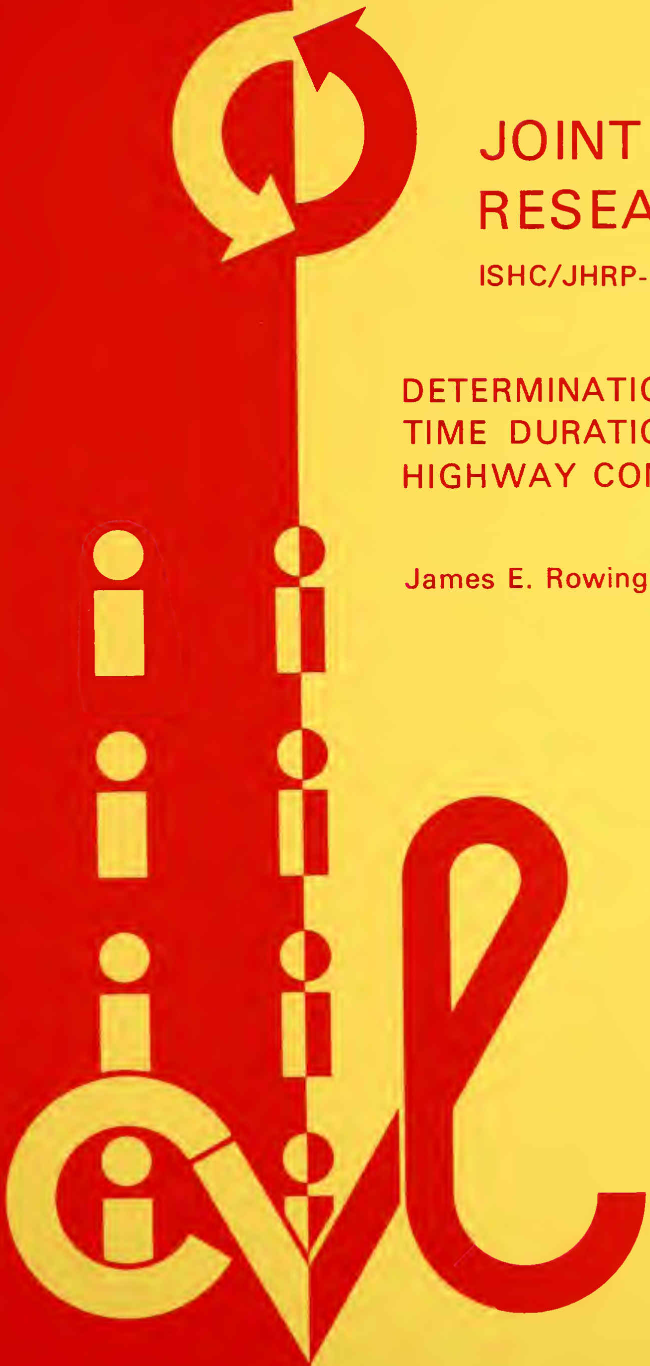
SCHOOL OF CIVIL ENGINEERING



JOINT HIGHWAY RESEARCH PROJECT

ISHC/JHRP-80/3

DETERMINATION OF CONTRACT TIME DURATIONS FOR ISHC HIGHWAY CONSTRUCTION PROJECTS

James E. Rowings, Jr.

PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

80-3

Final Report

DETERMINATION OF CONTRACT TIME DURATIONS FOR ISHC HIGHWAY CONSTRUCTION PROJECTS

TO: H. L. Michael, Director
Joint Highway Research Project

FROM: Donn E. Hancher, Research Engineer
Joint Highway Research Project

March 25, 1980

Project: C-36-67J

File: 9-11-10

The attached report is the Final Report on the JHRP Study "Determination of Contract Time Durations for ISHC Highway Construction Projects". The Report has been authored and conducted by James E. Rowings, Graduate Instructor in Research on our staff, under the direction of Professor Donn E. Hancher.

Objectives of the research were to review the current method within ISHC of establishing contract duration and to identify the factors which influence the time required, to review the methods used by nearby states to set contract times, and to develop improvements in the method currently used in Indiana so that total project cost would be reduced. All three objectives were attained and are detailed in the Report.

The findings of the Study have been made available to the ISHC Construction Division and we will continue to work with them on implementation of the results.

Respectfully submitted,

Donn E Hancher

Donn E. Hancher
Research Engineer

DEH:ms

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Final Report

DETERMINATION OF CONTRACT TIME DURATIONS FOR ISHC HIGHWAY CONSTRUCTION PROJECTS

by

James E. Rowings, Jr.
Graduate Instructor in Research

Joint Highway Research Project

Project No.: C-36-67J

File No.: 9-11-10

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
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in cooperation with the

Indiana State Highway Commission

Purdue University
West Lafayette, Indiana
March 25, 1980

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Finally the author wishes to thank the Indiana State Highway Commission for their financial support and their personnel for their assistance in obtaining the necessary data.

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ABSTRACT

Rowings, James Emerson, MSCE, Purdue University, December, 1979, "Determination of Contract Time Durations for ISHC Highway Construction Projects". Major Professor: Dr. Donn E. Hancher.

Review of the Indiana State Highway Commission (ISHC) monthly construction reports revealed that a significant number of highway construction projects are not completed within the specified contract duration. In most cases when contracts are not completed on time the contractor is assessed liquidated damages for the delay in completion. The liquidated damages serve to reduce the contract cost; however, the benefits of the project are delayed and the inconveniences are prolonged for the taxpayer. The project and administrative costs to the ISHC also increase the total project cost with each day of delay in the completion. After discussing the problem with personnel of the ISHC Construction Division it was determined that research would be beneficial in reducing the number of contracts with delayed completions. The primary goal of the study was to evaluate the current methods used to determine highway construction contract completion dates and recommend revisions which would improve the procedure for

establishing contract durations.

In order to attain the goal of the investigation, three major objectives were identified. The first objective was to review the current method of establishing contract duration and identify the factors which can influence the time necessary for completion. This objective was accomplished through interviews with the staff of the ISHC Construction Division. The second major objective was to review the methods used by nearby states for setting contract times as well as other methods described in current literature. This phase was accomplished through interviews with staff members of the Highway departments of Illinois, Kentucky, Ohio, and Michigan. Also the applicability of methods such as CPM, PERT, and Precedence was investigated. The final major objective was to develop improvements to the current method for contract time determination which would serve to reduce the overall total project cost of highway construction. Various possibilities for improvement were discussed with the ISHC construction personnel and the final recommendations were developed by the researchers.

The final recommendations include a step-by-step approach for documenting assumptions made, applying average productivity rates, determining the contract duration and representing the construction logic in the form of a time-scaled bar chart. Included with the recommendations are examples of the proposed method's use for highway construction projects, along with the advantages of the new procedure over the one currently being used.

CHAPTER 1

INTRODUCTION

To serve the needs of the public, the Indiana State Highway Commission (ISHC) identifies numerous highway construction projects every day which are necessary to expand and improve the Indiana Highway Transportation Network. Based on the funds available the ISHC establishes priorities for the construction and performs the engineering design for the projects. Construction contract documents are prepared as the design is completed, with each construction contract identifying the contract time allowed for performance of the specified work. The contract time is established by the construction staff of the ISHC based on the urgency of the project and an evaluation of the work units required for the completion of the contract.

The contract time can be expressed in several different ways. The contract time may be expressed as a number of calendar days, or a calendar date, for completion. Calendar days are simply every day shown on the calendar, including Saturdays, Sundays and holidays. Another way to express the contract time is by specifying the number of working days allowed for completion. From the Indiana State Highway Standard Specifications a working day is defined as:

> "A calendar day, exclusive of Saturdays, Sundays, and State recognized legal holidays, on which weather and other conditions not under the control of the Contractor will permit construction operations to proceed for at least fifty percent of the day with the normal working force engaged in performing the controlling operation or operations of work which would be in progress at that time. However, no work days will be charged during the months of December, January, February, or March, unless otherwise specified."

In addition to the contract time for completion of the project, many contracts also limit the closure time of roadways and structures or disruption of traffic. The limitations may be expressed as working days, calendar days, or calendar dates which identify a time period for the closure or disruption of traffic. The contracts also contain provisions for liquidated damages to be paid by the contractor should he fail to complete the project within the contract time, or delay the opening (or disruption of traffic) beyond the limitations specified in the contract. Currently a significant number of the construction contracts are not completed within the specified contract time. It is the purpose of this paper to investigate the present methodology used in establishing the contract times and propose to the Indiana State Highway Commission any changes in their procedure which would improve the determination of contract durations.

