open area type, three laboratories, a Home Economics room, a gymnasium, a conventional type classroom and a resource centre. The existing gymnasium was converted into an Industrial Arts area while three existing classrooms were developed into a Business Education centre. The existing facility plus the addition cover over 40,000 square feet and accommodate approximately 400 students in grades seven through twelve.

The presentation and analysis of information is in three stages:

1. Initial Stage. The original plan and schedule as submitted by the contractor is described and translated into a network diagram. CPM is also described and illustrated and then both techniques compared.

2. Actual Stage. This involves describing what really happened as the project progressed and indicates why it became necessary to replan in order to meet the anticipated completion date.

3. Review Stage. This features a comparison of the first two stages to determine the value that may be derived from the use of each type of schedule. The evaluation is based on the actual findings along with the opinions of the contractor and architect as reflected in the interviews carried out with them and the correspondence exchanged.

When this study was first being considered it became evident that it required the involvement and co-operation of both the architect and general contractor. Mr. H. A. Perrin, architect, then of Winnipeg, Manitoba and now of Victoria, British Columbia, and Mr. W. Hoffman, of Hoffman Construction of Minnedosa, Manitoba, expressed their interest and gave their consent to co-operate in this project.

At the beginning of the building project the contractor submitted an estimated progress and time schedule. This estimate was based on his experience in the field. As the building project progressed a record of activities and events was kept. This made it possible to compare completion dates, to identify reasons for variance and to describe what steps were taken in an attempt to overcome difficulties.

This study was based on manual calculations; a computer was not used.

LIMITATIONS

This study was based on a single case and on one CPM estimate of project time and cost. This limited the generalizability of the findings.

This study was confined essentially to the building stage rather than the total scope of construction which would have included the prebuilding phase. Although the prebuilding phase of a project may be more easily scheduled and time controlled, this may, however, have limited the conclusions drawn.

The application of the CPM technique was restricted to school building construction. The results may not apply to other types of school programs, for example, programming and maintenance.

The rural setting of the project in this case study might have had certain implications that are unique to rural areas and might not be applicable to urban settings, that is availability of trades and proximity to sources of supply.

ASSUMPTIONS

This study was based on the following assumptions:

1. This project is a typical one of school construction.

2. The suggested or initial time schedule provided by the contractor is also a typical one based on experience.

3. The architect and contractor would continue their support of this study to the completion of the construction project.

DELIMINTATIONS

This study concerned itself basically with time and resources since direct capital cost of school buildings, as a rule, is established before construction commences. It was based on one cost estimate only; CPM was not used to generate alternative cost estimates.

DEFINITION OF TERMS

For the purpose of this study the following definitions will apply:

Project Network: This is a graphical representation of a project plan, showing the interrelationships among the various activities that form parts of a total project. It is formed by depicting activities as arrows and events as nodes. When time estimates have been added to a network, it may be used as a project schedule.

CPM: The Critical Path Method is a project planning and control technique that involves developing a network model; the longest path through the model is known as the critical path of events. The critical path is the longest chain of events required to be completed in a project and is the longest minimum time of the whole project. In other words, the critical path is that series of activities which indicates the most time consuming path through the project. It can, in some cases, be shortened by increasing the resources, but not likely without increasing the cost.

Initial Time Schedule: The term "initial schedule" refers to the submission made by the contractor, estimating the time he felt would be required to complete each of the activities of the project. It indicates those activities that overlap and others that can be carried on concurrently.

Milestone: This is a term used to identify certain stages in a project, indicating completion of an activity or job. It enables the manager to identify what phase a project is at and thus serves as a checkpoint.

ORGANIZATION

Chapter 2 presents a critical review of some selected literature. It deals briefly with the conventional progress schedule and the Gantt Method. This is followed by a brief history of CPM and PERT and their related characteristics. It then goes on to compare CPM and PERT, describe their application and discuss their limitations.

Chapter 3 includes a discussion of the different stages of planning, a glossary of terms commonly used, basic ground rules applicable to CPM, and the development of a sample network.

Chapter 4 contains a copy of the original plan and schedule as submitted by the contractor. This in turn is converted into a network diagram which is included, and both types of schedules are compared.

Chapter 5 features a review of what actually happened during the building phase, what difficulties were encountered and what modifications had to be made to the original plan. Included in this chapter are also evaluative comments and an analysis of the events.

Chapter 6 contains a discussion of the major findings.

Chapter 7 concludes the study with a general summary of the major findings, the conclusions drawn, a number of recommendations, and several suggestions for further study.

CHAPTER II

REVIEW OF LITERATURE

Management has, over the years, experienced continual difficulties in the execution of projects without over-extending either cost or time limitations. Most projects are started well after the need has been established, seeming to follow the whimsy, "if I'd wanted it tomorrow, I'd have asked for it tomorrow." School Business Officials charged with the responsibility of construction of school buildings are constantly faced with this problem -- how to assure the completion of construction on a certain date previously estimated and established.

There is general agreement that a large majority of school projects are not completed on time. Much of this is due to the fact that the usual method of checking progress is either inadequate or the information is lacking. Under such conditions there is a tendency to increase the time for the completion of a school building, and when a minor delay does occur, to again extend the time scheduled for completion. If the delay is the contractor's fault, he will generally offer many excuses by either blaming the Board or one of the other prime contractors. It is really not important whose fault it may be; what is important is to be able to identify where delays may be or are occurring and to overcome these before it is too late.

Careful planning may enable management to overcome these difficulties and to achieve some flexibility in re-allocating time and resources. Further, it is quite obvious that unless management can identify possible delays and resolve these difficulties, it can be caught completely unawares. Effective planning and control techniques are apparent solutions to such problems.

Much has been written over the years with regard to the different techniques that have been developed in an attempt to overcome the difficulties experienced in project management. Yet it was until very recently that each project manager had only his own scheme which he adapted to his own purpose; there was no generally accepted formal procedure to draw on. However, a number of techniques have evolved since World War I, and now seem ready for general application.

While chapter 3 will present a detailed description of CPM, along with examples of its use, this chapter will briefly summarize and analyze the origin, characteristics, applications and advantages and disadvantages of four such techniques, namely: conventional progress schedule; Gantt; PERT; and CPM. It will deal with: (1) the conventional progress schedule, (2) the Gantt Method, (3) network techniques, (4) PERT, (5) CPM, (6) a comparison of CPM and PERT, (7) applications of CPM and PERT, and (8) some limitations of the two techniques.

CONVENTIONAL PROGRESS SCHEDULE

The conventional progress schedule is a basic planning and control technique that has been used by project managers over the years. There is no specific format that is generally followed and it is usually adapted by the user to fit his own needs.

It is comprised mainly of a listing of dates or times for the various phases of a project. There is very little breakdown of the activities which comprise the project and quite often an overlap of the various jobs with respect to the time during which they are to be carried out. The activities are listed only in general terms rather than broken down into specific tasks.

The conventional progress schedule is less sophisticated than the Gantt chart. It does not give any graphic representation of the requirements to be fulfilled let alone suggest any diagram for a network. In essence it is merely a listing of the requirements as conceived by the project manager, matched with anticipated dates during which these requirements will be fulfilled and completed.

The progress schedule has certain advantages. The ease of preparation is perhaps the main one. Since it is basically a listing of the main activities as envisioned by the project manager or the general contractor, it does not require the detailed planning essential to more sophisticated techniques. The time required to prepare such a schedule would be very minimal as compared to one like CPM. It does not require the expertise of interpretation as would be necessary for a more scientific technique.

Its main disadvantage is its limitations. It does not enhance the ease of monitoring progress or identifying specific responsibilities. With the use of the progress schedule, these functions have to be carried out intuitively. It also becomes more difficult to identify potential trouble spots and to ensure the smooth flow of the necessary materials required.

The conventional progress schedule is, however, still quite widely used. It may well be suited to smaller projects where control can be "at a glance", but its application is questionable in larger and more sophisticated projects. Its continued and rather wide use may be partially due to contractors' reluctance to depart from a method that has served them for many years, and perhaps equally so attributed to the unfamiliarity with and apprehension of more modern techniques.

THE GANTT METHOD

The Gantt method, the first modern project planning technique, was developed in the context of a World War I military requirement. The procedure was designed to control the time element of a project. It basically depicted work to be done (in a bar graph) but did not denote the interrelationships among all the phases of this work.

Levin and Kirkpatrick[1] argue that the Gantt method had severe limitations. Even though it could show the relationship between two specific milestone events within a specific task, it failed to indicate any relationship between milestone events in the different tasks.[2] Nor could the Gantt chart answer such questions as: What would be the effect on the overall project completion date if a specific activity were delayed by x weeks? How much would it cost to reduce the overall time of completion by y weeks? What would be the probability of attaining a given schedule?[3]

Morris Liebeskind reinforces this claim when he says that the Gantt chart has been a failure in its use as an accurate and workable construction schedule. He says that the Bar Diagram (Gantt) is nothing more than a number of lines with a list of dates, showing when each major operation will start and the date when it will be completed. This is virtually of no use to the school official or contractor, as a tool that will indicate actual progress. Everything from it is a matter of implication and speculation. Interrelationships and co-ordination cannot be indicated. It is woefully inadequate as an instrument for use on

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[1]Richard J. Levin and Charles A. Kirkpatrick, Planning and Control with PERT/CPM (New York: McGraw Hill Book Company, 1966), p. 3.

[2]Ibid., p. 4.

[3]H. W. Handy and K. M. Hussain, Network Analysis for Educational Management (Englewood Cliffs: Prentice Hall Incorporated, 1969), p. 9.

change orders, assessment of liquidated damages, claims, lawsuits and modification of schedules.[1]

NETWORK TECHNIQUES

With the limitations of the Gantt method the need arose for other planning and control techniques. This need led to the development of the network diagram technique which is essentially an outgrowth of the bar graph. Moder and Phillips say that:

> The important features of a project network that are designed to correct the deficiencies of the bar graph are that: (1) the dependencies of the activities upon each other are noted explicitly, and (2) more detailed definition of activities is made.[2]

Desmond Cook identifies the first step for network systems as that of determining the project objectives. That having been done, the elements of the total project are identified and placed in some type of hierarchical order. Once the project definition phase involving analysis has been completed, the work breakdown structure prepared, the process of synthesis accomplished through the network procedure, and the time estimates completed, the essential steps of project planning have been accomplished. The result is a plan for the future -- a

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[1]Morris Liebeskind, "Critical Path Method," <u>Design and Construction of School Buildings</u> (Bethesda, Md.: E R I C Document Reproduction Service, ED 020 624, 1965), p. 155.

[2]Joseph J. Moder and Cecil R. Phillips, <u>Project Management with CPM and PERT</u>, 2nd ed. (New York: Van Nostrand Reinhold Company, 1970), p. 7.

network representation of the project tasks as they are to be accomplished in order to achieve the project objective. This plan then provides us with a means of managing the project to ensure the various tasks are being completed in proper sequence and that we are staying on our time target.[1]

The network diagram, which is the graphical representation of the project made up by combining the various component activities (the complete development which is illustrated in chapter 3), can prove invaluable to a project manager. The following are just a few of its advantages:

(1) it breaks down a project into its component parts, thus making the project much more manageable

(2) it shows the interrelationships between and among various activities

(3) it sensitizes management to potential trouble spots

(4) it serves as a visual aid to the planner

(5) it forces the planner to be logical, and

(6) it facilitates the communication process since plans are portrayed in a graphic manner

In one sense the network is only a graphical

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[1]Desmond L. Cook, Better Project Planning and Control Through the Use of Systems Analysis and Management Techniques (Bethesda, Md.: E R I C Document Reproduction Service ED 019 729, 1967), p. 12.

representation of a project plan which may have previously existed in some other form -- in the minds of the project supervisors, in a narrative report, or in some other form such as a bar chart. In practice, however, the preparation of the network usually influences the actual planning decisions and results in a plan that is more comprehensive, contains more detail and is often different from the original thoughts about how the project should proceed.

Thus the construction of a network often becomes an aid to and an integral part of project planning rather than an after-the-fact graphical exercise. Indeed the planning stage has proven to be the most beneficial part of the critical path applications.[1] Users often make significant improvements over their original ideas and do a better job of early co-ordination with other groups associated with the project. The end result is a documented plan that has strong psychological effects on the future management of the project. It demonstrates to the key personnel the co-ordination and timeliness of all project activities and that means of closely monitoring these factors has been drafted.

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[1] Joseph J. Moder and Cecil R. Phillips, Project Management with CPM and PERT, 2nd ed. (New York: Van Nostrand Reinhold Company, 1970), p. 21.

PERT

Although the network concept was developed in an evolutionary way over many years, it was not until 1958 when the United States Special Projects Office was faced with the challenge of producing the Polaris missile system in record time, that PERT was developed.[1] The Polaris project involved approximately 250 prime contractors and at least 9,000 sub-contractors; it required very systematic control to accomplish the immense task of co-ordinating all the activities. The challenging responsibility of developing a control technique was assigned to Lockheed Aircraft Corporation (prime contractor of Polaris), the Navy Special Projects Office, and the consulting firm of Booz, Allen and Hamilton.[2]

In the development of the Polaris system, time was the crucial variable. Regarding costs, one can only assume that cost varies directly with time; on this premise PERT can also control cost. However, in many instances a speed-up can be much costlier than would be resultant from a less concentrated effort.

A method had to be developed which would allow management to co-ordinate the efforts of all the firms, to anticipate the occurrence of bottlenecks, to forecast with reasonable certainty the extent to which target dates would

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[1] Ibid., p. 5.

[2] Ibid., p. 6.

be met, and to channel the efforts of literally hundreds of thousands of persons into a finished operational weapon. PERT evolved to meet these objectives.[1]

One of the principal features of PERT is a statistical treatment of uncertainty in the performance time of activities. It enables management to determine the probability of meeting scheduled dates at various stages of a given project. PERT also emphasizes the control phase of project management by requiring various forms of project status reports. Although the function of the original PERT team was to control time, the technique has now been extended into involving the planning and controlling of costs.[2]

CPM

CPM grew out of a joint effort initiated in 1957 by du Pont and Remington Rand Univac. The objective of the team was to determine how best to reduce the time required to perform routine of plant overhaul, maintenance and construction. The essence of their interest was to determine the optimum trade-off between time (project duration) and total cost. What this really amounted to was determining the duration of a project which minimizes the sum of the

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[1]Richard J. Levin and Charles A. Kirkpatrick, Planning and Control with PERT/CPM (New York: McGraw Hill Book Company, 1966), p. 8.

[2]Joseph J. Moder and Cecil R. Phillips, Project Management with CPM and PERT, 2nd ed. (New York: Van Nostrand Reinhold Company, 1970), p. 6.

direct and indirect costs, where the direct costs would include labour and materials and where the indirect costs might include such items as supervision and cost of time lost to shutdown.[1]

Moder and Phillips categorize the leading features of CPM under five main headings.