1.1 Justification for the Study

One of the primary goals of every governmental agency is to provide their assigned services to the public in an efficient, economical, and timely manner. The ISHC makes every effort to set contract times which reflect the urgency of the work and the optimum production levels. Prequalification of the bidders seeks to assure that the contractor can perform the work if awarded the contract. Nevertheless, as noted earlier, a significant number of construction contracts are not completed within the limits set forth in the contract. Review of the monthly construction progress reports from January 1979 through June 1979, which listed data for 406 completed construction contracts revealed 69 contracts which have had liquidated damages assessed, with charges amounting to $260,155. There were another 95 contracts accepted later than the contract completion date.

Projects that are not completed on time delay the benefits of the project, and the inconveniences (as in the case of a bridge closure) are prolonged for the taxpayer. In addition, the project and administrative costs to the ISHC increase the total project cost with each day of delay. Although liquidated damages serve to reduce the contract cost, in most cases, the previous mentioned consequences far outweigh the penalty imposed. When comparing the cost of liquidated damages to the cost of working overtime, it is doubtful that the contractors have sufficient incentive to meet a completion date once he realizes normal production levels will not be adequate. The data presented indicates that research would be useful to examine the problem of late completions. It is hoped that the research report will provide useful findings which will significantly reduce the number and magnitude of completion delays on construction contracts. The conclusions and recommendations made should serve to reduce the overall cost of delays to the Indiana taxpayer for highway construction projects.

1.2 Objectives of the Study

There are many causes for late completions of highway construction contracts. Just as each project has a unique scope of work and site conditions, so too, the circumstances for late completions are unique for each project. When a contractor assumes the responsibility for performing the work, he also assumes the responsibility for the project's timely completion. It is questionable whether knowledge of the specific circumstances for every project which was completed late would serve any beneficial purpose to the ISHC other than documentation for the files. Further, in many cases, the causes would be extremely difficult to identify and obviously there would be the tendency of the parties involved to "point fingers" rather than assume any responsibility. During the early interviews with the ISHC

Construction Division staff it was suggested that, rather than identifying specific causes for delays of past projects, it would be more beneficial to look at the general causes for delays, to identify the factors which can affect the project duration, and develop an improved methodology, incorporating these factors, for prediction of contract durations.

There are three primary objectives of this investigation which will contribute to the attainment of the goal of the study.

The first objective of this study was to thoroughly review the current methods of establishing contract times. This included a complete evaluation of the methods used for each type of construction contract. Before completely understanding the method it was necessary to examine the sequence of events which take place prior to the awarding of a construction contract. It is important to understand who makes the decisions, what information is used in the evaluation and determination of contract times. From discussions with various members of the ISHC Construction Division the general cuases for completion delays were identified. Factors which influence the contract time, such as material delivery, machinery availability, manpower, weather, etc., were also investigated as part of this objective. The method for incorporating these factors in the time evaluation was another area of research.

Completion of the first objective established the starting point or datum from which improvements or refinements can be made. Without this information it would have been difficult to develop a methodology which would be a useful tool.

The second objective of the investigation was to make a comprehensive review of methods currently being used by other states in establishing highway construction contract times. Again a basic understanding of the entire contracting process was necessary as well as the specific details of their scheduling methods. Comparison of the methods used by other states with the procedure Indiana utilizes identified the similarities and differences, and the advantages and disadvantages of each. To supplement this information further investigation of the current literature on the subject of determination of contract times was conducted to seek other improvements which might be useful. The final part of the investigation was the overall evaluation of the many differing methods to determine their applicability to the Indiana system, with emphasis given to the economical and simple implementation of any improvements.

The third objective of this research study was the development of a procedure for evaluating a construction project to establish a contract time. The procedure developed includes steps for implementation within the current ISHC contracting system. The method developed has enough flexibility to allow its use on the various types of construction contracts awarded by the ISHC. The proposed system will account for several predictable factors which affect the contract duration, and will, hopefully, increase the accuracy of prediction. As part of the procedure, a list of time estimates for bid items was developed as a guide for establishing durations of projects. A review and explanation of the control uses of the method was also included as part of this objective.

1.3 Methods of Completing the Research

The objectives of this study were described in the preceding paragraphs. The method of completing the research and accomplishing these objectives will now be explained.

Considerable time is spent designing and planning highway construction projects before contract documents are given to contractors for their bid preparation. It is important to understand the many design and planning steps, as well as, their timing, sequence, and relationships with one another. Many people on the ISHC staff are involved with each project. Each of these individuals has specific tasks to accomplish which contribute to the successful completion of the project. Therefore the best approach to gaining a better understanding of the entire process was to interview the many individuals making the decisions related to the determination of contract times.

The first interview conducted in this investigation was with the Chief Engineer of the Construction Division of the ISHC, Mr. William Ritman and the Engineer of Construction Mr. Murray Cantrall. The interview centered around the general aspects of the contracting process for highway projects in Indiana. Specific types of projects, such as Maintenance, Traffic, Road, Bridge, etc. were discussed to identify the similarities and differences in the planning process for each. Individuals responsible for setting the contract times were identified and introduced. It was arranged for the researcher to receive monthly construction progress reports. Information was also provided indicating the status of current and past highway projects.

Individual interviews were then conducted with the various field engineers responsible for setting contract times. During these interviews the field engineers explained the process that they follow to establish the contract times. The assumptions made and factors considered along with the logic used were identified for each category of construction contract. Each interview included the actual setting of a contract time based on the contract documents by the field engineer with an explanation of the process being used.

The second phase of the investigation involved the review of the methods used by nearby states for setting contract times. Interviews were conducted with the Chief Construction Engineers from Illinois, Kentucky, and Ohio by telephone. The researcher traveled to Michigan to tour their facilities and interview the Deputy Director of Highways, Mr. G. J. McCarthy. The questions asked of all were as follows:

1. Who, in the organization (title), establishes the contract duration and completion date?
2. Who reviews and approves the duration and date specified in the contract?
3. What are the activities and sequence of events prior to contract letting?
4. At what point in the contract preparation are the duration and completion date established?
5. What method is employed in establishing the duration and completion date?
6. Which of these are used in identifying work activities?

    _____ area of responsibility

    _____ craft or crew requirement

    _____ equipment requirement

_____ material

_____ identifiable subdivision of work

_____ location of work

_____ payment of bidding items

7. What level of detail is used in defining activities?
8. What factors are considered in making the construction time estimates?
9. What assumptions are made about the contractors who will perform the work?
10. Are resource constraints assumed such as material, machinery, manpower, money, or time?
11. Is there an allowance made for uncontrollable factors such as weather, strikes, etc.?
12. Is a schedule included as part of the contract documents?
13. If a schedule is included, how is it used?
14. What schedule control is exercised over the contractor.
15. Roughly what percentage of your contracts run over the specified completion dates.

Subsequent to this, a review was made of current literature on scheduling techniques which would be applicable to the Indiana methodology. The various methods were evaluated to determine the possibilities for improvement or refinement for the current method being used.

The final part of this investigation centered around the development of an improved method for determination of ISHC highway construction contract times. The various possibilities were discussed with the field engineers and a procedure was developed. This included further input from the ISHC concerning time estimates for various construction activities. As a part of this development, anticipated productivities for various construction activities were compiled from members of the Indiana Highway Constructors Association. Final recommendations were made and reviewed with the ISHC.

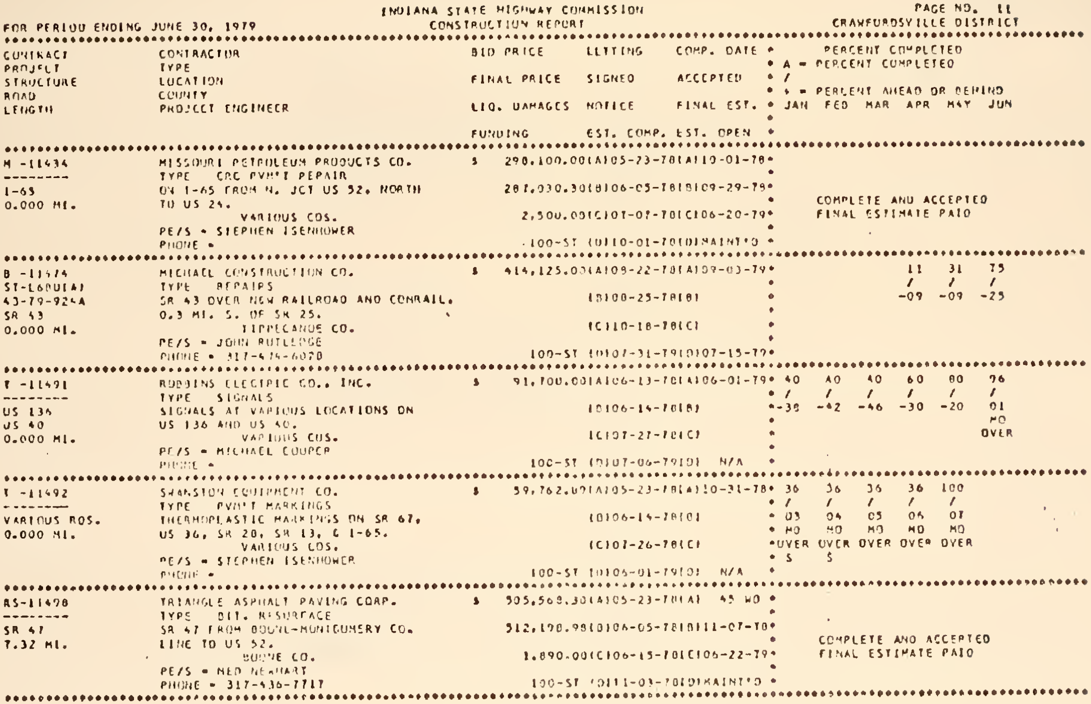
CHAPTER 2

GENERAL CAUSES FOR LATE COMPLETION OF HIGHWAY CONSTRUCTION CONTRACTS

The ISHC prepares a computer printout monthly showing the current status of highway construction contracts which are in progress or have been completed during the year. A sample of the data received from the Indianapolis office is shown in Figure 1. The report supplies information concerning the type of contract, the location and description of the work, the contractor, financial data, milestone dates, and progress of the project. A complete description of the information given is at the top of each page of the report. The contract number assigned to the project indicates the type of contract. The seven types of contracts are listed below indicating the letter designation used in the contract number.

Bridge - B
Road - R
Traffic - T
Maintenance - M
Road-Surface - RS
Road-Traffic - RT
Road-Maintenance - RM

Evaluation of the monthly reports from January through June of 1979 revealed that 40.4% of the highway contracts



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                                              INDIANA STATE HIGHWAY COMMISSION                                 PAGE NO.  11
FOR PERIOD ENDING JUNE 30, 1979                     CONSTRUCTION REPORT                                   CRAWFORDSVILLE DISTRICT
*************************************************************************************************************************************
CONTRACT           CONTRACTOR                             BID PRICE     LETTING    COMP. DATE *      PERCENT COMPLETED
PROJECT            TYPE                                                                       * A = PERCENT COMPLETED
STRUCTURE          LOCATION                               FINAL PRICE   SIGNED     ACCEPTED   * /
ROAD               COUNTY                                                                     * + = PERCENT AHEAD OR BEHIND
LENGTH             PROJECT ENGINEER                       LIQ. DAMAGES  NOTICE     FINAL EST. * JAN  FEB  MAR  APR  MAY  JUN
                                                                                              *
                                                          FUNDING       EST. COMP. EST. OPEN  *
*************************************************************************************************************************************
M -11434           MISSOURI PETROLEUM PRODUCTS CO.        $   290,100.00(A)05-23-78(A)10-01-78*
---------          TYPE   CRC PVM'T REPAIR                                                    *
I-65               ON I-65 FROM N. JCT US 52, NORTH           281,030.30(B)06-05-78(B)09-29-79*
0.000 MI.          TO US 24.                                                                  *    COMPLETE AND ACCEPTED
                             VARIOUS COS.                       2,500.00(C)07-07-78(C)06-20-79*    FINAL ESTIMATE PAID
                   PE/S - STEPHEN ISENHOWER                                                   *
                   PHONE -                                     100-ST (D)10-01-78(D)MAINT'D *
*************************************************************************************************************************************
B -11474           MICHAEL CONSTRUCTION CO.               $   414,125.00(A)09-22-78(A)09-03-79*              11   31   75
ST-L6PUI(A)        TYPE   REPAIRS                                                             *              /    /    /
43-79-924A         SR 43 OVER NEW RAILROAD AND CONRAIL.                 (B)00-25-78(B)        *              -09  -09  -25
SR 43              0.3 MI. S. OF SR 25.                                                       *
0.000 MI.                    TIPPECANOE CO.                             (C)10-18-78(C)        *
                   PE/S - JOHN RUTLEDGE                                                       *
                   PHONE - 317-474-6070                        100-ST (D)07-31-79(D)07-15-79*
*************************************************************************************************************************************
T -11491           ROBBINS ELECTRIC CO., INC.             $    91,700.00(A)06-13-78(A)06-01-79* 40   40   40   60   80   96
---------          TYPE   SIGNALS                                                             * /    /    /    /    /    /
US 136             SIGNALS AT VARIOUS LOCATIONS ON                      (B)06-14-78(B)        *-38  -42  -46  -30  -20   01
US 40              US 136 AND US 40.                                                          *                         MO
0.000 MI.                    VARIOUS COS.                               (C)07-27-78(C)        *                        OVER
                   PE/S - MICHAEL COOPER                                                      *
                   PHONE -                                     100-ST (D)07-06-79(D)   N/A    *
*************************************************************************************************************************************
T -11492           SWANSTON EQUIPMENT CO.                 $    59,762.07(A)05-23-78(A)10-31-78* 36   36   36   36  100
---------          TYPE   PVM'T MARKINGS                                                      * /    /    /    /    /
VARIOUS RDS.       THERMOPLASTIC MARKINGS ON SR 67,                     (B)06-14-78(B)        * 03   04   05   06   07
0.000 MI.          US 36, SR 20, SR 13, & I-65.                                               * MO   MO   MO   MO   MO
                             VARIOUS COS.                               (C)07-26-78(C)        *OVER OVER OVER OVER OVER
                   PE/S - STEPHEN ISENHOWER                                                   * S    S
                   PHONE -                                     100-ST (D)06-01-79(D)   N/A    *
*************************************************************************************************************************************
RS-11498           TRIANGLE ASPHALT PAVING CORP.          $   305,568.30(A)05-23-78(A)  45 WD *
---------          TYPE   BIT. RESURFACE                                                      *
SR 47              SR 47 FROM BOONE-MONTGOMERY CO.            312,190.98(B)06-05-78(B)11-07-78*
7.32 MI.           LINE TO US 52.                                                             *    COMPLETE AND ACCEPTED
                             BOONE CO.                          1,890.00(C)06-15-78(C)06-22-79*    FINAL ESTIMATE PAID
                   PE/S - NED NEWHART                                                         *
                   PHONE - 317-436-7717                        100-ST (D)11-03-78(D)MAINT'D *
*************************************************************************************************************************************
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Figure 1

Monthly Construction Progress Report

shown as completed were not completed within the specified time duration.

When contracts are not completed in the specified time, liquidated damages are assessed against the contractor. Table 1, from the Indiana State Highway Standard Specifications, indicates the daily charges assessed for delays.

TABLE 1

Schedule of Liquidated Damages for Each Day of Overrun in Contract Time

Original Contract Amount		Daily Change	
From More Than	To and Including	Calendar or Fixed Date	Work Day
0	25,000	30.00	42.00
25,000	50,000	50.00	70.00
50,000	100,000	75.00	105.00
100,000	500,000	100.00	140.00
500,000	1,000,000	150.00	210.00
1,000,000	2,000,000	200.00	280.00
2,000,000	4,000,000	300.00	420.00
4,000,000	7,000,000	400.00	560.00
7,000,000	10,000,000	550.00	770.00
10,000,000	-----	700.00	980.00

TABLE 2

Contracts with Liquidated Damages

Type of Contract	Number with Liquidated Damages
Bridge	22
Traffic	6
Road	11
Maintenance	11
Road-Surface	16
Road-Traffic	3
Road-Maintenance	0
Total	69

During this six month period liquidated damages were assessed on 69 of these contracts. A breakdown by contract type of the contracts with liquidated damages is shown in Table 2.

For the contracts shown in Table 2, it must be assumed that the reason for the late completion was due to the contractor's inability to perform the work in the specified time, or the contractor's choice to not perform the work in the specified time due to economic considerations. The state prequalifies contractors before allowing them to bid on contracts in an attempt to eliminate those contractors who do not have the resources or the expertise needed to perform the work. Prequalification of contractors generally involves evaluation of their financial status, their special area of expertise, and their past performance on projects for the Indiana State Highway Commission. The prequalification will imply minimum performance standards but the various contractors who will qualify may vary greatly in their abilities above the minimum. Therefore, each contractor will have his own economically optimal production rate which may be above or below the rate implied by the contract duration. For this reason contractors may choose to exceed the specified duration, because they are operating at a lower but more economical production rate, and add the anticipated cost of liquidated damages to their bid. Their bid may be competitively lower than other contractors who are pricing the work on the basis of the specified duration. At first glance, the contract price appears to be satisfactory since the low bid infers the least cost to the public. This may not be the case, however, when the additional costs of project staffing and administration are included in the total cost of the project for the days beyond the specified duration. Additionally, delays in completion deprive the public of the anticipated benefits of the project and often prolong inconveniences associated with construction.

Reviewing the monthly construction reports also revealed a significant number of projects for which liquidated damages were not yet charged but were late in their completion. Table 3 shows the breakdown of these projects between January and June 1979 by contract type.