1. Planning. Control path methods first require the establishment of project objectives and specifications and then provide a realistic and disciplined basis for determining how to meet these objectives, with due consideration given to pertinent time and resource constraints. It not only reduces the risk of overlooking tasks which are necessary to complete a project but it also provides a realistic way of conducting more long-range planning of projects, including their co-ordination at all levels of management. Unless this is done, it may be reasonable to question how much may be taken for granted or overlooked, which may come to haunt management later.

2. Communication. Critical path methods can provide a clear and concise way of documenting and communicating project plans, schedules and time and cost performance.

3. Psychological. The critical path method, if properly developed and applied, can create and promote a team feeling. It can be useful in establishing

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[1] Ibid.

interim schedule objectives that are most meaningful to operating personnel and in the delineation of the various responsibilities. It can, however, lose value if used as a weapon against any of its participants. Its greatest potential lies in projects with several prime contractors, each jealous of his own rights, and unwilling to subordinate his schedule to any of the others.

4. Control. By identifying the most critical elements in the plan, the critical path method facilitates the application of the principle of management by exception. It focuses attention on the 10 - 20% of project activities that are most constraining on the schedule; it enables the manager to define schedules; and it shows the effects of technical and procedural changes on the overall schedule. CPM enables the manager to monitor the progress of the project at any given stage. This in turn can provide the opportunity for "trading off" time and cost and applying these trade-offs to critical areas. (A critical area being defined as one that can delay the completion date of the whole project).

5. Training. Critical path methods can be useful in training new management and in indoctrinating other personnel that may be connected with a project from time to time. It is agreed that experienced and supportive personnel can improve on their

functioning by the use of this technique.[1]

CPM may be defined as a technique which will assist school building officials to visualize the entire construction project clearly, so that immediate decisions can be made which will be in the best interests of the Board. This technique breaks down all the steps in the design and construction of a school building and arranges them into a specific logical order which takes into consideration the interrelationships and co-ordination of all parties. The monitoring and analysis of the progress reports which list all the activities, provide a basis for determining delays, so that decisions can be made accordingly.

In the planning stages of a new school building, an addition, or a modernization project, every step can be scheduled from the inception of the project to the completion of the building. All such scheduling and then the analysis of progress can be carried out by the use of CPM techniques.[2]

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[1] Ibid., p. 18.

[2] Morris Liebeskind, "Critical Path Method," Design and Construction of School Buildings (Bethesda, Md.: E R I C Document Reproduction Service, ED 020 624, 1965), p. 153.

A COMPARISON OF CPM AND PERT

It is important to note that both CPM and PERT are forms of project networking, and although developed separately and apart from each other, that there are distinct similarities between them. Of their own development Moder and Phillips write:

> It was not until 1957 - 1958 that project networking was formally defined concurrently by two research teams, one developing PERT and the other CPM.[1]

They go on further to say:

> In pioneering PERT and CPM the groups did not know of each other's existence until early in 1959, when the momentum of each effort was too great to influence the other. However, the underlying basis for both is the project network diagram.[2]

In his first volume of Project Management and Control Martino reinforces this when he writes:

> The basic elements of PERT and CPM are a network and a critical path. The network is a model of the project as a whole, created by linking together arrows representing specific jobs which must be done. The time required to perform each job is used to find the critical path, which is the longest chain from a project's beginning to its completion.[3]

Although CPM is not unlike PERT with relation to time, CPM adds a consideration of cost. Levin and Kirkpatrick point out that CPM makes two fundamental

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[1]Joseph J. Moder and Cecil R. Phillips, Project Management with CPM and PERT, 2nd ed. (New York: Van Nostrand Reinhold Company, 1970), p. 5.

[2]Ibid., p. 6.

[3]R. L. Martino, Project Management and Control, vol. 1: Finding the Critical Path (New York: The Comet Press Incorporated, 1964), p. 9.

departures from PERT:

1. CPM brings the concept of cost into the planning and control process, and

2. The CPM user is assumed to be on firmer ground when estimating the time required for the performance of each activity.[1]

These two differences can be significant in the case of a building construction project. Through repeated experience, fairly accurate time and cost estimates can be made and each activity performance can be treated in a deterministic manner. This is unlike dealing with uncertainties in non-repetitive projects (e.g. Polaris), which can only be approached in a probablistic manner. Moreover Robert Miller concedes that one of the short comings of PERT is that it deals in the time domain only.[2] He goes on to say that PERT is used most effectively in the area in which no two programs are ever exactly the same and no two individuals will have exactly the same approach to the development of a network.[3] Thus is becomes evident that CPM is the more logical choice for school building construction.

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[1]Richard J. Levin and Charles A. Kirkpatrick, Planning and Control with PERT/CPM (New York: McGraw Hill Book Company, 1966), pp. 120 - 121.

[2]Robert Miller "How to Plan and Control with PERT," in New Decision-Making Tools for Managers, ed: Edward C. Bursk and John F. Chapman (New York: The New American Library, 1963), p. 106.

[3]Ibid.

Levin and Kirkpatrick support these arguments when they say that:

> When time can be estimated fairly well and when costs can be calculated in advance, CPM may well represent the better of the two alternative control methods. On the other hand when there is an extreme degree of uncertainty and when control over time outweighs control over costs, PERT or one of its variants may well represent the better choice.[1]

To illustrate the major difference in the use of the two techniques Levin and Kirkpatrick contrast as an example two firms, a construction company with a research and development company. An intelligent estimator for a construction company can give accurately an estimated cost and time figures on the basis of this type of work being done before. On the other hand, a project director of a recently launched spacecraft is involved with work never done before and the range of possible technical problems is so immense that time estimates may be little more than guesses.[2]

While a manager of a research project might prefer and be required to control time only and be in a position to let costs go uncontrolled, this is something that a construction company can ill afford to do. By using the Critical Path Method to identify possible trouble spots with relation to time, the construction company could redirect its resources in such a manner that neither time

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[1] Richard J. Levin and Charles A. Kirkpatrick, <u>Planning and Control with PERT/CPM</u> (New York: McGraw Hill Book Company, 1966), p. 121.

[2] Ibid.

nor cost are likely to suffer.

APPLICATION OF PERT AND CPM

Explicit in both techniques and fundamental to them are three managerial functions:

1. Planning. The listing of tasks or jobs that must be performed and determining requirements of materials, equipment and manpower. In this phase estimates of costs and durations for the various jobs are also made.

2. Scheduling. The laying out of actual jobs in the time order in which they have to be performed and calculating manpower and material resources required as well as expected completion time of each of these jobs.

3. Control. This managerial function which begins with reviewing the differences between schedule and actual performance and analyzing and correcting these differences as the project progresses. The analysis and correction of these differences forms the basic aspect of control.[1]

Research and development programs range from pure research to design and production engineering. While PERT is most useful in the middle of this spectrum,

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[1] Jerome D. Wiest and Ferdinand K. Levy, A Management Guide to PERT/CPM (Englewood Cliffs: Prentice Hall Incorporated, 1970), p. 3.

variations of it are being used in the production end. PERT is not particularly suited to pure research, and perhaps should be avoided as it may stifle ingenuity and imagination, both of which are the keystones of success in pure research.

CPM is basically concerned with obtaining the trade-off between cost and completion date for projects. It emphasizes the relationship between applying more men or other resources to shorten the duration of given jobs in a project and the increased cost of these additional resources. With CPM the amount of time needed to complete various facets of a project is assumed to be known with some certainty; moreover, the relation between the amount of resources employed and the time needed to complete the project is also assumed known. Thus while CPM is not concerned with uncertain job times PERT deals with time-cost trade-offs. Because of these differences PERT is used more in research and development projects while CPM is used in projects such as construction, where there has been some experience in handling similar endeavours.[1]

Despite the fact that maintenance and shutdown procedures (the area in which CPM was initially developed) continue to be productive areas for application of CPM, construction type projects continue to be able to evaluate alternate project plans and resource assumptions on paper

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[1]Ibid. p. 2.

rather than in mortar and bricks.[1]

Although widely diverse kinds of projects lend themselves to analysis by either PERT or CPM, the construction industry has several well defined characteristics that make it especially suited to such analysis, with CPM being the logical choice. Three such characteristics are:

1. Construction projects consist of well defined jobs, or activities, which when completed, mark the end of the project.

2. The jobs may be started or stopped independently of each other, within a given sequence.

3. The jobs are ordered, that is, they must be performed in technological sequence.[2]

In addition to the numerous application possibilities, is should be emphasized that once a technique is chosen, it should be very useful for monitoring and control.

LIMITATIONS OF CPM AND PERT

Some practitioners who have had the experience of applying the CPM and PERT models to project management

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[1]Joseph J. Moder and Cecil R. Phillips, Project Management with CPM and PERT, 2nd ed. (New York: Van Nostrand Reinhold Company, 1970), p. 17.

[2]Jerome D. Wiest and Ferdinand K. Levy, A Management Guide to PERT/CPM (Englewood Cliffs: Prentice Hall Incorporated, 1970), pp. 2 - 3.

claim that there are definite limitations of their use, based on the assumptions which underly each one of them. Let us examine three of these assumptions and their implications:

1. That a project can be subdivided into a set of predictable, independent activities. While it is not unreasonable to assume that the activities of which a project is comprised can be known beforehand in such projects as building construction, it is not necessarily true for research and developmental projects.

2. That the precedence relationships of project activities can be completely represented by a graph in which each activity connects directly to its successor. Although for many types of projects (of which building construction is again a prime example) this may be valid; there are situations such as research where not all precedence relationships can be determined before the project begins since some activities may be contingent upon the outcome of previous ones.

3. That activity times may be estimated. Once again these can be assumed fairly accurately in construction but much less so in projects like research and one-of-a-kind projects for which there has been no precedence.[1] The above considerations would tend to indicate that since CPM is more suited to building construction, and while so

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[1] Ibid. pp. 127 - 129.

applied, its limitations would be lesser than those associated with the use of PERT as applied to one of a kind projects.

In a more general way, notwithstanding the numerous advantages of a project network, it is not to say that a project cannot and will not fail. Desmond Cook expresses two basic ideas: (1) that management systems are designed to provide information, and (2) that the decision making operation is left to the manager.[1] Levy and Wiest support this premise by saying that when wisely used by a project manager who understands the strengths and limitations of project networking, the technique can be an effective amplifier of his managerial skills.[2] It follows then from these basic ideas that systems are primarily aimed at facilitating the control functions of a given manager's job, not doing it for him. It is a tool useful to planning but does not plan in and of itself. Cook contends that "It will only reflect the degree of planning that is present in the minds of the planners."[3] Miller

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[1]Desmond L. Cook, Better Project Planning and Control Through the Use of Systems Analysis and Management Techniques (Bethesda, Md.: E R I C Document Reproduction Service Ed 019 729, 1967), p. 6.

[2]Jerome D. Wiest and Ferdinand K. Levy, A Management Guide to PERT/CPM (Englewood Cliffs: Prentice Hall Incorporated, 1970), p. 136.

[3]Desmond L. Cook, PERT Applications in Educational Planning (Bethesda, Md.: E R I C Document Reproduction Service Ed 019 751, 1966), p. 11.

reinforces this claim by saying that: "the usefulness of new management controls is no greater than the ability of management to act on the information revealed."[1] CPM is not a cure-all but a technique which, if applied properly, can be a very useful aid.

CONCLUSION

In this chapter an attempt has been made to provide a review of some of the literature related to managerial techniques and control tools. In so doing the strengths and weaknesses of the three techniques have been discussed along with the applications and limitations of network techniques.

The following chapter will provide a more detailed discussion of CPM and application of the technique. In the discussion will be included the related concepts, terms, definitions and mathematical rules. To illustrate these two hypothetical problems will be used, with a solution for each.

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[1]Robert Miller, "How to Plan and Control with PERT." in New Decision-Making Tools for Managers, ed: Edward C. Bursk and John F. Chapman (New York: The New American Library, 1963), p. 114.

CHAPTER III

THE CPM TECHNIQUE

The Critical Path Method is a management technique which has special characteristics and requirements and a terminology of its own. The purposes of this chapter are to: (a) review the basic requirements of CPM, (b) develop a glossary of CPM terminology, (c) describe the ground rules of the method, and (d) provide some examples of the use of CPM in construction projects.

BASIC REQUIREMENTS OF CPM

The essence of CPM can be summarized in the question "How can a job be completed on time?". CPM answers the question in three stages: (a) the planning stage, (b) the monitoring stage, and (c) the control and revision stage. This chapter will deal exclusively with the planning stage. The monitoring and control and revision stages will be discussed in subsequent chapters.

The first stage in the utilization of CPM is the planning stage. The planning stage deals with the logic and work sequence of the project. It involves: (a) the identification of all the activities which make up the project, (b) the specification of the relationships among the activities, and (c) the development of a time schedule for the completion of the activities and the total project. This phase is limited by two basic principles: (a) the planning and scheduling functions are to be treated separately, and (b) the sequence of activities must be known and specified.

The results of the planning phase are depicted in an arrow diagram, or in a flow chart of the activities of the project. There are several simple but essential steps in drawing an arrow diagram. These steps represent planning in the CPM technique. The steps can be described in terms of the following questions:

1. What are the activities that make up the project?
2. What immediately precedes a particular activity?
3. What immediately follows a particular activity?
4. What activities are not sequential but can be done concurrently?

A CPM GLOSSARY

CPM has a terminology of its own. An understanding of this terminology is basic to understanding the method and how it can be used. Some of the more important terms are defined below.

Activity: A discernible, time consuming part of a project which requires resources and is the smallest unit of work in a project. It is illustrated by an arrow.

Activity Duration (t_e): An estimate of time required to perform the activity, derived from a study of the activity and given by the most reliable sources.

Backward Pass: The reverse (right to left) computation of the latest allowable event occurrence time (T_L) for each event, starting with the final event.

Burst Point: Single events which have several activities succeeding them as follows:

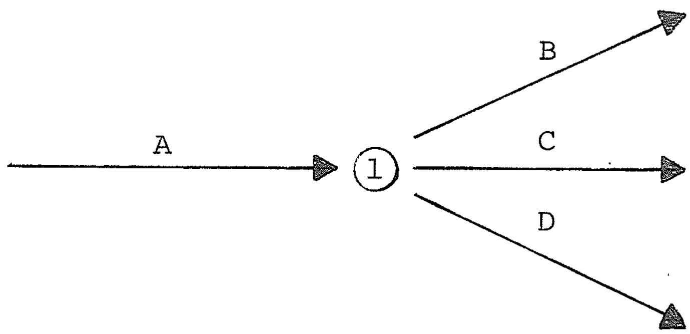

Fig. 1. Burst Point

Critical Path: The critical path of a project is that series of activities which indicate the most time consuming path through the project. This will be illustrated later on.