TABLE 3

Contracts Completed Late Without Liquidated Damages

Type of Contract	Number completed late without liquidated damages
Bridge	27
Road	19
Maintenance	3
Traffic	33
Road-Traffic	6
Road-Surface	7
Road-Maintenance	0
Total	95

For many of the contracts listed in Table 3, the liquidated damage charges had not yet been computed and assessed at the reporting date. On the others, the delay could not be traced to the contractor.

Several reasons, for the completion delays in the 164 contracts shown in Tables 2 and 3 exist. Some of these problem areas can be identified with specific contract types while others can arise on any of the types of contracts. Indiana State Highway Personnel have indicated that material procurement is the primary problem encountered in completing traffic contracts. The delivery time for materials has recently increased greatly along with the increased demand on the manufacturing industry. Little can be done when the demand exceeds the supply. Since the contractor has bid the work on a fixed price basis, he cannot afford to offer the manufacturer an incentive or reimburse him for production overtime costs involved in meeting the delivery dates required by the contract. This problem is reflected in the large number of late completions for traffic contracts. Material delivery problems are not limited to traffic contracts. Often projects requiring either large orders of steel or steel fabrication such as bridges are delayed for months because of late deliveries. In general, contractors are not assessed liquidated damages when material shortages delay the project completion.

Unpredictable or severe weather can also delay most types of construction contracts. The delay may vary depending on the type of activity being performed. In some cases work may proceed regardless of weather, such as traffic signal work or shop fabrication. In still other instances, work will be halted beyond the period of severe weather due to such conditions as flooding or excessively wet soil conditions. Seasonal weather changes should not be considered as a factor in construction delays since it is accounted for either by specifying work days or in the calendar day conversion tables.

Another reason for completion delays arises from design changes after construction has started. In some cases this might occur from a mistake by the designers or from some obvious oversight of the existing conditions.

However, more commonly the design changes come about when something which has been hidden from sight is uncovered during the construction phase and must be replaced. A case of this type is often encountered on bridge deck repair work where the extent or scope of the project cannot be clearly defined until the existing surface is removed. Clearly if the designers must alter their original plans then the project will be delayed until a new design can be approved. Design change delays, in most cases, are unpredictable and unavoidable for the contractor and he is not assessed liquidated damages for the delay since the responsibility for the design is not within his scope of work.

In highway construction projects it is often impossible to determine the exact quantities prior to the commencement of work. For example, the designers cannot determine the quantity of muck to be removed for a project, but instead use an estimated quantity for bidding purposes and then pay the contractor for the measured amount removed. When quantities are greater than originally thought, it is obvious that a delay in completion may result. It is often difficult to analyze the extent of the delay without reviewing the entire construction plan for the possible secondary effects of the changes in quantities.

The current procedure for determing the time estension is quite simple. Using the contract unit prices, the new total contract price (computed with actual quantities) is divided by the original total contract price (computed with estimated quantities) and this value is multiplied by the original duration to give the new contract duration. This procedure has some drawbacks. First, it does not permit the determination of the new contract duration until after all work is complete. Therefore, the contractor does not have a goal or target date for completion established once the original quantities have been exceeded. Also, this procedure does not reflect the construction logic or the secondary effects of quantity changes on other activities. Finally, unbalanced bidding for units of work or work items which are low in cost, but very time consuming, cannot be accurately handled using this procedure to establish a new contract duration.

Construction projects are undertaken as needs are identified. Often a large number of similiar type work will be concentrated in a relatively small geographical area. After a severe winter in one corner of the state, there may be the need to resurface a large portion of the roads. Many times contractors will be awarded numerous projects which must all be completed in approximately the same time frame. To perform the work profitably the contractor is constrained to using his own manpower, equipment, and supervision. The contractor often has to make a choice as to which projects will be finished on time and which projects will be delayed.

Less frequently the completion of a project may be delayed due to the failure of a subcontractor to perform his portion of the work in a timely manner. The responsibility for subcontractor performance rests with the prime contractor in accordance with the contract between the ISHC and the prime contractor. Therefore, extreme care should be taken in the selection of subcontractors. A small delay by a subcontractor can have major implications to the overall project completion date.

There are numerous other causes for completion delays which may be unavoidable and unpredictable. Problems such as strikes, equipment failure, construction accidents or mistake, inspection delays, approval delays, transportation problems, site availability, and contractor default occur less frequently but still often have major impacts on the duration of a construction project.

CHAPTER 3

CURRENT ISHC METHOD FOR CONTRACT TIME DETERMINATION

The Unit Price Contract system is used in the State of Indiana for most highway construction projects. This system has been chosen for its inherent flexibility and controlled low cost feature. On highway projects it is often difficult to identify the exact work quantities to be performed by the contractor. Unknown subsurface conditions, unpredictable situations, and management decisions can cause changes to the estimated quantities. The Indiana State Highway Commission makes an estimate of the quantities of work or work items which are used in the contract. The estimate identifies units of work corresponding to an activity, such as lineal feet for pipe laying. The ISHC then compiles a comprehensive list of all of the work items and quantities, which is used to prepare the engineer's estimate. The list of quantities for work items is also the basis for determining the contract completion date to be used in the contract.

The completion dates for all highway projects are set in the Indianapolis office. Field engineers in the

Indianapolis office establish the duration or completion date for the projects in their geographical district. Each field engineer follows the same basic process in establishing the duration for completing the work items. It should be pointed out at this time that the entire process requires that many assumptions and judgments be made by the field engineers.

3.1 Procedure

The current procedure used involves the following steps.

1. EXAMINATION OF THE DRAWINGS, SPECIFICATIONS, AND CONTRACT DOCUMENTS. This step is extremely important to insure that the field engineer completely understands the scope of work of the contract. The field engineer gains an understanding of the existing items. Then he examines the special provisions to determine if there are any limitations placed on traffic disruption or closure. Further, he must determine if any special safety procedures must be followed. The purpose of this step is the familiarization of the field engineer with the project.
2. IDENTIFICATION OF THE CONTROLLING ACTIVITIES. In this step the field engineer reviews the quantities for each work item and makes a judgment

as to which work items will take the most time to complete. On many projects this may be a simple task; for example, a road project with massive quantities of earthwork and pavement. However, other projects such as bridges will have numerous work items of smaller quantities. Some of these work items may be dependent on each other, while others can be performed concurrently. The engineer must use his experience and make a judgment as to which activities will be the controlling ones.

3. <u>ESTABLISH THE ORDER OF THE WORK ACTIVITIES</u>. Upon determination of the controlling activities the field engineer establishes an order for the construction of those activities. Again the field engineer must use his experience and make an assumption about the probable order or sequence the contractor will follow. For some projects there may be more than one sequence of activities which could control the project duration, therefore the engineer identifies each of these.

4. <u>DETERMINATION OF THE ACTIVITY DURATION</u>. Activity durations are established from judgments made by the field engineer based on assumptions made about production rates. Production may vary widely depending upon the contractor. Generally the

engineer assumes higher productivity rates on larger projects. This assumption is based on the fact that larger contractors will bid on larger projects and these contractors will achieve higher daily production rates. It is assumed that smaller projects will experience lower production rates, since smaller contractors will perform the work and will probably not have the equipment and manpower to achieve higher rates of production. Larger contractors will probably not bid the smaller work or may not be competitive due to their higher overhead costs.

Another factor which is considered in this analysis is the location of the work. Urban construction will often be slower than rural due to traffic conjestion in the work area. Haul distance may also be a delay factor if borrow material is not readily available. The effect of the project location on activity duration must be evaluated by the field engineer.

5. SUMMATION AND ANALYSIS OF ACTIVITY DURATIONS. The activity durations for the controlling work items are added to give the total project duration. The field engineers review the sequence of controlling activities to determine if any overlap might exist

between work items. This would shorten the project duration. The review also reveals possible activities which might not be listed as a work item but would require time. Examples of this might be curing of concrete or drying of paint between applications. This type of activity would lengthen the duration of the project.

6. APPLY CONTINGENCY FACTOR. To the total duration calculated in the proceding steps a contingency factor is applied. The contingency allowance which is added usually varies from ten to twenty percent. The engineer evaluates the degree of uncertainty involved in his initial assumptions used to compute the activity durations and project schedule, and makes a judgment about the allowance he will use for the contingency factor.

7. APPLY WORK DAY TABLES TO TOTAL DURATION. For projects in which the contract duration will be expressed in calendar days or contracts with a specified calendar day completion date, the workday duration is translated to calendar days by use of Tables 4, 5, 6, and 7. These tables have been compiled based on actual historical experience for the different categories of highway construction projects performed in Indiana. The

Table 4

Distribution of Work Days

- Light Grading & Urban

DISTRIBUTION OF WORKING DAYS
BY MONTHS, THROUGH 110 W.D. YEAR
CUMULATIVE TOTALS PER MONTH.

LIGHT GRADING & URBAN

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	JAN												
0	FEB												
0	MAR												
4	APR	4	4	4	4								
3	MAY	17	17	17	17	13							
7	JUN	34	34	34	34	30	17						
8	JUL	52	52	52	52	48	35	18					
8	AUG	70	70	70	70	66	53	36	18				
8	SEP	88	88	88	88	84	71	54	36	18			
7	OCT	105	105	105	105	101	88	71	53	35	17		
5	NOV	110	110	110	110	106	93	76	58	40	22	5	
0	DEC												0
0	JAN												
0	FEB												
0	MAR												
4	APR	114	114	114	114	110	97	80	62	44	26	9	4
3	MAY	127	127	127	127	123	110	93	75	57	39	22	17
7	JUN	144	144	144	144	140	127	110	92	74	56	39	34
8	JUL	162	162	162	162	158	145	128	110	92	74	57	52
8	AUG	180	180	180	180	176	163	146	128	110	92	75	70
8	SEP	198	198	198	198	194	181	164	146	128	110	93	88
7	OCT	215	215	215	215	211	198	181	163	145	126	110	105
5	NOV	220	220	220	220	216	203	186	168	150	132	115	110
0	DEC												
0	JAN												
0	FEB												
0	MAR												
4	APR	224	224	224	224	220	207	190	172	154	136	119	114
3	MAY	237	237	237	237	233	220	203	185	167	149	132	127
7	JUN	254	254	254	254	250	237	220	202	184	166	149	144
8	JUL	272	272	272	272	268	255	238	220	202	184	167	162
8	AUG	290	290	290	290	286	273	256	238	220	202	185	180
8	SEP	308	308	308	308	304	291	274	256	238	220	203	198
7	OCT	325	325	325	325	321	303	291	273	255	237	220	215
5	NOV	330	330	330	330	326	313	296	278	242	225	220	
0	DEC												
0	JAN												
0	FEB												
0	MAR												
4	APR	334	334	334	334	330	317	300	282	264	246	229	224
3	MAY	347	347	347	347	343	330	313	295	277	259	242	237
7	JUN	364	364	364	364	360	347	330	312	294	276	259	254
8	JUL	382	382	382	382	378	365	348	330	312	294	277	272
8	AUG	400	400	400	400	396	383	366	348	330	312	295	290
8	SEP	418	418	418	418	414	401	384	366	348	330	313	308
7	OCT	435	435	435	435	431	318	401	383	365	347	330	325
5	NOV	400	400	400	400	436	423	406	393	370	352	335	330
0	DEC												

Table 5

Distribution of Work Days

-Medium & Heavy Grading

DISTRIBUTION OF WORKING DAYS
BY MONTHS, THROUGH 100 W. D. YEAR
CUMULATIVE TOTALS PER MONTH.

MEDIUM & HEAVY GRADING

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JAN												
FEB												
MAR												
APR	4	4	4	4								
MAY	17	17	17	17	13							
JUN	32	32	32	32	28	15						
JUL	48	48	48	48	44	31	16					
AUG	65	65	65	65	61	48	33	17				
SEP	80	80	80	80	76	63	48	32	15			
OCT	95	95	95	95	91	78	63	47	30	15		
NOV	100	100	100	100	100	83	68	52	35	20	5	
DEC												0
JAN												
FEB												
MAR												
APR	104	104	104	104	100	87	72	56	39	24	9	4
MAY	117	117	117	117	113	100	85	69	52	37	22	17
JUN	132	132	132	132	128	115	100	84	67	52	37	32
JUL	148	148	148	148	144	131	116	100	83	68	53	48
AUG	165	165	165	165	161	148	133	117	100	85	70	65
SEP	180	180	180	180	176	163	148	132	115	100	85	80
OCT	195	195	195	195	191	178	163	147	130	115	100	95
NOV	200	200	200	200	196	183	168	152	135	120	105	100
DEC												
JAN												
FEB												
MAR												
APR	204	204	204	204	200	187	172	156	139	124	109	104
MAY	217	217	217	217	213	200	185	169	152	137	122	117
JUN	232	232	232	232	228	215	200	184	167	152	137	132
JUL	248	248	248	248	244	231	216	200	183	168	153	148
AUG	265	265	265	265	261	248	233	217	200	185	170	165
SEP	280	280	280	280	276	263	248	232	215	200	185	180
OCT	295	295	295	295	291	278	263	247	230	215	200	195
NOV	300	300	300	300	296	283	268	252	235	220	205	200
DEC												
JAN												
FEB												
MAR												
APR	304	304	304	304	300	287	272	256	239	224	209	204
MAY	317	317	317	317	313	300	285	269	252	237	222	217
JUN	332	332	332	332	328	315	300	284	267	252	237	232
JUL	348	348	348	348	344	331	316	300	283	268	253	248
AUG	365	365	365	365	361	348	333	317	300	285	270	265
SEP	380	380	380	380	376	363	348	332	315	300	285	280
OCT	395	395	395	395	391	378	363	347	330	315	300	295
NOV	400	400	400	400	396	383	368	352	335	320	305	300
DEC												

Table 6

Distribution of Work Days-Bridges

BRIDGE

DISTRIBUTION OF WORKING DAYS
BY MONTHS, THROUGH 135 W.D. YEAR
CUMULATIVE TOTALS PER MONTH.

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	JAN												
0	FEB												
0	MAR												
4	APR	14	14	14	14								
6	MAY	30	30	30	30	16							
8	JUN	48	48	48	48	34	18						
9	JUL	67	67	67	67	53	37	19					
8	AUG	85	85	85	85	71	55	37	18				
8	SEP	103	103	103	103	89	73	55	36	18			
7	OCT	120	120	120	120	106	90	72	53	35	17		
5	NOV	135	135	135	135	121	105	87	68	50	32	15	
0	DEC												0
0	JAN												
0	FEB												
0	MAR												
4	APR	149	149	149	149	135	119	101	82	64	46	29	14
6	MAY	165	165	165	165	151	135	117	98	80	62	45	30
8	JUN	183	183	183	183	169	153	135	116	98	80	63	48
9	JUL	202	202	202	202	188	172	154	135	117	109	82	67
8	AUG	220	220	220	220	206	190	172	153	135	117	100	85
8	SEP	238	238	238	238	224	208	190	171	153	135	118	103
7	OCT	255	255	255	255	241	225	207	188	170	152	135	120
5	NOV	270	270	270	270	256	240	222	203	185	167	150	135
0	DEC												
0	JAN												
0	FEB												
0	MAR												
4	APR	284	284	284	284	270	254	236	217	199	181	165	149
6	MAY	300	300	300	300	286	270	252	233	215	197	180	165
8	JUN	318	318	318	318	304	288	270	251	233	215	199	183
9	JUL	337	337	337	337	323	307	289	270	252	234	217	202
8	AUG	355	355	355	355	341	325	307	288	270	252	235	220
8	SEP	373	373	373	373	359	343	325	306	288	270	253	238
7	OCT	390	390	390	390	376	360	342	323	305	287	270	255
5	NOV	405	405	405	405	391	375	357	338	320	302	285	270
0	DEC												
0	JAN												
0	FEB												
0	MAR												
4	APR	419	419	419	419	405	389	371	352	334	316	299	284
6	MAY	435	435	435	435	421	405	387	368	350	332	315	300
8	JUN	453	453	453	453	439	423	405	386	368	350	333	315
9	JUL	472	472	472	472	458	442	424	405	387	369	352	337
8	AUG	490	490	490	490	476	460	442	423	405	387	370	355
8	SEP	508	508	508	508	494	478	460	441	423	405	385	373
7	OCT	525	525	525	525	511	495	477	458	440	422	405	390
5	NOV	540	540	540	540	526	510	492	473	455	437	420	405
0	DEC												

Table 7

Distribution of Work Days -Traffic

DISTRIBUTION OF WORKING DAYS
BY MONTHS, THROUGH 150 W.D. YEAR.
CUMULATIVE TOTALS PER MONTH.