Dummy Activity: A network activity which represents a constraint (e.g. the dependency of a succeeding event on a predecessor) but which does not have activity time or require any resources. It is shown by a broken line.

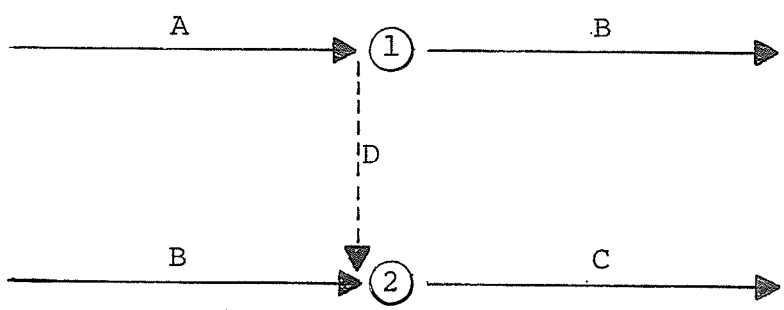

Fig. 2. Dummy Activity

D illustrates that C depends on the completion of both A and B while E can begin after the completion of A only. If a dummy activity was not used our diagram would be as shown in Fig. 3., which would be false since E does not depend on the completion of B.

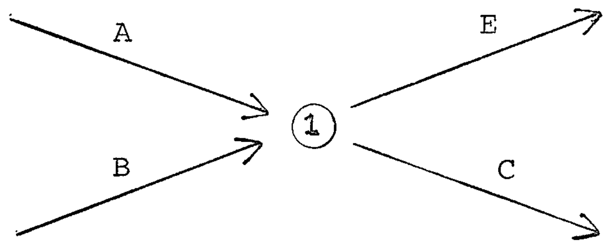

Fig. 3 Diagram showing false interdependencies of activities in the absence of a dummy activity.

Earliest Event Time (T_E): The earliest time at which all activities arriving at a node are completed and the event takes place.

Earliest Finish Time (EF): The earliest time at which an activity can be completed.

Earliest Start Time (ES): The earliest time at which an activity can begin.

Event: The point at which all activities arriving at a node are completed and the event takes place as illustrated by 1.

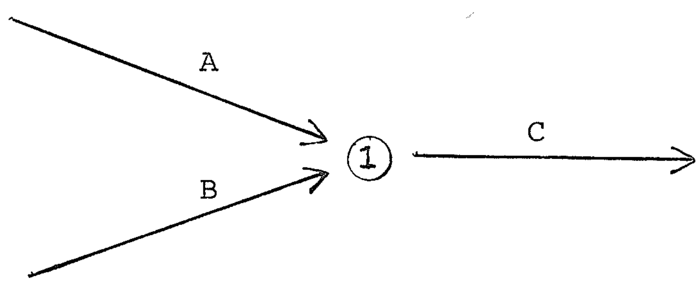

Fig. 4. Illustration of when an event occurs

Float (or Slack): The amount of time that the activity completion time can be delayed without affecting the start or occurrence time of any activity on this critical path.

Forward Pass: The forward (left to right) computation of the earliest expected time for each event (T_E), starting with the first event.

Latest Event Time (T_L): The latest time at which all activities arriving at a node must be completed to avoid delaying the project.

Latest Finish Time (LF): The latest allowable time by which an activity must be completed to avoid delay down the line.

Latest Start Time (LS): The latest allowable time by which an activity must be started to avoid any delay later on.

Merge Point: An event which is a terminal point for several preceding activities as indicated by 1.

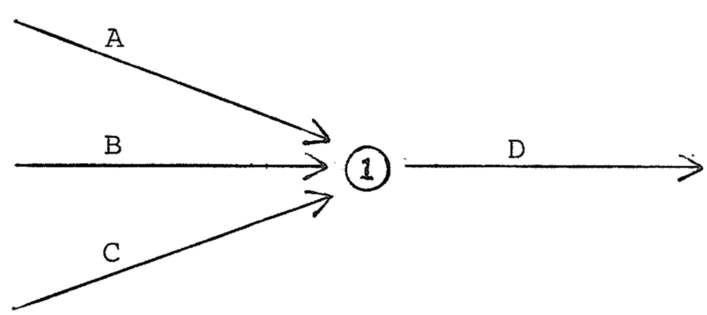

Fig. 5. Merge Point

Scheduling: The process by which the time element is applied to a network and the critical path determined.

THE GROUND RULES OF CPM

CPM is a logical procedure for project planning. It has definite rules, especially concerning the development of the arrow diagram which is the graphical representation of the plan. This section reviews some of the rules of CPM.

Network Rules

1. Each activity is represented by an arrow and each event by a node.

2. Arrows imply logical procedure only, and neither their direction nor their length has any significance.

3. All activities arriving at a node must be completed before work can commence on any activity leaving that node.

4. Any two events can be connected by no more than one activity.

5. Event numbers must not be duplicated in a network.

6. Networks may have only one initial event (with no predecessor) and only one terminal event (with no successor). (It should be noted that rules 4 - 6 apply only to some computer programs but are not required for methods of hand computation).

In order to determine the critical path it is necessary to identify the longest time path through the network. This is done by both forward and backward passes to establish earliest finish and latest start times for activities. There are three important rules to be followed in each of them.

Forward Pass Rules

1. Earliest occurrence time of initial event is taken as zero. Initially, T=O.

2. Each activity begins as soon as predecessor event occurs.

3. Earliest event occurrence time is largest of the finish times of the activities merging to that event, e.g. T_E=Maximum of EF_1, EF_2 - - - - EF_n for event with n merging activities.

Backward Pass Rules

1. Latest allowable occurrence time of final event is set equal to earliest occurrence time computed in forward pass, e.g. $T_L=T_E$ (final).

2. Latest allowable start time for activity is latest allowable start time for its successor event minus duration time of activity in question.

3. Latest allowable time for event is smallest of latest allowable start times of the activities bursting from event in question, e.g. T_L=minimum of LS, LS_2 - - - -LS_n for event with n bursting activities.

Drawing a Network Diagram

There are several basic procedures to follow in diagramming a network.

1. Itemize all activities required to complete the task at hand.

2. Establish a logical sequence of these activities.

3. Consider each activity by itself with relation to the total project.

4. Identify those activities which can be carried on simultaneously.

5. Proceed from left to right and avoid crowding.

6. Sketch out trial layouts before drawing network in finished form.

7. Observe the network rules as given.

EXAMPLES

At this stage it would be useful to attempt to draw the foregoing ideas together by means of examples. Two examples will be presented, one of them simple, the other more complex.

Problem 1

As a first example and introduction let us take a very small project - a steam pipe maintenance job, which requires the replacing of old pipe and valves with new materials and parts. Following is a series of activities required (with anticipated time for each) to carry out the job.

The project begins by moving the required material and equipment to the site (5 hours). Then we may erect a scaffold and remove the old pipe and valves (3 hours). While this is being done we can fabricate the new pipe (2 hours). When the old pipe and valves are removed and the new pipe fabricated, we can instal the new pipe (4 hours). However, the new valves can be placed (1 hour) as soon as the old line is removed. Finally when everything is in place, we can weld and insulate the new pipe (5 hours).

Before diagramming this project, let us list our events and number them as in Table I.

TABLE I

List of Events for CPM Problem 1

Event No.	Event Name
1	start
2	required material and equipment on site
3	scaffold erected and old pipes and valves removed
4	new pipes fabricated
5	new valves installed
6	start placing new pipe
7	new pipe placed
8	start final welding and insulation
9	complete final welding and insulation

Then our event orientated solution to this problem could be translated into the diagram in Fig. 6, p. 42.

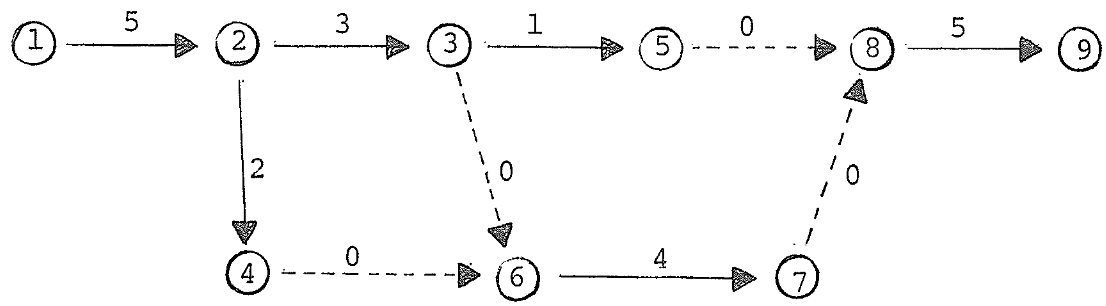

Fig. 6. First step in solution to Problem 1. Redundant activities are included. The numbers on the arrows indicate the length of time (in hours) it will take to carry out each activity which is indicated by the arrow. The numbers in the circles indicate the events.

In the diagram are included four dummy activities, three of which are redundant. The reason for their inclusion is to illustrate all the activities that are necessary to complete the events listed. Although all dummy activities have a time of zero, they can be constraints on events and succeeding activities as is activity (3 - 6) in this network. Activities (4 - 6), (5 - 8), and (7 - 8) can be eliminated and the network revised as in figure 7. Event numbers 4, 7, and 8 are eliminated but all necessary events are numbered as in original diagram for ease of following through.

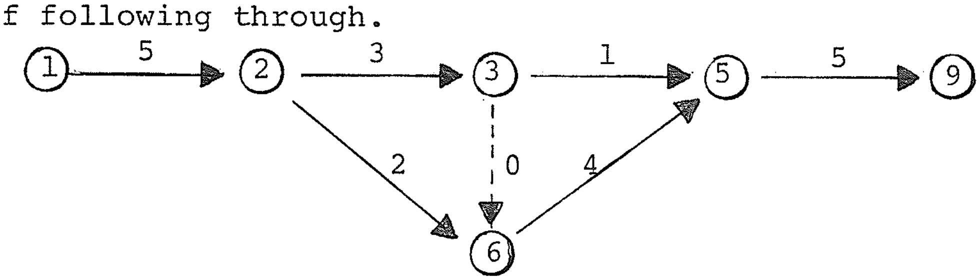

Fig. 7. Second step in solution of Problem 1. Redundant activities are eliminated.

Activity 3 - 6, although zero time, is necessary since the new pipe cannot be placed until the old pipe and valves are removed. Event 4 can be eliminated since the new pipe can be fabricated while scaffold is being erected and old pipe and valves are being removed. Event 7 is unnecessary since it is only a continuation of event 6, that is the installation of the new pipe. Event 8 is also redundant in that it merely illustrates the beginning of the welding of the new pipe, which can only begin after event 6 is completed. The diagram in figure 7 shows that the final activity (5 - 9) cannot begin until (6 - 5) is complete.

We now can proceed to determine slack time (float) and the critical path for our sample project. To illustrate this we will repeat figure 7 and insert two additional sets of numbers on each arrow e.g. 0 5 5 → . The number at the head of the arrow indicates the earliest possible time at which the activity can be completed, the middle one the duration time of the activity itself, and the number at the tail of the arrow denotes the latest time at which the activity can start in order that the project can be completed by a certain time.

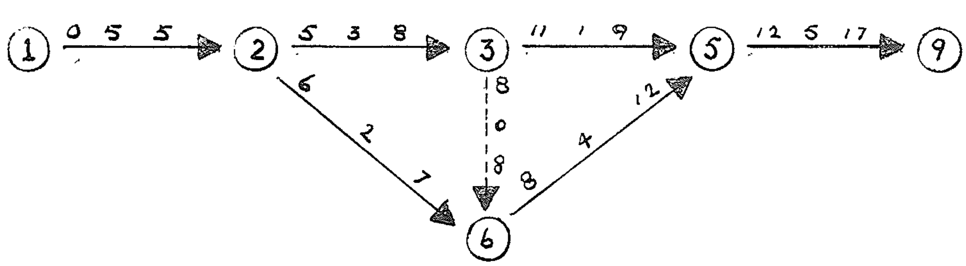

Fig. 8. Third step in solution to Problem 1. The earliest possible start times (ES) and latest start times (LS) for each activity are indicated.

The first step in determining the critical path is the forward pass. We shall proceed by referring to each activity individually, considering only the middle and arrowhead numbers. Activity (1 - 2) requires 5 hours to complete as is represented by the "5" on the middle of the arrow. The "5" at the arrowhead indicates that the earliest finish time (EF) for this activity is 5 hours. Activity (2 - 3) requires 3 hours to complete and since it is dependent upon activity (1 - 2) (5 hours duration time), the earliest finish time is 8 hours as indicated by "8" at the head of the arrow. Activity (2 - 6) requires 2 hours to complete as indicated by the "2" and adding on the 5 hours required for activity (1 - 2) makes the earliest completion time 7 hours as indicated by the "7". Activity (3 - 5) requires only 1 hour to complete and this added on to the 8 hours of time required to reach event 3, making the (EF) 9 hours. Activity (3 - 6) does not require any time but is dependent upon event 3 as well, thus event 6 completion time is "8" hours, even though activity (2 - 6) can be completed at the end of 7 hours. Activity (6 - 5) requires 4 hours as indicated and added to the 8 hours of completion time for event 6, makes the earliest possible finish time for event 5 the 12 hours as shown "12". This in turn makes the (EF) for the event 17 hours by adding on the 5 hours required for activity (5 - 9).

It has now been determined that 17 hours are required to complete the job. By following through backwards we can ascertain the path in which there is no slack time and this is then known as the critical path.

Working backwards on activity (9 - 5) we see that the latest starting time (LS) for that activity is 12 hours since it takes 5 hours to complete it. This is so marked by the "12" at the tail of the arrow. Activity (5 - 3) requires one hour, thus latest starting for activity (5 - 3) is 11 hours thus giving 2 hours of slack time or float. Even though it can be completed at the end of 9 hours, it really doesn't need to be finished before 12 hours to enable crew to commence with activity (5 - 9). Activity (5 - 6) requires 4 hours, thus (LS) for that activity is 8 hours, in order that event 5 may be completed at the end of 12 hours. This is also indicated by the "8" at the end of the arrow. Activity (6 - 3) does not require any time but is a constraint on event 6, thus (LS) for that activity is "8" as indicated. Activity (6 - 2) requires 2 hours to complete, thus does not have to begin until 6 hours as noted by the "6" at the tail of the arrow since event 6 cannot be completed until after 8 hours as necessitated by events 3 and 2. This would then give a slack of one hour for activity (6 - 2). Activity (3 - 2) requires 3 hours, thus the (LS) for it is 5 hours, as the "5" represents. It then follows that activity (2 - 1) would have a (LS) of "O" since event 1 is the beginning of all operations.

The network diagram in fig. 9 is complete, with the critical path indicated by the double line. Any delay in any of the activities on this path would delay the completion of the total project unless extra resources were applied. This is a very important consideration for a contractor who may be faced with this type of situation.

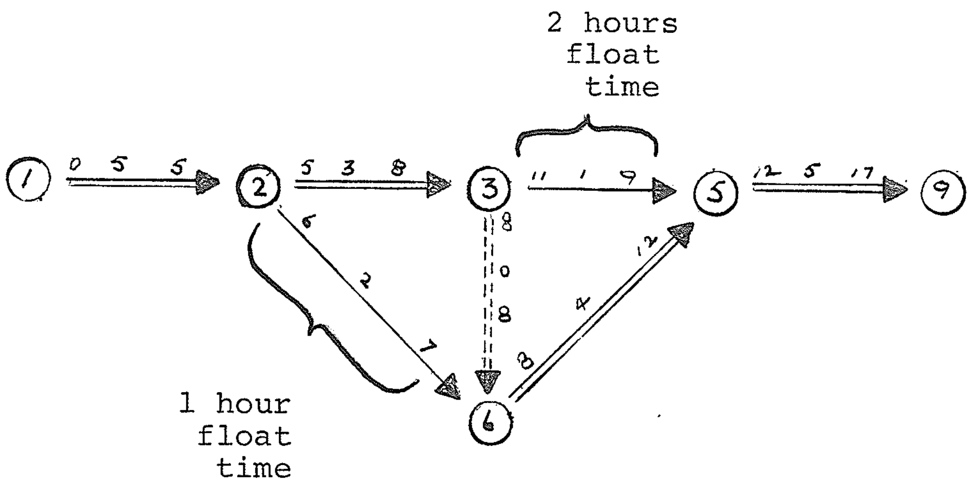

Fig. 9. Complete network diagram for solution to Problem 1. Critical Path is indicated by double line. Two illustrations of "float time" are included.

Problem 2

Now let us look at a more detailed example of a network diagram which will be activity - orientated, with activities A - R. The activity times and predetermined dependencies are indicated in Table II on page 47.

TABLE II

List of Activities for CPM Problem 2

Activity	Activity Time	Depends on Activities
A	3	--
B	3	A
C	12	B
D	5	B, M, L
E	5	A
F	6	A
G_s	8	E
G_f	2	G_s, H
H	7	F
J	3	E, H
K	4	F
L	5	G_f, J, K
M	9	G_f
N	4	L, M
O	6	C, D, N
P	4	C, D, N
Q	7	O, R
R	5	P

To diagram the project described above we need to analyze its description, keeping in mind the following points:

1. determine independent activities and draw them in

2. determine their immediate followers and insert them into the diagram, which should flow to the right

3. determine the immediate followers of the last activities drawn in and place them in the diagram, maintaining at all times the proper interdependencies

4. continue drawing until all activities have been included (revising Table II into blocks showing interdependencies as shown in Table III helps determine order in which activities should be drawn in)

TABLE III

Interdependencies of Activities in Problem 2

Block	Predecessor	Successor	Block	Predecessor	Successor
1	-	A	5	G_f J K	L
				G_f	M
2	A	B	6	L M B	D
	A	E		L M	N
	A	F	7	C D N	O
3	B	C		C D N	P
	E	G	8	P	R
	F	H	9	O R	Q
	F	K			
4	G_s H	G_f			
	E H	J			

Table III can now be converted into a network diagram with activity times noted opposite activity names as in fig. 10, on page 49.

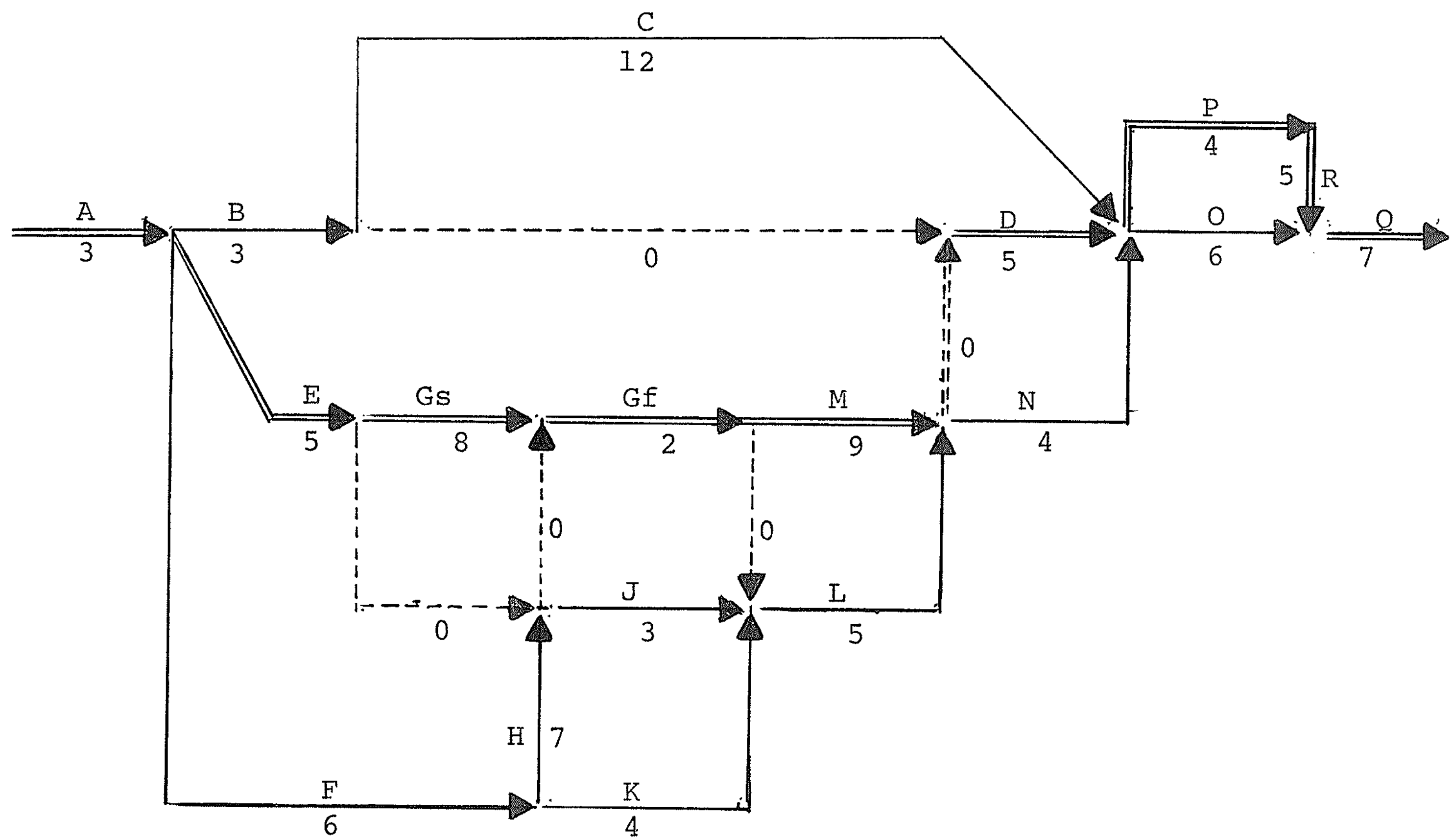

Fig. 10. Solution to Problem 2

The critical path is denoted by the double line and the project requires a minimum of 48 units of time to complete. As shown in fig. 10, page 49, any delay in any of the activities along the critical path would invariably result in a delay in the completion date unless the contractor could either trade-off time in any of the activities, that is be able to better utilize it than his original estimates required or add extra resources and/or manpower. The latter could be very costly and could well be prohibitive if the budget is very tight.

In the network diagram for problem 2 earliest finish and latest start time are not indicated but this could be determined by making the forward and backward passes as applied to problem 1: as a result, slack or float times have not been calculated. In an actual construction project the contractor would concern himself mainly with the activities along the critical path, while utilizing the float time as deemed expedient.

CONCLUSION

The preceding material should suffice to prepare the reader for the network of the case study in the following chapter. Chapter 4 will present a copy of the original time schedule as presented by the contractor, and this in turn will be converted into a network diagram of the total building phase of the project.

CHAPTER IV

THE CONTRACTOR'S SCHEDULE AND CPM

INTRODUCTION

This chapter contains: (1) the original progress schedule submitted by the contractor upon commencement of the project, (2) the CPM network diagram prepared for the project, (3) a comparison of the two schedules, and (4) a summary. These are restricted to the building phase only, and do not include any of the pre-planning nor the related procedures such as negotiations with the Department of Education, tendering and selection of the successful bidder.[1] The first is a very simple schedule with an overlap of activities, while the second (the CPM) is a complete breakdown and separation of the various tasks.

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[1]As pointed out in the "Limitations" in chapter 1, the progress schedules do not include any preplanning activities such as population surveys, determining needs and selecting locations, submissions to the Department of Education, selection of an architect, or tendering and awarding of contract. A time schedule could be planned for all the phases of a project beginning with the initial study and following through to the expiration of the guarantee period on the building. With the exception of the latter consideration which would be dependent upon the workmanship in the building, all the other factors are certainly related directly to the time required to put a new facility into operation. Perhaps a more inclusive study could reveal some valuable findings and suggestions.

THE CONTRACTOR'S SCHEDULE

One of the stipulations in the "Instructions to Bidders" was that the contractor would co-operate in the preparation of the critical path network and in the execution of the project in accordance with the network. Since the network was not prepared prior to the commencement of the project, the requirement to apply it was not enforced.

It should be pointed out, however, that the contractor did co-operate in the preparation of the network which, while prepared during the construction phase, was used to rate the various aspects of the project's progress. Its main purpose was for comparison with the conventional schedule as submitted by the contractor, and to determine whether any advantages can be gained from its use.

As required, within ten days of the signing of the contract, the contractor submitted a work schedule showing proposed commencement and completion times of each portion of work in the project. The schedule is a conventional one which does not reflect any features of CPM or similar techniques for systematic management and control of projects.

The contractor's schedule is very similar to the conventional progress schedule discussed in chapter 2. The information that is contained in table 4 could be organized quite easily into a form of the Gantt Chart. The limiting features of the Gantt Chart would still prevail. The detail is expressed in the CPM network diagram which is included in Table IV, later on in this chapter.

There are several features of this particular schedule that should be noted:

1. units of time are in blocks of weeks;

2. activities are combined for each week rather than specific times assigned for each;

3. there is an overlap of activities from week to week; and

4. the activities are designated in a general way rather than specifically.

Table IV, which begins on page 54 and continues through to page 57, is a copy of the contractor's original submission of a progress schedule.

TABLE IV

THE CONTRACTOR'S PROGRESS SCHEDULE

FOR STE. ROSE COLLEGIATE

Week of	Activity
July 23 - July 29	Move to site; establish temporary services; job layout; strip black dirt; pile layout.
July 30 - August 5	Job layout; commence piling; commence pre-fabing forms; anchor bolts and setting sketch required.
August 6 - August 12	Commence fill placement; complete piling; commence grade beams erection; commence plumbing roughin.
August 20 - August 26	Pour grade beams; masonry material at site for auditorium walls; complete fill placement; plumbing roughin.
August 27 - September 2	Structural steel erection; masonry to gymnasium; delivery of all hollow metal doors and frames; rebar placement for slabs; gymnasium layout required for floor sockets.
September 3 - September 9	Complete slab rebar; commence pouring slabs; structural steel erection; steel joists required; complete masonry to gymnasium to low roof joist bearing.
September 10 - September 16	Pouring slabs; complete steel joist erection to low roof section; complete masonry to gymnasium to joist bearing; commence steel decking to low roof; exterior grading.
September 17 - September 23	Complete slab pouring; masonry to exterior walls; complete gymnasium long span joist erection; commence roof cant and blocking; complete exterior grading.
September 24 - September 30	Exterior masonry; complete all steel decking; aluminum windows required; exterior masonry; mechanical trades

Continued ...

TABLE IV (continued)

Week of	Activity
	must have all curb sizes and factory made fan curbs at the site.
October 1 - October 7	Exterior masonry; roof curbs; cants; pouring main exterior paving slabs; complete exterior grading; all exterior glazing required; incinerator required; pour exterior sidewalks.
October 8 - October 14	Roofing and sheet metal; complete exterior masonry.
October 15 - October 21	Roofing and sheet metal; commence interior masonry.
October 22 - October 28	Complete roofing sheet metal; interior masonry; carpentry.
October 29 - November 4	Building weather-tight; interior masonry; drywall; plaster; stucco; delivery of finish hardware.
November 5 - November 11	Interior masonry; commence plastering trade and drywall; delivery of interior millwork items; miscellaneous furring by carpentry trade.
November 12 - November 18	Drywall, plastering, carpentry, mechanical and electrical trades are to be 100% roughed in at this point.

Continued ...

TABLE IV (continued)

Week of	Activity
November 19 - November 25	Drywall, plastering, carpentry, commence painting; delivery of all interior hollow metal and wood doors; finish carpentry; commence acoustic tile grid system; ceramic tile; heating and ventilating systems to be operative; permanent distribution in service.
November 26 - December 2	Painting; finish carpentry; lockers; acoustic tile grid; toilet partition erection; complete ceramic tile; plumbing and electrical fixture installation.
December 10 - December 16	Same as previous week plus chalk and tack board installations and control system operating.
December 17 - December 22	General job clean-up; finish carpentry; painting; renovation work complete except flooring.
December 24 - January 2	Project shut down for Christmas - New Year.
January 3 - January 6	Delivery of resilient flooring and carpet; complete painting in gymnasium area; delivery of cork tile.
January 7 - January 13	Complete resilient flooring and all painting; commence cork carpet in gymnasium; delivery of carpeting; all electrical and mechanical work to be complete.
January 14 - January 20	Request mechanical and electrical inspection; complete cork carpet in gymnasium; commence carpet installation; request semi-final architectual inspection.

Continued ...

TABLE IV (continued)

Week of	Activity
January 21 - January 27	Complete carpeting; delivery and installation of gymnasium equipment; correction of mechanical, electrical and architectural deficiencies.
January 28 - February 3	Correction of deficiencies and general clean up.
February 4 - February 10	Final inspection and turn over to owners.
February 11	Completion of project.
	Note - All sub-trades and materials or specialties contractors are expected to meet the dates as outlined herein and to schedule deliveries to coincide with the schedule irrespective if their product or service is specifically mentioned herein. (example - Miscellaneous metal contractor must schedule delivery of all items imbedded in concrete floors prior to commencement of slab pouring week of September 3 - 9. The Contractor reserves the right to modify the schedule from time to time as the on-site conditions vary.