TRAFFIC W. DAY SCHEDULE

	MON	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	JAN	0											
0	FEB	0	0										
0	MAR	0	0	0									
10	APR	10	10	10	10								
15	MAY	25	25	25	25	15							
22	JUN	47	47	47	47	37	23						
22	JUL	69	69	69	69	59	44	22					
23	AUG	92	92	92	92	82	67	45	23				
23	SEP	115	115	115	115	105	90	68	46	23			
18	OCT	133	133	133	133	123	103	86	64	41	18		
15	NOV	148	148	148	148	138	123	101	79	56	33	15	
2	DEC	150	150	150	150	140	125	1103	81	58	35	17	2
0	JAN	"	"	"	"	"	"	"	"	"	"	"	"
0	FEB	"	"	"	"	"	"	"	"	"	"	"	"
0	MAR	"	"	"	"	"	"	"	"	"	"	"	"
10	APR	160	160	160	160	150	135	113	91	68	45	27	12
15	MAY	175	175	175	175	165	150	128	106	83	60	42	27
22	JUN	197	197	197	197	187	172	150	128	105	82	64	40
22	JUL	219	219	219	219	209	194	172	150	127	104	86	71
23	AUG	242	242	242	242	232	217	195	173	150	127	109	94
23	SEP	265	265	265	265	255	240	218	196	173	150	132	117
18	OCT	283	283	283	283	273	258	236	214	191	168	150	135
15	NOV	298	298	298	298	288	273	251	229	206	183	165	150
2	DEC	300	300	300	300	290	275	253	231	208	185	167	152
0	JAN	"	"	"	"	"	"	"	"	"	"	"	"
0	FEB	"	"	"	"	"	"	"	"	"	"	"	"
0	MAR	"	"	"	"	"	"	"	"	"	"	"	"
10	APR	310	310	310	310	300	285	263	241	218	195	177	162
15	MAY	325	325	325	325	315	300	278	256	233	210	192	177
22	JUN	347	347	347	347	337	322	300	278	255	232	214	199
22	JUL	369	369	369	369	359	344	322	300	277	254	236	221
23	AUG	392	392	392	392	382	367	345	323	300	277	259	244
23	SEP	415	415	415	415	405	390	368	346	323	300	282	267
18	OCT	433	433	433	433	423	408	386	364	341	318	300	285
15	NOV	448	448	448	448	438	423	401	379	356	333	315	300
2	DEC	450	450	450	450	440	425	403	381	358	335	317	302
0	JAN	"	"	"	"	"	"	"	"	"	"	"	"
0	FEB	"	"	"	"	"	"	"	"	"	"	"	"
0	MAR	"	"	"	"	"	"	"	"	"	"	"	"
10	APR	460	460	460	460	435	435	413	391	368	345	327	312
15	MAY	475	475	475	475	465	450	428	406	383	360	342	327
22	JUN	497	497	497	497	487	472	450	428	405	382	364	349
22	JUL	519	519	519	519	509	494	472	450	427	404	386	371
23	AUG	542	542	542	542	532	517	495	473	450	427	409	394
23	SEP	565	565	565	565	555	540	518	496	473	450	432	417
18	OCT	583	583	583	583	573	558	536	514	491	468	450	435
15	NOV	598	598	598	598	588	573	551	529	506	483	465	450
2	DEC	600	600	600	600	590	575	553	531	508	483	467	452

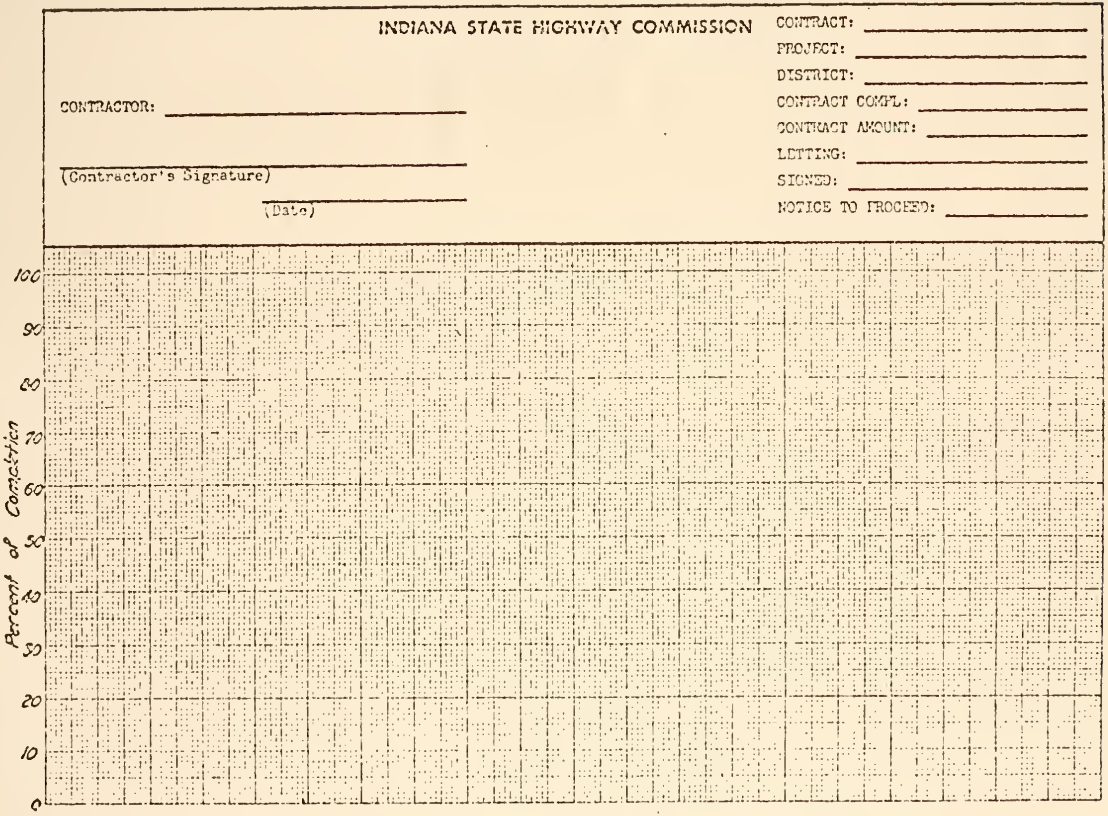
translation is made by choosing the month of commencement of work on the horizontal scale and reading vertically downward until you read a number of working days equal to or larger than the estimated workday duration. Reading horizontally to the left produces the month for completion of the project. As an example, if it is estimated that a bridge contract will require 180 working days to complete and work is expected to begin on July 15, 1980, the completion date would be determined from Table 6 as follows: Reading vertically downward from July until a number equal to or larger than 180 is reached and then reading to the left yields September, 1981 as the month of completion. It should be noted that work days are not charged during the months of December, January, February, or March, nor is it assumed that work will be performed during these months when converting to a calendar date completion. Thus the completion date which would be used for the example project would be September 15, 1981. This procedure and the tables which have been developed attempt to account for the contractor being unable to work due to poor weather conditions.

8. COMPARE DURATION OR COMPLETION DATE TO PREVIOUS PROJECTS. Finally the engineer compares his time prediction with similar previous projects of the same type and scope. This provides a good check for the reasonableness of his estimate. Assuming this is in line, the completion date, or duration for the project, is now set.

3.2 General Comments on the Current Procedure

The entire process for determination of contract duration is performed in, at most, a couple of hours. The engineer makes his working notes on a few 8 1/2" x 11" pages for even a large project. This is the only record of the assumptions made and the logic used in determination of contract duration for a project. It should also be noted that the Engineer's Cost Estimate is performed completely independent of the determination of the project completion date.

For monitoring, the monthly construction report discussed in Chapter Two shows the current progress of projects not yet completed. The report shows the planned percent complete and the actual percent complete. The planned percent complete is taken from the progress schedule, Figure 2, which must be prepared by the contractor and approved by the Indiana State Highway Commission prior to



INDIANA STATE HIGHWAY COMMISSION

CONTRACTOR: ____________________

____
(Contractor's Signature)

____
(Date)

CONTRACT: ____________________
PROJECT: ____________________
DISTRICT: ____________________
CONTRACT COMPL: ____________________
CONTRACT AMOUNT: ____________________
LETTING: ____________________
SIGNED: ____________________
NOTICE TO PROCEED: ____________________

Figure 2

Progress Schedule

starting construction. The percent of completion is shown on the left edge vertically and the accumulated time on the bottom horizontally. The percent completion is computed on a monetary basis for both the planned and actual percent completions. While the information may be useful for budget information to the Indiana State Highway Commission, it lends little relevance to identification of contracts which are seriously behind schedule. If the contractor changes his work plan he may appear to be ahead of schedule because he has completed more expensive work items while in fact, he is behind schedule because he has not started less expensive, but more time consuming, activities. It appears that while the current procedure is quite simple, modifications could be made which would improve the current methodology for establishing contract times.