THE CRITICAL PATH METHOD FLOWCHART

The CPM flowchart is a network diagram covering all the activities beginning with the letter of intent to build to the expiration of the guarantee period one year after final inspection. The emphasis is on the building phase as already mentioned. The flowchart is unlike the conventional schedule and does reflect features of systematic management and control techniques.

The network is in a sense only a graphical representation of a project plan which may have existed in some other form (as has been shown in this case by the conventional progress schedule submitted by the contractor). In practise, however, the preparation of a network influences the actual planning decisions and results in a plan that is more comprehensible, contains more detail, and is often different from the original thoughts about how a project should proceed. These changes derive from the discipline of the networking process, which requires a greater degree of analytical thinking about the project than does any other type of project description.[1]

There are a number of features of the CPM network

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[1]Joseph J. Moder and Cecil R. Phillips, Project Management with CPM and PERT, 2nd ed. (New York: Van Nostrand Reinhold Company, 1970), pp. 20 - 21.

that are different from the conventional progress schedule:

1. all activities are identified and placed in sequence

2. all interconnections of activities are identified

3. construction of network is based on logic and technical dependencies among the activities

4. the activities are designated in a specific way, e.g. approve cabinet shop drawings

5. units of time are in number of days

6. none of the activities overlap but some are diagrammed to be carried out concurrently, and

7. an identification of the Critical Path (in fig. 11 this is designated by a heavier line and any delay in any of the activities on this path will invariably delay the completion date of the project unless extra resources can be made available)

A note of explanation regarding the numbers on the network lines is warranted at this time. The unbracketed numbers indicate the anticipated number of days required for each activity while the numbers in parenthesis are the actual times required to carry out such specific activities. These reflect certain time savings but no indication is given on the network in respect to any delays. These will be explained later.

The foldout in fig. 11, see page 60, is a network diagram prepared by the architect for the same project as the contractor's progress schedule in the preceding section.

A COMPARISON OF BOTH SCHEDULES

In comparing the two schedules a number of differences became very evident. The detail in the network diagram is much finer than it is in the contractor's schedule. Activities are spelled out more precisely rather than left to the reader and interpreter as "understood" to be part of a more general activity. As an example, the preparation and approval of shop drawings are listed as separate and specific activities in the CPM schedule, yet are not mentioned in the contractor's schedule. The progress schedule is essentially based on main activities relating mainly to the actual building process; the network separates and defines the steps specifically, with time requirements for each.

The estimated time of one hundred eighty days by the CPM schedule was more realistic than the thirty weeks suggested by the contractor's schedule. Even though the thirty six-day weeks would tend to indicate that the time required was essentially the same, it was not practically so. Time blocks of "weeks" as opposed to "days" are not specific enough and leave loop-holes that can easily cause delays. It is much easier to assess delays and pinpoint responsibilities by using the unit of days rather than weeks.

Both schedules have check points for completion of certain phases of the project but the progress schedule has only several as opposed to the individual activities on the network diagram. It would seem to follow that a much easier and more up-to-date monitoring could be carried out through the CPM network.

The amount of detail included in the network diagram reflects the planning that must go in to the drafting of such a network and the time required to carry this out. It becomes very obvious that it is more time and effort consuming than is the listing of the activities in a conventional schedule. The time required for the preparation of each and the benefits that could be realized from each type will be discussed in a later chapter. These evaluations will be based on the proponents of each method, the architect and the contractor.

The main feature of the network diagram, that is the critical path, is lacking in the contractor's progress schedule. There is no way of telling which are the critical events and unless the contractor or his foreman has this well in hand, delays can easily occur. No doubt the contractor uses the critical path, either consciously or intuitively, but the network diagram spells it out specifically, and in so doing ensures an organized check on flow of materials and the progress of activities.

SUMMARY

In the preceding sections both the CPM network and the conventional progress schedule as submitted by the contractor have been illustrated. Their respective features have been noted and compared. The following chapter will review what actually happened during the construction of the building and reasons for these happenings. This will then be followed by evaluative and analytical comments relating to this case study.

CHAPTER V

THE BUILDING PHASE

INTRODUCTION

The preceding chapter featured characteristics and examples of each of the two types of schedules - the conventional schedule and the CPM network, both for the same project, as well as a comparison of the two. This chapter contains a description of what actually happened during the construction of the building, the effects of the happenings and the steps taken to overcome some of the difficulties that were encountered.

FORTUITOUS EVENTS

During the course of this project there were a number of fortuitous factors which ensured that the project would not suffer any major delay in completion date.

From the very beginning the weather was unusually good and this enabled the ground work to proceed without any interruptions. Despite the other numerous delays that occurred, the contractor was able to take advantage of the ideal weather conditions. The building was virtually closed in before any bad weather could interfere, even though the October 29 scheduled date for this phase suffered a delay of approximately one month.

The contractor was able to benefit by the willingness of certain crews to work beyond the average working day; most of the crews were too far away from home to go back during the week and felt they would rather work longer hours than be idle. Neither the contractor nor his foreman spared themselves to expedite the building process. Quite often they themselves would do certain jobs that could have caused delays had they not been done at the required time.

The contractor's foresight in ordering the steel for the superstructure much in advance proved to be to great advantage. His persistence with the sub-trades helped to minimize what could have been serious delays.

VARIOUS DIFFICULTIES AND DELAYS

There were various difficulties and delays. A number of the difficulties experienced had immediate effects, while others which were less evident, had serious implications for later activities. Amongst the first type were those associated with masonry, electrical, dry wall and plaster, millwork and floor covering. Those which were less evident were related to colour schemes and shop drawings which eventually affected the arrival of materials and furnishings. In general it was the sub-trades that created the problems.

Masonry

The masonry trade was the first to start causing delays. Although starting their job only about one week later than the scheduled last week of August, there was a continual falling behind in schedule. The late start appeared to be due to inadequate preparation for the job while the continual falling behind was due to lack of sufficient and knowledgeable manpower. From the very beginning the masonry trade seemed to lack a sense of urgency and a rather relaxed approach prevailed. Local help which had been hoped for, was not available.

The masonry trade failed to meet the mid-September schedule for the erection of the gymnasium walls. This delay caused other trades to revise their plans and schedules. The height of the gymnasium walls required more manpower than was available at the time and this prevented the raising of the steel joists for the gymnasium roof along with the superstructure for the rest of the building. As a result arrangements had to be made to have the roof deck contractor raise the steel joists for the gymnasium roof since it was not economically feasible to retain the crane contractor on location while waiting for the gymnasium walls to be erected.

The masonry delay was not confined to the gymnasium walls. The same type of delay was experienced in the erection of the walls of the remainder of the building.

<u>Late Submission of Hardware Requirements</u>

In addition to the masonry difficulty there was a month late submission by the architect of hardware requirements for the gymnasium floor which in turn delayed the pouring of the cement floor. Difficulties in flooring were compounded by the installation of the cork tile.

Floor Covering

Cork tile which was chosen as floor covering in the gymnasium, is relatively new in this part of the country with only a few schools in the province having used it to date; there was little or no expertise on which to draw for installation procedure. Despite the fact that tests showed that the concrete had cured properly and that the manufacturer's specifications for installation were followed, the tiles failed to adhere properly. Corrective measures were sought but the problems still continued. Each attempt at correction was time costly since there had to be a waiting period to determine if the measure taken was successful.

While it was planned to have the cork tile installed and the gymnasium ready for use by the second week in January, work was still being done on it during the last week in April. The end result was that while the Division accepted the main part of the building for maintenance and occupancy as of May 1, the gymnasium unit was not completed until the latter part of May.

Although the job of laying the tile was accepted, a number of trouble spots do exist and further corrective measures are being sought. Only time will tell whether or not the number of tiles that did not adhere properly will increase and cause any major problem that can be corrected, if the need arises, at a minimal cost. The possibility of having to invoke the guarantee does exist at this time.

Lack of Gymnasium Facilities

It had been originally planned to move ahead with the gymnasium in order that it would be ready for use when the existing gymnasium was being converted into an Industrial Arts facility. As it turned out plans had to be changed since the time loss suffered due to masonry delays and floor covering problems was never recovered. Since the contractor had to proceed with the conversion of the existing gymnasium, for approximately four months there was no facility available for the physical education program. Not only did the program suffer but both staff and students were subjected to various inconveniences as well. The administration was faced with the problems of rescheduling classes and accommodating students.

PROBLEMS RELATED TO INTERIOR CONSTRUCTION AND FINISHING

Masonry

A further delay similar to that experienced with exterior walls, was caused by the masonry trade in the erection of the interior walls. This delay had implications for the electrical trade since installations had to be made concurrently. Other interior trades were delayed accordingly and the time lost was never really recovered.

While endeavouring to regain some of the time lost due to masonry delays, the sequencing of other activities was changed. Although changing the sequence of activities might be necessary to recover lost time, it can have undesirable side effects. It can cause disorganization amongst the various sub-trades that are effected, and in turn loss of their confidence and co-operation, which, in the long run, can become a serious constraint.

Electrical Delays

The electrical trade, although delayed by the masonry people, followed a pattern similar to that of the masonry trade. There was insufficient manpower and lack of supervisory personnel on site. Their delays could have been critical had the masonry been on time. A delay in electrical installations could hold back the pouring of concrete as well as dry walling and plastering, which in turn delays painting and flooring.

After continued and repeated demands to provide more manpower and qualified supervision the only recourse that was left was to turn to the Department of Labour. It is a requirement to have a qualified journeyman electrician on the job at all times, which was not the case in this project. The involvement of the Labour Department brought results, but only after come considerable delay, not all of which could be recovered. Although the job was considered completed, another electrician had to be brought in to correct numerous deficiencies.

Dry Wall Difficulties

The dry wall contractor added to the list of difficulties experienced in this project. His problem appeared to be two-fold - that of insufficient manpower and that of inability to meet his commitments. His overall delay amounted to approximately three weeks and this caused delays with the millwork and painting trades.

Several steps were taken to correct this problem. Extra manpower was procured for the dry wall contractor at his expense. This caused some difficulty in relationships with him but helped to expedite the work. Another measure taken was to get some of the work done with the contractor's own forces. In the case of a plaster ceiling, which was being delayed, it was agreed to change the requirement to ceiling tile that could be readily installed by the ceiling contractor. All three steps prevented any significant loss of time.

Carpentry

Difficulty with floor covering was not confined to the gymnasium area. The carpet for a large portion of the remainder of the building proved to be defective. Although the initial delay in its arrival was less than two weeks, replacement took considerable time.

Upon beginning of installation it was discovered that the carpet was mouldy and would not stand any measure of stretching. The manufacturer was contacted immediately and another supply was shipped only to be as defective as the first. The manufacturer was contacted again and it was determined that the drying mechanism in the plant did not function properly during the production process. This resulted in a carpet that was not completely dry being rolled up and sealed in a plastic wrap for shipment, thus causing it to mould. A different shade was offered as a replacement but the offer was rejected since the areas in which the carpet was to be installed were already painted and a specific colour was required. This resulted in a further four week delay before another supply of the required carpet could be produced. The defective carpet, coupled with other delays, caused the January scheduled date for its installation to be delayed to the end of April. Further loss of time was prevented by the installer providing tradesmen upon very short notice, and of the type who expedited the installation by exerting extra time and effort at no extra cost.

Materials and Supplies

Not all the fault should be attached to the lack of sufficient and qualified manpower. The supply of materials, which in many cases were of special nature, was another source of delay since their arrival was not always timely.

Although the time at which these are ordered is very important, commitments by suppliers were not met. This type of situation is difficult to overcome since once a trade is committed to a supplier, it is not expedient to change because a further loss of time is likely to result. By changing suppliers one would have to start from the beginning of the ordering stage, which would likely be more time consuming than suffering the delay from the original source.

A good example of this is the supply of hardware and hollow metal doors. Since these have to be installed as the masonry goes up, it is imperative that such materials be on site as required. To ensure this shop drawings for such requirements must be submitted in good time and a close check kept on the supply of the related hardware. A constant check has to be kept on these as it seems customary to experience delays in procuring items in which steel is required. It is deemed expedient to actually visit the plant in which such items are manufactured and to keep enquiring for enough in advance to guard against late delivery. The contractor's foresight in doing this, along with the masonry delay prevented this from becoming a problem.

Late submission of colour schemes and shop drawings can also create problems. While these problems may not be immediate, they can become critical when the need for supplies dependent upon these arises. In this particular project the architect was tardy in submitting the colour schemes for the millwork, which in turn delayed the submission of those shop drawings. Even when the millwork shop drawings were submitted, they were improperly drawn up and had to be returned for corrections. This resulted in a late arrival of millwork and such time loss is difficult to recover since materials have to be on the job when required. Millwork is all custom made and substitutes are unacceptable. The amount and type of materials required were such that no local source could be drawn upon for supply. Coupled with the commitment to the original supplier there was no alternative but to wait.

Equipment and Furnishings

Similar to the supply of materials was that of equipment and furnishings. Specifications for these must be timely or arrival and installation can be delayed. Although the tendering for equipment and furnishings was carried out in relatively good time, suppliers were not as prompt as had been anticipated. Some of the scheduled thirty day delivery dates turned out to be more like ninety days. This in turn caused inconveniences since installations had to be made just before and during the beginning of the school term rather than when work in school was less pressing during the summer vacation. The delay in the arrival of some of the equipment, particularily that of Industrial Arts, caused considerable inconvenience and not unlike that of the Home Economics equipment, necessitated revision in the implementation of the respective programs.

Renovations and Conversions

Apart from the new building, considerable difficulty was experienced in renovations and conversion of part of the existing building to a Business Education facility. After the initial planning and award of the contract, it was suggested by members of the Department of Education that a review of the plans was warranted. As a result of the re-planning, which was very time consuming, Divisional needs to the contractor had changed. Much time had expired before approval was secured.

While all this was happening certain trades had already left the site and the change in plans had caused the costs to more than double. This obliged us to delete this portion of the project from the original contract and seek special funds to cover the increased costs. The only recourse the School Division had was to rely on special funds out of the following year's budget.

Since some of the trades had already left the site certain changes in plans had to be made to avoid still higher costs. This resulted in changing Divisional requirements of two interior masonry walls to frame and dry wall in order to cut back on costs of bringing back the masonry trade. The contractor had to rely on his own forces to carry out this work and this reduced costs considerably.

The carpet delay was in a sense to Divisional advantage in this area as by the time the proper carpet had arrived, the Business Education conversion was far enough advanced that the carpet could be installed in it at the same time as in the rest of the building. This in turn saved the cost of bringing back the installers another time. The end result, however, was an increased cost plus a need for make-shift arrangements as the space was not available at the required time. This as well affected the program to a degree and caused considerable inconvenience to both students and staff.