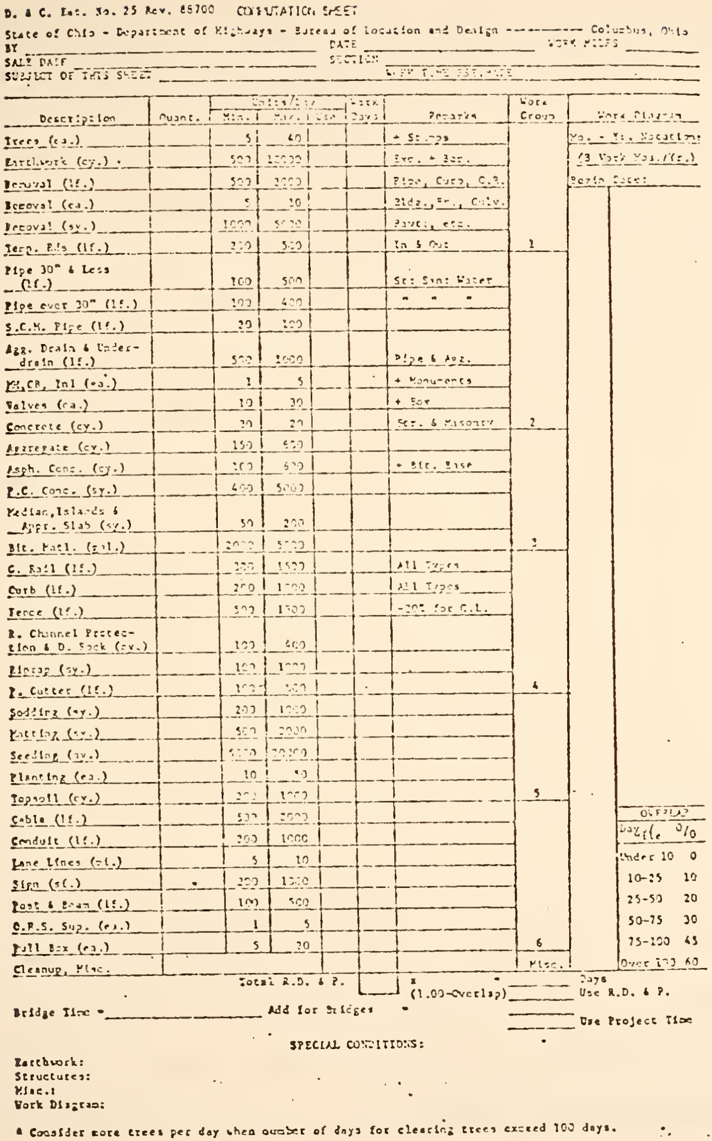
Chapter 4

METHODS USED BY OTHER STATES FOR CONTRACT TIME DETERMINATION

The second major objective of this study was the evaluation of current methods used by other states for determination of contract times for highway projects. The four bordering states to Indiana were chosen due to their proximity and similar working environments. All of these states, as well as Indiana, utilize the unit-price contracting system for highway projects. The researcher contacted members of each state's highway department staff responsible for setting contract times. Included in the following pages are descriptions and supplemental information for the methods employed by Ohio, Illinois, Kentucky and Michigan to establish contract times.

4.1 Ohio Methodology

The Department of Highways in Ohio has developed a unique method for determination of contract times. The contract time is established by the estimating engineer. The duration is, therefore, set by the same person who establishes the cost estimate. The duration must then be approved by both the Engineer of Planning and the Engineer of Construction. Ohio has developed a computation sheet for use by the estimating engineer to evaluate the project and establish the number of work days necessary for completion (see Figure 3). A brief description of the methodology used by the estimating engineer and an explanation of the computation sheet follows. The estimating engineer first examines the bid items to establish the items of work or activities which are required for completion. Listed in the left hand column of the computation sheet are typical work or bid items used for highway construction projects. The listing on the computation sheet is not inclusive of all work items but does identify the items of work which, in most cases, will be the controlling items. The items listed will, in most contracts, be a major part of the project or may be items which must be completed before other major items of work can commence. Column two, titled "Quant" is provided for the estimating engineer to compile the total amount of the work item involved in the project. It is necessary for the estimating engineer to combine actual bid items to determine the quantities for the work items described on the computation sheet. In columns three and four are listed minimum and maximum production rates which can be expected for each of the listed work items. As can be seen from the values listed, a wide range of productivity exists. It is therefore necessary for the estimating



D. & C. Est. No. 25 Rev. 85700 COMPUTATION SHEET

State of Ohio - Department of Highways - Bureau of Location and Design ---------- Columbus, Ohio

BY ____________ DATE ____________ WORK MILES ______

SALE DATE ____________ SECTION ____________

SUBJECT OF THIS SHEET ____________ [illegible] TIME ESTIMATE

Description	Quant.	Units/Day Min.	Units/Day Max.	Units/Day Use	Work Days	Remarks	Work Group
Trees (ea.)		5	40			+ Stumps	
Earthwork (cy.)		500	10000			Exc. + Bor.	
Removal (lf.)		500	2000			Pipe, Curb, C.B.	
Removal (ea.)		5	20			Bldg., Fr., Culv.	
Removal (sy.)		1000	5000			Pavt., etc.	
Temp. Rds (lf.)		200	500			In & Out	1
Pipe 30" & Less (lf.)		100	500			Stm. San. Water	
Pipe over 30" (lf.)		100	400			" " "	
S.C.M. Pipe (lf.)		20	100				
Agg. Drain & Underdrain (lf.)		500	2000			Pipe & Agg.	
MH, CB, Inl (ea.)		1	5			+ Monuments	
Valves (ea.)		10	30			+ Box	
Concrete (cy.)		10	20			Str. & Masonry	2
Aggregate (cy.)		150	600				
Asph. Conc. (cy.)		100	600			+ Bit. Base	
P.C. Conc. (sy.)		400	5000				
Median, Islands & Appr. Slab (sy.)		50	200				
Bit. Matl. (gal.)		2000	5000				3
G. Rail (lf.)		200	1500			All Types	
Curb (lf.)		200	1000			All Types	
Fence (lf.)		500	1500			-20% for C.L.	
R. Channel Protection & D. Rock (cy.)		100	400				
Riprap (sy.)		100	1000				
P. Gutter (lf.)		100	500				4
Sodding (sy.)		200	1000				
Matting (sy.)		500	2000				
Seeding (sy.)		5000	20000				
Planting (ea.)		10	50				
Topsoil (cy.)		200	1000				5
Cable (lf.)		500	2000				
Conduit (lf.)		200	1000				
Lane Lines (ml.)		5	10				
Sign (sf.)		200	1000				
Post & Beam (lf.)		100	500				
O.R.S. Sup. (ea.)		1	5				
Pull Box (ea.)		5	20				6
Cleanup, Misc.							Misc.

Work Diagram

Mo. - Yr. Vacations

(3 Work Mos./Yr.)

Begin Date:

OVERLAP	
Days [illegible]	%
Under 10	0
10-25	10
25-50	20
50-75	30
75-100	45
Over 100	60

Total R.D. & P. ______ x (1.00-Overlap) = ______ Days Use R.D. & P.

Bridge Time = ____________ Add for Bridges = ______

______ Use Project Time

SPECIAL CONDITIONS:

Earthwork:
Structures:
Misc.:
Work Diagram:

* Consider more trees per day when number of days for clearing trees exceed 100 days.

Figure 3

Contract Time Computation Sheet

Ohio

engineer to make a judgment or assumption about the productivity rate which can be reasonably expected.

Many factors may enter into the decision the estimator makes. Such factors might be working conditions (urban or rural), type or size of equipment to be used, labor availability, and prequalifications of the contractor. The assumptions made and the decision concerning the production rate are the keys to reasonable and accurate time estimates. The productivity rate chosen is then entered in column five. The work days for each work item is computed by simply dividing the quantity, from column two, by the chosen productivity rates, in column five. The work days for each item are entered in column six. The "remarks" column is provided for further descriptive information about each work item. The work items are classified into seven major work groups.

The right hand portion of the computation sheet is space provided to show the planned beginning and completion dates of each of the groups of work. After the computed work days for each activity have been entered into Column 6 a total for all activities is computed and entered in the space provided at the bottom of that column. In the lower right hand portion of the computation sheet overlap factors are listed. As can be seen the degree of overlap varies directly with the days per mile of road construction. For instance, if the total work days for a 5 mile project is computed to be 120 days then an overlap factor of 10% would be applied. This table attempts to demonstrate and reflect the degree of overlap of work activities on highway projects which are large in scope. Smaller projects would have little or no overlap and very large projects would have up to 60 percent overlap reflecting the many con-current activities which would be ongoing at any time during the project duration. The total work days are then multiplied by one minus the overlap factor. This value represented the adjusted total work day duration for the roadway portion of the project. Finally consideration is made for the time needed for any bridges included in the project. With this information the project time is established.