SUMMARY

There were a number of fortuitous circumstances that prevailed in this project. These were as follows:

1. good weather (an act of God)
2. good will of contractor and foreman
3. foresight of contractor in pre-ordering of steel and visiting suppliers
4. constant vigilance of foreman and contractor, and
5. willingness of men to work overtime

The benefits that were derived from these were several:

1. speeded up production
2. minimized and prevented delays
3. made it possible to recover lost time, and
4. helped to avoid serious hold-ups and possibly

complete halt of activities

The fortuitous events enhanced:

1. having the opportunity to call on men for overtime when required

2. having the assurance and co-operation of the contractor and foreman, and

3. meeting deadlines fairly closely

There were, however, a number of sources of delays. Some of the types and causes were as follows:

1. Subtrades:

   (a) insufficient manpower

   (b) lack of sufficient expertise

   (c) inadequately prepared for job

   (d) apparent difficulty in meeting commitments, and

   (e) relaxed approach and no sense of urgency

2. Submission of specifications (poor planning):

   (a) colour schemes late, and

   (b) shop drawings improperly done up

3. Supply of materials, furnishings and equipment:

   (a) suppliers unable to meet deadline dates

   (b) certain equipment and materials in short supply, and

   (c) defective materials

In order to minimize delays and overcome the difficulties experienced, the following steps were taken:

1. the sequencing of some of the activities was revised

2. plans for the use of certain portions of the building were altered

3. requirements for certain materials were substituted - e.g. ceiling tile instead of plaster and frame partitions in Business Education area

4. extra manpower was hired at the sub-contractor's expense

5. assistance was sought from the Department of Labour, and

6. the contractor's own forces were used in some of the jobs to prevent further delays

It should be emphasized that while immediate effects were felt mainly as a result of the sub-trades, delayed and remote difficulties were created by poor planning in the way of late submission of certain specifications and shop drawings improperly prepared. A detailed CPM network should have prevented this from happening as deadline dates for these are specifically and definitely spelled out.

The preceding summary is a resume of the circumstances and events that prevailed throughout the project with identification of causes and remedial steps taken to alleviate some of the difficulties. The following chapter will deal with the major findings as based on this case study, which although confined to a building situation, might be extended to other types of projects as well.

CHAPTER VI

MAJOR FINDINGS

While the preceding chapter reviewed what actually happened during the construction stage of the project, this chapter will feature the major findings as related to this case study. The findings will be based primarily on the project in question, with some general implications that might be characteristic of other projects.

This source of data is based on the interviews conducted with both the architect and the general contractor as well as the information gained by the writer. It will deal with: (1) cost of planning and implementing, (2) benefits to be derived from breaking down the various activities into a network diagram, (3) problems related to suppliers and subtrades, (4) difficulties that could have been avoided, (5) implications for respective parties involved, (6) importance of deadline dates, (7) length of work units, (8) advantages, (9) disadvantages, and (10) summary.

COST OF PLANNING AND IMPLEMENTING

The initial preparation of a CPM network for this particular project would require four to five days of work by the person designated to carry out this task. This may be an agent of any of the three parties involved, that is, the owner, the general contractor or the architectural firm. A conventional schedule would require about one-third of the time for preparation. In addition to this, time would have to be devoted on a regular basis throughout the course of the project to control all aspects of the work and to adjust the network to meet the end objectives.

Irrespective of what method of control and re-planning may be used, it would still require time and effort to a greater or lesser degree. A well planned program set out in a network diagram should not require as much time to monitor a project as would a conventional schedule. Consequently this aspect of cost cannot really be considered as one specifically related to a CPM network, but rather as one associated with monitoring and control.

Accepting the premise that time is money, then the initial preparation of a network would be more expensive than that of a conventional progress schedule. This cost, however, would be more than offset by the savings that may accrue from the efficiency and ease with which the management of the project could be carried out.

The general contractor, who is accustomed to using the conventional schedule, questions whether or not the time required to prepare a network diagram is really worth it. He does agree, however, that there are certain benefits to be derived from the use of the CPM, and these will be discussed under later headings.

The architect claims that the cost of preparation and implementation would not be worth it to him individually but that it had definite advantages to him as one of the team of architect, contractor and owner (providing all three parties shared in the effort and cost of implementing this method as their interests were affected). Savings could be enjoyed in "Time of Construction" and "Time of Occupancy", and invariably be to the advantage of the contractor and owner. If the time of construction can be shortened, or at least not prolonged, ultimately this would result in benefits to the architect whose time and travel could be lessened and thus the project cost reduced. There doesn't seem to be any doubt that the initial cost would be very minimal compared to the benefits to be derived from this systematic planning and control technique.

An important consideration in comparing the value of the use of the CPM as opposed to cost is the size of the project. If the project is small enough to be handled by the contractor himself and if his operation is such that he can afford to do things himself then there may be less value than in a project whose size requires delegation of authority. Its use, however, can more easily enable someone other than the "boss" to co-ordinate the flow of materials and the progress of the various activities. This does not mean to suggest that even in a small project benefits cannot be derived from good planning and systematic execution.

BENEFITS TO BE DERIVED FROM BREAKDOWN OF ACTIVITIES INTO A NETWORK

There are a number of benefits to be derived from breaking down the various activities involved in a construction project into a network diagram. Some of these benefits result from the amount of planning that is required to prepare the detail that is characteristic of a network diagram.

The consideration of the detail in the initial planning stage causes the planners to be more logical and specific than would be required in a conventional progress schedule. It reduces the possibility of overlooking certain steps and taking things for granted or understood. The planners can improve on their original thoughts which may have existed in their minds in some other form.

Once a project is broken down it becomes more manageable as the various tasks are distinctly separated, and there is no overlap of activities. It then shows the interrelationships between and among the various activities. Planners and management can then use it as a visual aid in identifying possible trouble spots.

Benefits can also be derived from using the CPM network in monitoring the progress of a project. A network makes it much simpler to assess the stage of activities when they are distinctly separated and this can be done with greater efficiency. It then becomes much easier to pinpoint responsibility for any difficulties that may arise.

A network diagram can facilitate the communication process since plans are portrayed in a graphic manner. Not only can such a technique minimize the danger of disorganization and misunderstanding which could result from poor communication, it can also sensitize the various parties involved to their respective responsibilities. The end result should then be a better co-ordinated and more timely project.

PROBLEMS RELATED TO SUPPLIERS AND SUB-TRADES

As already indicated in chapter 4 and chapter 5 various difficulties were experienced with sub-contractors and suppliers. These could have been critical had a definite deadline date been established.

Quite often a general contractor is faced with situations where sub-contractors are either not performing satisfactorily or not meeting scheduled dates. Either of these could be for various reasons amongst which could be insufficient manpower, lack of expertise, financial problems, too many commitments, poor management and the like. Whichever one or combination of reasons this may be, the general contractor must take steps to overcome delays.

If performance does not meet requirements and expectations of the architect, then it may become necessary to have certain aspects corrected or redone, both of which may be time consuming and costly to the sub-trades. This can have implications of delays and financial burdens that may be difficult to overcome. If the latter prevails further time may be lost while attempts are made to procure funds for supplies necessary to continue with the job.

The general contractor can apply certain pressures, one of them being a hold back on progress payments. This can only be effective to a degree because if too much money is held back a sub-contractor may not be able to pay his help, who in turn may refuse to work. The other possibility is that if there are hold backs, the sub-contractor can put a lien against the building and this in turn forces the owner to hold back payments from the general contractor. This can become a vicious circle and its use rather ineffectual. With a predetermined budget, a general contractor is quite restricted in his choice of sub-trades, even if he has reason to doubt the calibre of performance of some of the lowest bidders.

If a sub-contractor is entitled to sufficient monies for work already performed but is not carrying out the remainder of his responsibility, the general contractor has the recourse of hiring other help to complete the certain job, at the expense of the sub-contractor. Most general contractors are reluctant to avail themselves of this prerogative, but this had to be done in two cases in the Ste. Rose project.

Another type of problem that can be faced is that of supply of materials. In most cases specific components are required and specified, thus causing limitations on sources of supply. To get approval for substitutes can be time consuming. Associated with this type of difficulty can be that of faulty materials. Once committed, it is not likely that by changing suppliers can a contractor save time. He is more apt to lose some time, thus in essence leaving him at the mercy of the supplier. Such was the situation with the millwork and floor covering in this particular project. These delays were compounded by the use of a gym floor covering that was relatively new in Manitoba and installation problems arose.

Although these types of problems can arise with the use of any type of schedule, the CPM network would enable the administration to monitor much more readily and closely the flow of materials and progress of activities. Where bottlenecks were developing it could be used effectively in rescheduling certain activities, changing sequences and in making time trade-offs. It was found that the conventional progress schedule, with its overlap of activities, became somewhat nebulous and thus time loss resulted.

DIFFICULTIES THAT COULD HAVE BEEN AVOIDED

Although this project did not have any major or critical setbacks, various difficulties could have been avoided if a CPM method of scheduling had been employed.

This method could have been used to more closely control material and shop drawing approval at the early stages of construction. It would have indicated and emphasized the need of the architect and Divisional authorities to provide colour selections and related specifications at the onset of on-site construction. The conventional schedule left these in abeyance too long. These requirements were not broken down and scheduled, thus the tendency towards the delay.

In later stages, completion of the work of the sub-trades and "take-over" of the building could have been monitored more closely and better expedited by the general contractor and architect respectively. The Divisional authorities could have been better informed throughout the entire project as to the state of progress and completion of the various activities had a more detailed breakdown of activities been available to them throughout and utilized. Although there were periodic check-ups by the architect, the local administration was quite often at a loss as to the state of affairs. Current knowledge of possible and existing trouble spots might have enabled the owners to direct some course of action to help avoid and overcome such situations.

Closer control of all aspects of the building construction might have avoided some of the sub-trade difficulties. In a project undertaken some two hundred miles from the principal source (Winnipeg) of material and labour supply, it is particularily difficult to achieve completion by the separate trades. In this respect, a project can only be satisfactorily completed if the general contractor employs an efficient means of controlling the activities of his forces. The use of CPM would take a lot of the guess work out of this process.

IMPLICATIONS FOR THE RESPECTIVE PARTIES INVOLVED

Every project in which several or numerous parties are involved requires teamwork. There must be co-operation amongst the management people who come from the ranks of the architect, general contractor and owner. Planning could be done co-operatively at the initial stages and a general consensus of opinion reached before plans are drawn up. These could be done by the general contractor or the architect. It may well be that a network could be a requirement of the bidding process, in which case it would have to be done by the general contractor.

The CPM could be useful to all three parties in monitoring the progress of a project. Although it is the general contractor who is responsible to the owner for having a project proceed on schedule, both the architect and the owner's designate, presumably the Superintendent, could find the CPM network very useful in assessing the progress as well. With all three parties having ready access to the state of progress, prompt action could be taken to deal with difficulties, if such arose.

It is also imperative that each member of the team of tradespeople live up to his obligations if extra costs in time and expenses are to be eliminated. This would invariably apply to whatever type of schedule may be used, either conventional or systematic, like a network diagram.

It must be realized that even the most sophisticated type of planning and scheduling, and for that matter, even contracts and agreements are only as good as the integrity, expertise and financial capabilities of the participants. Factory production and delivery of building components, as well, affect the on-site progress of a project. The CPM is effective in providing a sequence of anticipated events, but to transpose these events into some tangible product requires competent personnel and financial responsibility.

Not unlike being responsible for the timely execution of a project it is also the general contractor who is solely responsible to the owner for the performance of all trades; smooth execution of a project may be hampered very seriously if any one or several of them do not fulfil their responsibility.

The ideal, of course, would be a team of responsible trades who take pride in carrying out their respective functions well and during the time their activities are scheduled. Unless each party takes its responsibility seriously, CPM can become merely an academic exercise. Selecting such a team is often very difficult, if not impossible, as budgetary limitations often restrict the general contractor as to which trades he can choose.

The general contractor questions very strongly the present system of tendering. The acceptance of tenders by the architect and owners, is by necessity, made upon a price budget relationship. Capital costs are very closely set by the Department of Education, and most school boards are reluctant to exceed these to any extent. The general contractor is then virtually forced to accept the lowest bids from sub-contractors in order to be able to tender competitively. As a result he often finds himself obliged to accept sub-trades whose records of performance are questionable. The only apparent advantage is a reduced price which enables the owners to meet their budget, but this can easily prove to be false economy which can result in premature replacement and maintenance costs.

The easy credit pattern which has been adopted by many wholesalers and manufacturers has tended to increase the problems in the construction industry rather than alleviate them. To "make a sale" suppliers have granted many concessions which make it far too easy to go into business. Many former tradesmen have done this and found themselves in financial difficulty and unable to meet their contractual obligations. This was the case with two trade contractors at the Ste. Rose project.

One should point out, however, that the size of the company is not necessarily related to the on-site performance. In the Ste. Rose project the structural steel work was performed by a comparatively small company, and yet the efficiency with which the job was performed was unexcelled. The manufacturers of the steel decking and carpet, however, who are amongst the largest in the country, created delays that were also unequalled in this project.

It is the general contractor's contention that if sub-contractors were required to be bonded in similar manner as are the general contractors, a very large risk factor could be eliminated. This would also enable the general contractor to be selective within a group of sub-trades that are able to obtain bonds and consequently increase the effectiveness of CPM.

In essence every party connected with a project must be able and willing to produce if a project is to be carried out efficiently and effectively. There must be singular and combined commitment on the part of all concerned.

IMPORTANCE OF DEADLINE DATES

It is imperative that realistic deadline dates for completion of a project be set and adhered to as closely as possible. This was not the case with respect to the project at Ste. Rose. There were really two dates set, one by the architect on behalf of the Board and the other by the general contractor in his progress schedule. Based on the completion date of the project the date set by the architect proved to be the more realistic of the two but was not an absolute necessity as there was no urgency for the building.

Since it was not the intent to use the building (except replacement areas for those being converted) until the following school year, there was no deadline during that time that had to be met as long as the building was ready for occupancy for the fall term. The project was begun in July and in view of the fact that approximately forty weeks was a realistic time for construction, there was ample time to spare. The Board's main concern was to set a deadline, which was May 1 of the following year, as a safety precaution that everything would be in readiness by September 1.

The lack of an absolute final date of completion presented a problem that could have been critical in a situation where the building was in fact required and planned to be used sooner than was the case at Ste. Rose. A sense of pressure has to exist at all times and urgency must be implied, or a relaxed attitude will develop amongst the trades. When such a situation develops the contractor is faced with crews that see no high priority for really moving and prolonged delays will invariably be the result. The contractor's experience would suggest that in order to prevent or at least minimize the possibility of this happening, both the architect and the owner should continuously apply pressure for occupancy. Most trades will respond favourably since it is not in their best interests to have it known who delays a project.

LENGTH OF WORK UNITS

One of the main weaknesses of any schedule can be the length of the work unit. If this unit is established in weeks rather than days various problems can arise.

It is much easier to assess responsibility for job delays if units of time used are shorter, such as days as opposed to weeks. Using a block of a week can have overlaps and it becomes much easier to pass on responsibility from one trade to the next. If days are used to designate the length of time each activity should require then trades can be more easily identified and thus required to live up to their responsibilities. A contractor could more easily request a trade to make up a day at a time as opposed to a week and expect the trade to comply with such a request. This, in turn, could assist in expediting the carrying on of other activities.

A problem, peculiar to rural Manitoba, is that of the availability of sub-trades. Most of these operate out of the larger towns or cities and are reluctant to come out in the middle of a week. If time blocks are set up in weeks, and either their services are not required at the beginning of the week or they are not ready to come at that time, then they are not likely to come out mid-week, but will rather wait until the beginning of the following week, thus a whole week could easily be lost. If time blocks were in units of days then trades could be required to come out at any time, irrespective of whether or not, to cite an example, all five days of work all fell in the same work week, or perhaps two days one week and three the next.

Another possible advantage of using units of days as opposed to weeks may be derived in the event damages had to be assessed against any particular trade. It would be quite easy to determine damages on a daily basis whereas a weekly basis could become quite nebulous and consequently ineffectual. The same, of course, could apply to any bonuses.

ADVANTAGES

CPM affords an efficient and logical development of a building project from outset to completion. It helps to avoid delay at any point which could seriously affect the thorough and appropriate consideration of factors at another point in the developmental sequence of work to be undertaken.

The following is a list of advantages that can be gained by a School Board and school business officials in adopting CPM as a management tool:

1. A standard system of planning for design and construction.

2. A more effective tool for periodic rescheduling and evaluating.

3. CPM could give the contractor a better control over his job, and if he uses it effectively, would enable him to submit lower bids.

4. It can offer a reliable basis for extension of time and negotiations or assessment of liquidated damages, should the need arise.

5. If change in personnel became necessary, it could be easily accomplished as all records are available at any point.

6. If overtime had to be ordered, it would only be applied to critical jobs, which could be easily determined with the use of CPM.

7. CPM would enhance the identification of immediate or future trouble spots.

8. Quick rescheduling of a project to meet unpredictable conditions or emergencies can be provided.

9. Realistic and easily interpretable scheduling can enhance ordering of furniture and supplies to arrive at proper time.

10. A better analysis of change orders and appraisals can be made.

11. CPM can be used to provide the Board with the correct information and fix responsibilities of the various parties involved.

12. The Board can be in a better position to arrange financing more efficiently by being able to determine times of payments to contractors.

13. If changes are required, rediagramming can indicate the impact of such changes on cost and timing, and adjustments can be made accordingly.

14. The most important advantage, after experience is gained, is the reduction in time required to complete a project. With this advantage the opening of a school can be scheduled with a better assurance that the date can be met. This can result not only in educational benefits but in a reduction of costs as well.

DISADVANTAGES

Not unlike any other system the CPM can and does have certain disadvantages. Network analysis is not the solution to all management problems. It is not a substitute for the manager's knowledge, intelligence, experience and judgment, but merely a tool to facilitate and co-ordinate these.

Some of the main disadvantages can be listed as follows:

1. A poorly organized network can be worse than any conventional or traditional schedule, and can thus compound problems rather than alleviate them.

2. Personnel who have no knowledge and understanding of the system can be helplessly lost and create problems that might otherwise be avoided or not develop at all.

3. The method of analyzing, diagramming and adjusting a CPM network can easily become too complex and too cumbersome. Details must be considered carefully, but an imaginative flexibility of the system must be allowed to prevail.

4. Use of CPM may tend to reduce all time considerations to objective fact. Adequate allowance for flexibility must be maintained for many subjective considerations of a building program that are difficult to pin-point or accurately time. These same subjective considerations will be imperative to the project development.

5. An attitude of "policing a project" must not be allowed to develop. The advantage of CPM is to assist and co-ordinate. It may be used to isolate problems, but an over-all attitude of co-operation and participation must be nurtured carefully if the technique is to be effective.

A SUMMARY

The preceding sections have been a review of the major findings regarding CPM. The review points out the costs and expertise involved, the various implications and experiential solutions. A variety of experienced and possible advantages are listed along with the disadvantages that may be encountered. The following and final chapter of this study will attempt to highlite the features of CPM and a conventional system along with recommendations for their use as well as suggestions for further study.

CHAPTER VII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The need for this study arose from the various types of difficulties that school officials are experiencing if school building construction projects are not carefully and adequately planned.

The Problem

The purpose of this study was to examine the usefulness of CPM for planning and scheduling school building construction. Means are needed to improve management controls that might alleviate such difficulties as:

1. frustrations, inconveniences and losses resultant from delays in completion of a school building, and
2. cost over-runs

The Design of the Study

This was a case study designed to illustrate and assess the application of CPM to school building construction. The study concerned itself with the construction of a major addition to an existing school at Ste. Rose du Lac, Manitoba, in the Turtle River School Division Number 32.

Following the review of literature the CPM was described and illustrated by way of two examples.

This was then followed by a presentation of the contractor's schedule as submitted to the Division Board. This schedule was then transformed into a CPM network. The two schedules were compared.

Although the CPM network was not prepared at the outset of the project it was used to compare actual progress as estimated by each of the schedules -- that of the contractor and the CPM network. The requirement to use the CPM network was not enforced but rather used to monitor the actual progress as estimated in the contractor's schedule.

This study was done with the co-operation and assistance of both the architect and the general contractor and their views and opinions are reflected in the chapter devoted to the major findings.

Summary of Findings

A number of findings have resulted from this study. These can be categorized under several main headings:

1. Cost of planning and implementing. The initial and operative costs associated with the use of CPM may not be worth it to any one party of a project, that is the architect, the contractor or the owner, but a sharing of these costs would be an excellent investment that would eventually produce great dividends.

2. Benefits derived from activity breakdown. Breaking down a project into the component activities provides benefits related to planning and scheduling.

By its very nature a CPM network causes critical thinking and replanning before scheduling is diagramed. It then provides a visual aid that makes monitoring easier and more efficient.

3. Dealing with problems. Discretion is the better part of valour and should prevail in dealing with problems of sub-trades and suppliers. Various measures can be taken and certain recourses are open but unless discreetly exercised can produce negative long-term results.

4. Avoiding difficulties. Numerous difficulties could have been avoided in this project had the CPM been applied. CPM could have provided closer monitoring and potential trouble spots could have been identified and avoided.

5. Implications for the respective parties involved. All parties must be willing and able to live up to their responsibilities in the total project or delays and very likely increased costs will result.

6. Importance of deadline dates. It is imperative that realistic and definite deadline dates for completion be established. Unless this is done and adhered to, numerous delays are likely to develop. There must exist at all times a sense of urgency or a relaxed approach will invariably develop.

7. Establishing length of work units. The length of the work units should be established on a daily rather

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7. Establishing length of work units. The length of the work units should be established on a daily rather

than weekly basis. If project activities are based on number of weeks rather than days, time loss can easily occur. Make up time becomes difficult and pin-pointing responsibilities for delays becomes more so.

8. Advantages and disadvantages. There are numerous advantages to be gained from the use of a management technique like CPM. These are listed in the previous chapters. Along with these are also listed some possible disadvantages and should be heeded to ensure maximum returns from CPM.

CONCLUSIONS

On the basis of this study I would conclude that CPM is useful under the following conditions:

1. that it be a co-operative effort involving the architect, contractor and owner

2. that each of the parties concerned have an understanding of the technique.

3. that it not be used as a tool for policing but rather as a management technique used to monitor, co-ordinate and control progress of activities and flow of materials

4. that it be used in the planning process and applied from the beginning of the project

5. that the owner, rather than just expect to realize immediate cost savings, accept CPM as an assurance that the job will be done efficiently and

within the scheduled period of time (both considerations which can bring about long range savings)

6. that it be updated as conditions and times dictate in order that necessary steps be taken to overcome unanticipated difficulties, and

7. that the CPM technique not be viewed as a cure-all but rather as a management technique which is useful only when properly administered

I would further conclude that wherever CPM is used wisely by a project manager who understands its strengths and weakness, it can be an effective amplifier of his managerial skills and it can produce the following results:

1. a disciplined approach to planning
2. a better definition of the scope of the work
3. a separation of planning and scheduling
4. an identification of the critical activities
5. a graphic plan of work which can be constructively reviewed
6. better communication between and amongst people
7. more accurate forecast of time requirements, and
8. cost and resource forecasts, if needed

RECOMMENDATIONS

Taking into consideration the findings derived from this study and the increasing acceptance of CPM by industry, I would recommend that CPM be used as an integral part of construction management in education. Although we are primarily concerned here with school buildings being completed on time, and with minimal, if any, cost over-runs, the technique could be equally successful in any type of construction as well as other areas of management and planning.

Recognizing the fact that CPM is not widely known and little used in Manitoba educational circles, a number of recommendations are worthy of consideration:

1. that school trustees and administrators become better informed as to the possibilities of CPM and how to use it

2. that orientation courses in management techniques like CPM be made more readily available (at present the University of Manitoba offers these on a very limited basis to limited enrolments)

3. that the Department of Education develop some policy and guidebook on the use of CPM

4. that CPM become a requirement in school building construction which would ultimately result in more competitive bidding and help keep costs from rising so dramatically, and

5. that CPM not be confined to construction management but applied to other areas of educational planning, e.g. implementation of new programs, designing new approaches to instruction, experimenting with evaluative procedures and change-over of educational systems

AREAS FOR FURTHER STUDY

This case study has examined the usefulness of CPM planning and scheduling a school building construction project. Since it was based on only one case I feel there are other areas in which CPM could be applied.

Generating Alternate Costs And Times

This study was based on a one time estimate. It might be useful to use this method of planning to generate three time estimates - optimistic, probable and pessimistic, and then apply these to a specific project. It could similarily be used to generate alternate costs, which was not done in this study. An established cost was accepted and was not a main consideration.

Comparing Rural And Urban Costs

This case study was based on a rural setting. The availability of materials and trades might be much more constraining on rural projects than urban ones. A comparison of the two may identify whether or not there are increased costs due to the location of a project. Such findings could support rural Boards of Education in their requests to the government for more financial assistance, based on their proximity to the main centre of materials and labour supply (in Manitoba's case it would be Winnipeg). It might also serve as a guide to more realistic scheduling by architects and contractors.

Computer Utilization

This study was based on manual computations; a computer was not utilized. A study and comparison of each might reveal some very useful information and evaluate the merits and limitations of each.

Application To Other Areas Of Education

Long range educational planning can use a much more systematic approach than is being evidenced in many instances at the present time. Rather than being confined to the provision of physical facilities CPM could be applied to areas like introduction of new programs, the utilization of facilities and the use of different techniques and approaches to instruction. CPM could well be the answer to many of the problems that arise due to insufficient or haphazard planning. Such a study might provide information that could enhance the fulfillment of this very important responsibility.

BIBLIOGRAPHY

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A. Books

Benson, Ben. Critical Path Methods in Building Construction. Englewood Cliff: Prentice Hall Incorporated, 1970.

Campbell, W. G. Form and Style in Thesis Writing. Boston Houghton Mifflin Company, 1954.

Handy, H. W., and Hussain, K. M. Network Analysis for Educational Management. Englewood Cliffs: Prentice Hall Incorporated, 1969.

Levin, Richard J., and Kirkpatrick, Charles A. Planning and Control with PERT/CPM. New York: McGraw Hill Book Company, 1966.

Martino, R. L. Project Management and Control Vol. 1. Finding the Critical Path. New York: The Comet Press Incorporated, 1964.

Miller, Robert W. "How to Plan and Control with PERT," In New Decision-Making Tools for Managers, pp. 95 - 118. Edited by Edward C. Bursk and John F. Chapman. New York: The New American Library, 1963.

Moder, Joseph J., and Phillips, Cecil R. Project Management with CPM and PERT. 2nd ed. New York: Van Nostrand Reinhold Company, 1970.

O'Brien, James J. CPM in Construction Management. 2nd ed. New York: McGraw Hill Book Company, 1965.

Turabian, Kate C. A Manual for Writers of Papers, Thesis and Dissertations. 4th ed. Chicago: The University of Chicago Press, 1973.

Wiest, Jerome D., and Levy, Ferdinand K. A Management Guide to PERT/CPM. Englewood Cliffs: Prentice Hall Incorporated, 1970.

B. Microfilm Reproductions

Bliss, Shirley and Hitchcock, R. P. Introduction to Critical Path Scheduling, Bethesda, Md.: E R I C Document Reproduction Service, ED 020 301, 1964.

Cook, Desmond L. Better Project Planning and Control Through the Use of Systems Analysis and Management Techniques. Bethesda, Md.: E R I C Document Reproduction Service, ED 019 729, 1967.

Cook, Desmond L. PERT Application in Educational Planning. Bethesda, Md.: E R I C Document Reproduction Service, ED 019 751, 1966.

General Learning Corporation. Task/Event Network for School Construction, Boston Public Schools - A Generic Model. Bethesda, Md.: E R I C Document Reproduction Service, ED 035 204, 1968.

Liebeskind, Morris. "Critical Path Method," In Design and Construction of School Buildings. Bethesda, Md.: E R I C Document Reproduction Service, ED 020 624, 1965.

McIssac, Donald N., North, Stewart D., and Wakefield, Howard E. Time Management Planning for Educational Facilities. Bethesda, Md.: E R I C Document Reproduction Service, ED 029 462, 1965.

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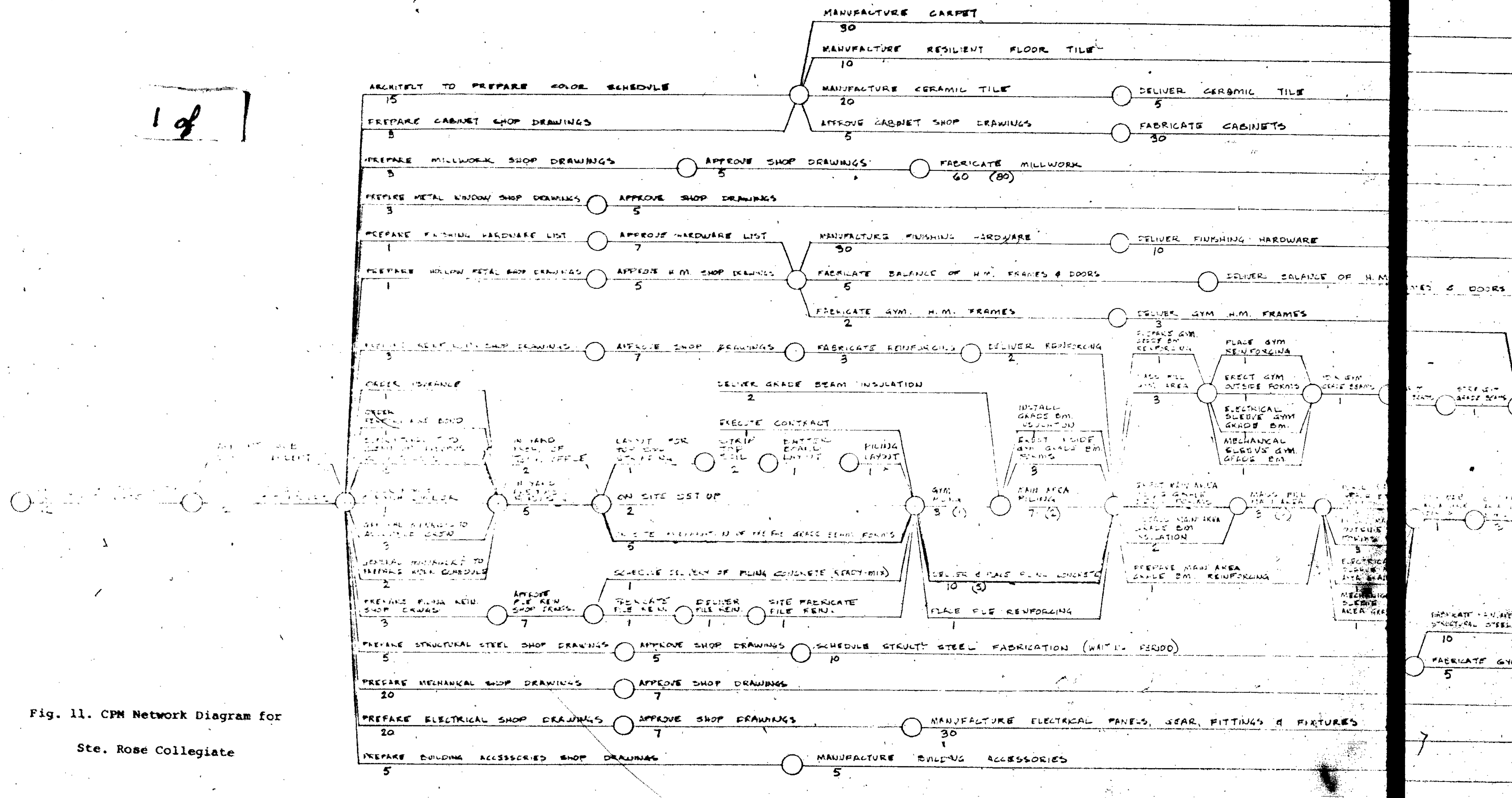
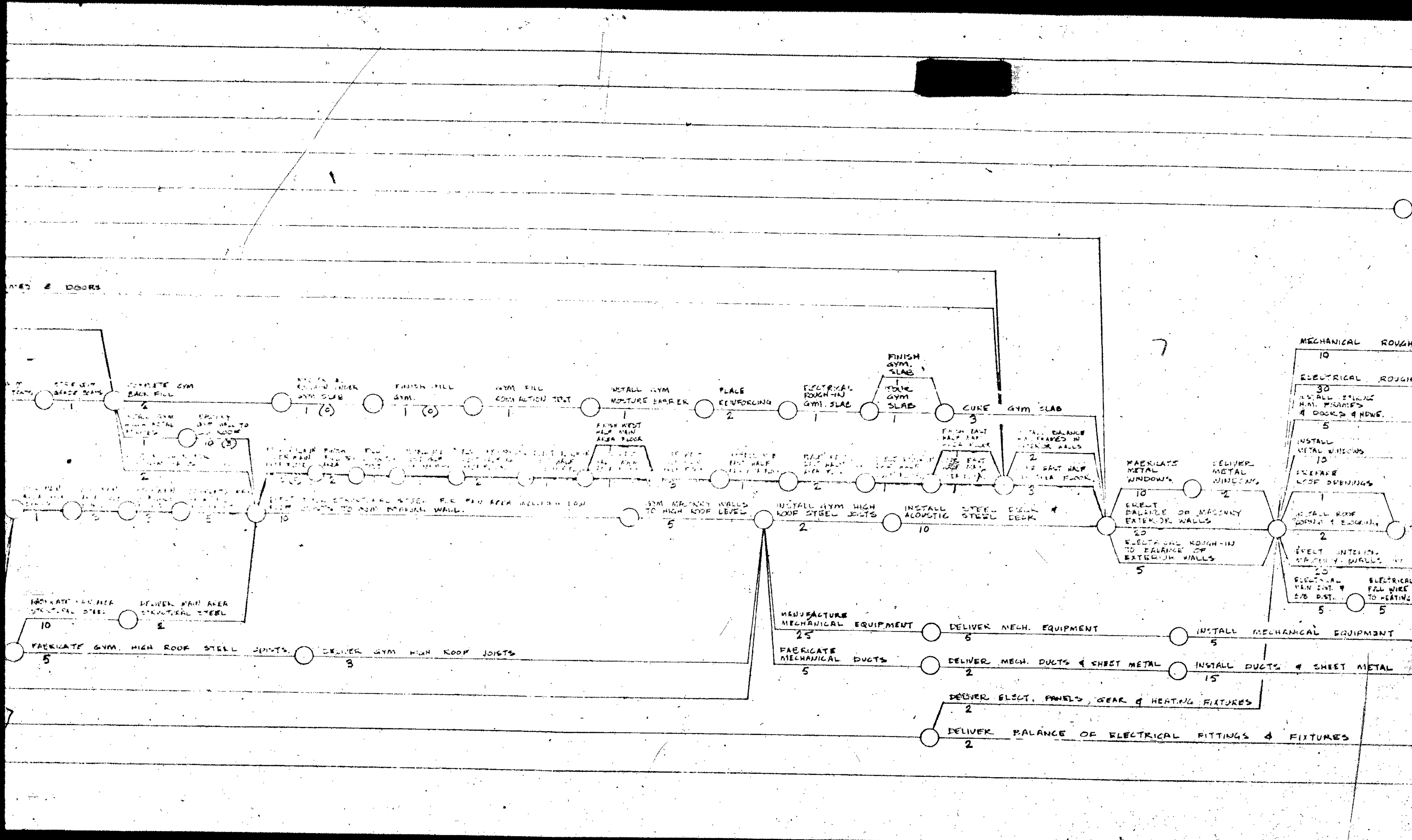
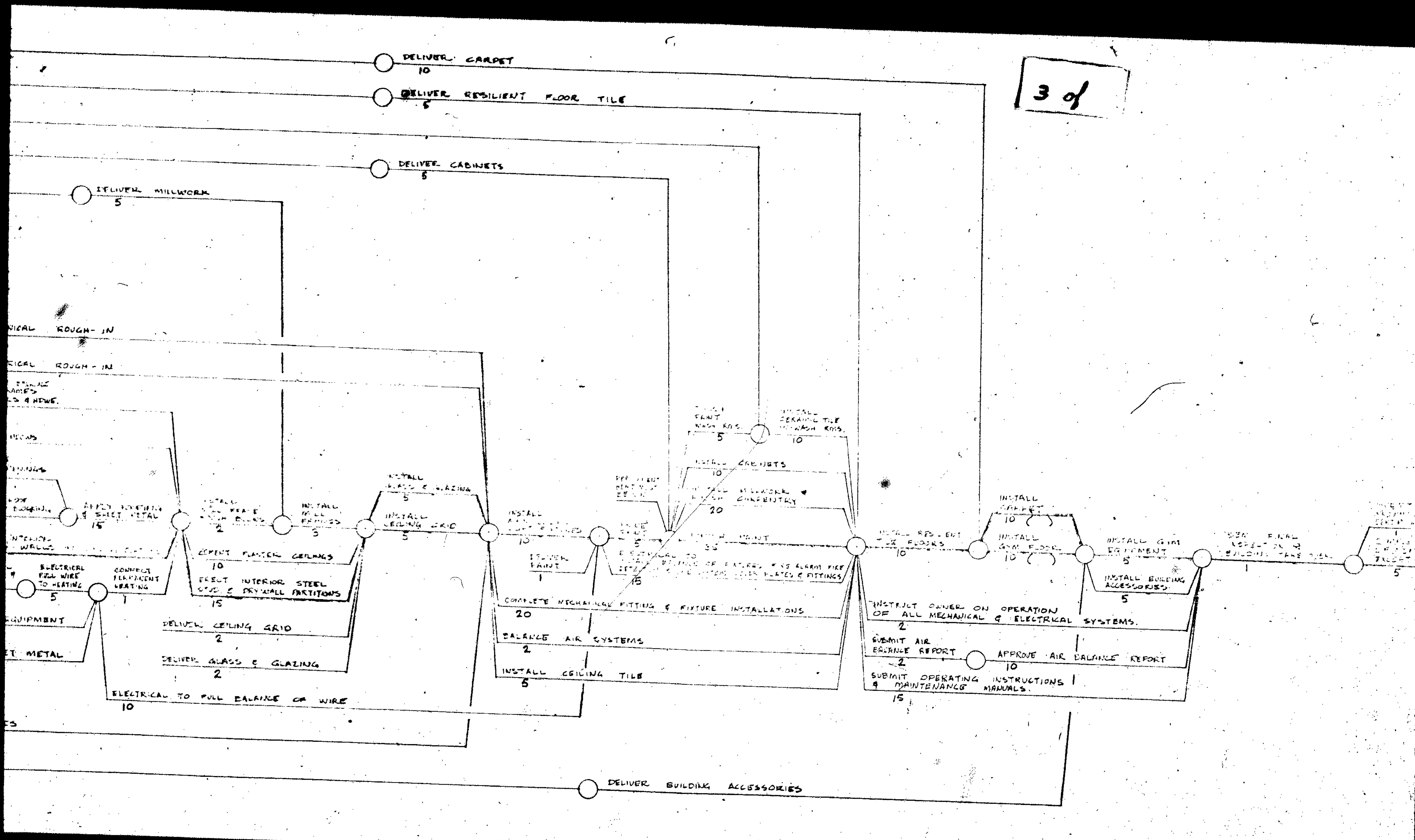


Fig. 11. CPM Network Diagram for

Ste. Rose Collegiate



COMPLETE GYM BACK FILL
4
FINISH FILL GYM
1 (0)
GYM FILL COMPACTION TEST
1
INSTALL GYM MOISTURE BARRIER
1
PLACE REINFORCING
2
ELECTRICAL ROUGH-IN GYM. SLAB
1
FINISH GYM. SLAB
POUR GYM SLAB
1
CURE GYM SLAB
3
GYM MASONRY WALLS TO HIGH ROOF LEVEL
5
INSTALL GYM HIGH ROOF STEEL JOISTS
2
INSTALL ACOUSTIC STEEL DECK
10
FABRICATE METAL WINDOWS
10
DELIVER METAL WINDOWS
2
ERECT BALANCE OF MASONRY EXTERIOR WALLS
25
ELECTRICAL ROUGH-IN TO BALANCE OF EXTERIOR WALLS
5
MECHANICAL ROUGH-
10
ELECTRICAL ROUGH
30
H.M. FRAMES & DOORS & HDWE.
5
PREPARE ROOF OPENINGS
1
ERECT INTERIOR MASONRY WALLS
25
MANUFACTURE MECHANICAL EQUIPMENT
25
DELIVER MECH. EQUIPMENT
6
INSTALL MECHANICAL EQUIPMENT
5
FABRICATE MECHANICAL DUCTS
5
DELIVER MECH. DUCTS & SHEET METAL
2
INSTALL DUCTS & SHEET METAL
15
DELIVER ELECT. PANELS, GEAR & HEATING FIXTURES
2
DELIVER BALANCE OF ELECTRICAL FITTINGS & FIXTURES
2
FABRICATE GYM. HIGH ROOF STEEL JOISTS
5
DELIVER GYM HIGH ROOF JOISTS
3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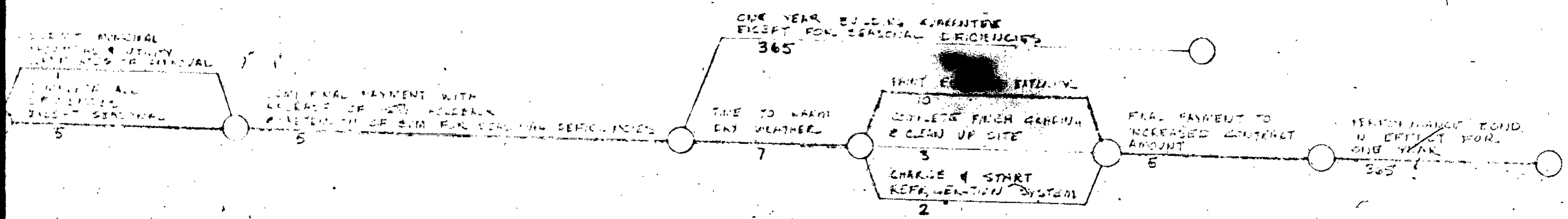
DELIVER CARPET
10
DELIVER RESILIENT FLOOR TILE
5
DELIVER CABINETS
5
DELIVER MILLWORK
5
ROUGH-IN
ROUGH-IN
APPLY ROOFING & SHEET METAL
15
INSTALL GLASS & GLAZING
5
INSTALL CEILING GRID
5
CEMENT PLASTER CEILINGS
10
ERECT INTERIOR STEEL STUD. & DRYWALL PARTITIONS
15
ELECTRICAL PULL WIRE TO HEATING
5
CONNECT PERMANENT HEATING
1
EQUIPMENT
SHEET METAL
DELIVER CEILING GRID
2
DELIVER GLASS & GLAZING
2
ELECTRICAL TO PULL BALANCE OF WIRE
10
DELIVER PAINT
1
INSTALL CERAMIC TILE IN WASH RMS.
10
INSTALL CABINETS
10
INSTALL MILLWORK & FINISH CARPENTRY
20
COMPLETE MECHANICAL FITTING & FIXTURE INSTALLATIONS
20
BALANCE AIR SYSTEMS
2
INSTALL CEILING TILE
5
INSTALL RESILIENT TILE FLOORS
10
INSTALL CARPET
10
INSTALL GYM FLOOR
10
INSTALL GYM EQUIPMENT
5
INSTALL BUILDING ACCESSORIES
5
INSTRUCT OWNER ON OPERATION OF ALL MECHANICAL & ELECTRICAL SYSTEMS.
2
SUBMIT AIR BALANCE REPORT
2
APPROVE AIR BALANCE REPORT
10
SUBMIT OPERATING INSTRUCTIONS & MAINTENANCE MANUALS.
15
DELIVER BUILDING ACCESSORIES



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