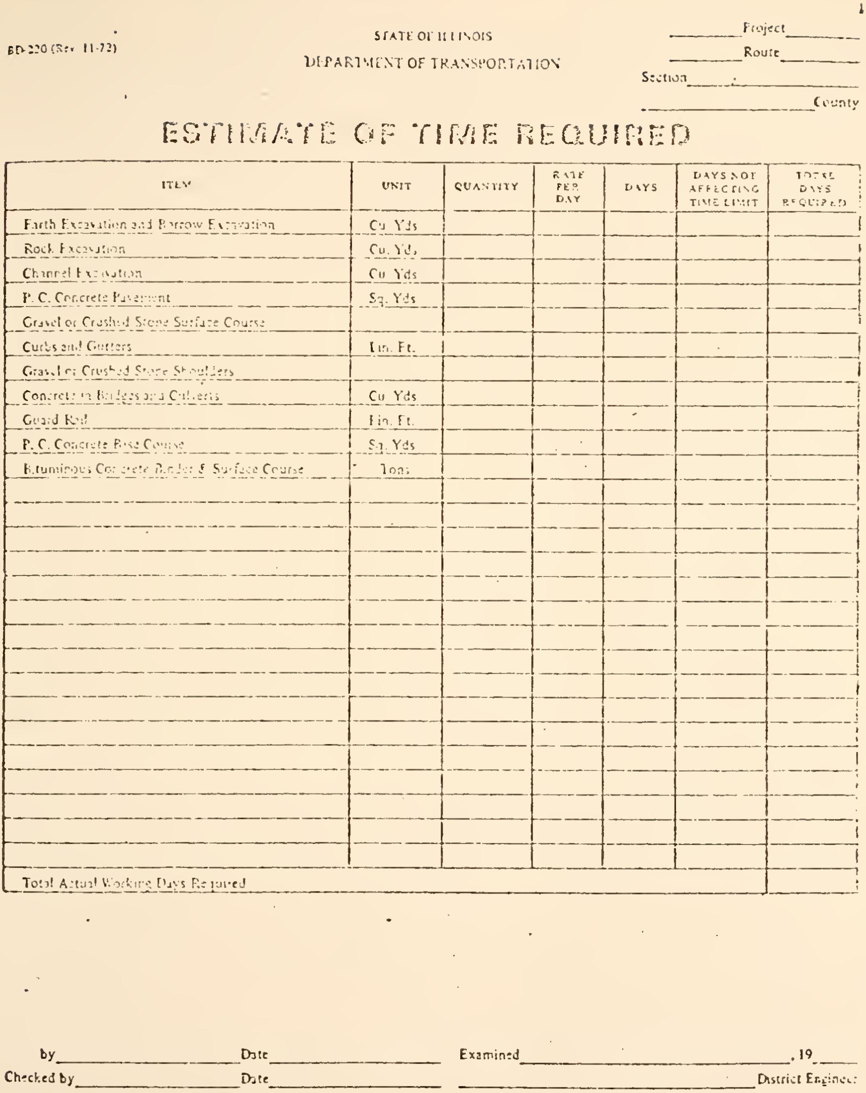
Ohio establishes the completion time by specifying the contract duration in terms of work days on nearly all of its highway construction work. Work days are not charged during the months of December, January, February, or March. Normally, only ten work days in November and ten in April can be expected. May and October are assumed to each have fifteen work days available and June, July, August, and September are assumed to have twenty work days each. Ohio does not include a schedule as part of the contract documents but does require the contractor to submit a progress schedule prior to commencement of work. The schedule must be revised if the contractor falls more than fifteen percent behind. Currently, roughly forty percent of the highway construction projects are completed late in Ohio.

4.2 Illinois Methodology

The Illinois Department of Transportation has also developed their own unique system of establishing contract duration. The project engineer in the appropriate district office is the originator of the contract duration. After the project duration has been estimated a review is made by the district design engineer and the Chief Engineer of Plan Review and Assembly in the Central Bureau of Design. Upon their review and approval the duration is established for use in the contract documents. Illinois utilizes a working day approach to specify the contract duration. The method of establishing the allowable working days is quite simple; a brief description of the method follows.

The project engineer primarily considers the location of the work and the payment or bidding items in identifying the work activities. The level of detail used is quite extensive since all major pay items are considered in his overall evaluation of the project. The guidelines which have been established by Illinois for the estimation of contract time merit consideration to adquately explain the rationale for the assumptions the project engineer makes. First, the guidelines stress that severe time limitations can unnecessarily constrain contractors, and thereby cause inflated bids and less than desirable relationships between the contractor and the Department of Transportation. More specifically, feasible time limits should consider the logical sequence of construction operations and be based on sound engineering judgments. The guidelines highlight that the magnitude of the project must be evaluated and considered when making estimates. The contractor on a small project will utilize a smaller work force and equipment fleet than a contractor involved in large multimillion dollar project. The guidelines also specify that consideration should be given to material delivery time in making contract time estimates. As a final point, the guidelines recommend periodic review and revision of the construction productivity rates to incorporate changes which may come about through advancements in either equipment output or construction techniques. As a part of the guidelines developed, the project engineer prepares his time estimate on a form BD220. A copy of this form is shown in Figure 4.

Completion of form BD220 will establish the number of allowable working days for a project. In column one of the form the project engineer lists each of the work items which are major bid items for the project. Column two is provided for the production units which pertain to the various work items. Quantities of each work item are entered in the third column by the project engineer. The fourth column is used for the expected daily productivity rates. The project engineer obtains productivity data



BD-220 (Rev 11-73)

STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION

______ Project ______
______ Route ______
Section ______
______ County

ESTIMATE OF TIME REQUIRED

ITEM	UNIT	QUANTITY	RATE PER DAY	DAYS	DAYS NOT AFFECTING TIME LIMIT	TOTAL DAYS REQUIRED
Earth Excavation and Borrow Excavation	Cu Yds					
Rock Excavation	Cu. Yds					
Channel Excavation	Cu Yds					
P. C. Concrete Pavement	Sq. Yds					
Gravel or Crushed Stone Surface Course						
Curbs and Gutters	Lin. Ft.					
Gravel or Crushed Stone Shoulders						
Concrete in Bridges and Culverts	Cu Yds					
Guard Rail	Lin. Ft.					
P. C. Concrete Base Course	Sq. Yds					
Bituminous Concrete Binder & Surface Course	Tons					
Total Actual Working Days Required						

by ______ Date ______ Examined ______, 19____
Checked by ______ Date ______ ______ District Engineer

Figure 4

Estimate of Time Required

Illinois

from various sources. The rates for major items have been tabulated by the Illinois Department of Transportation from past experience. The production rate data which Illinois uses is shown in Table 8. In the case of earth excavation and concrete pavement the project engineer uses the graphs shown in Figures 5 and 6. For earth excavation the project engineer computes the cubic yards of excavation per mile. Identifying this value on the horizontal scale and proceding upward to the intersection with the curve will yield the average daily production rate on the vertical scale. A similar procedure is followed to determine production rates for concrete pavement. For work items which are not included in the table the project engineer uses rates from the district construction files determined on previous highway projects. The fifth column on form BD220 is completed by dividing the quantity by the daily production rate for each work item. The value computed is the number of work days which will be necessary for completion of the work item. The sixth column is intended to indicate the number of days of overlap that the work item has with other activities. The project engineer must make a judgment concerning which operations will be performed similtaneously or

TABLE 8

CONSTRUCTION DAILY PRODUCTION TABLE

ITEM	PRODUCTION RATE PER DAY
Adjusting Frames & Grates	5 Each
Aluminum Handrail	80 Lin. Ft.
Bituminous Concrete Base Course Widening 9"	1,100 Sq. Yds.
Bituminous Concrete Binder & Surface Course, Sub I-11	500-550 Tons
Bituminous Materials	5,000 Gals.
Bituminous Materials Pumped	5,000 Gals.
Borrow Excavation	See Figure 8-401.02a
Catch Basins	5 Each
Chain Link Fence	1,200 Lin. Ft.
Channel Excavation	650 Cu. Yds.
Class "A" Concrete	8 Cu. Yds.
Class "A" Excavation for Structures	150 Cu. Yds.
Class "B" Excavation for Structures	100 Cu. Yds.
Class "X" Concrete (Culverts)	8 Cu. Yds.
Class "X" Concrete (Headwalls)	4 Cu. Yds.
Class "X" Concrete (Superstructure Bridge)	12 Cu. Yds.
Class "X" Concrete (Substructure Bridge)	8 Cu. Yds.
Cleaning & Painting	50,000 (3 men/day)
Cofferdams Excavation	75 Cu. Yds.
Combination Curb & Gutter	300 Lin. Ft.
Concrete Gutter	500 Lin. Ft.
Concrete Removal	20 Cu. Yds.
Concrete Riprap	175 Sq. Yds.
Continuously Reinforced Concrete Pavement	See Figure 8-501.02b
Curb & Gutter	300 Lin. Ft.
Curb & Gutter Removal	800 Lin. Ft.
Driving Concrete Piles	250 Lin. Ft.
Driving Steel Piles	350 Lin. Ft.
Driving Timber Piles	300 Lin. Ft.
Electric Cable	2,500 Lin. Ft.
Embankment	2,200 Cu. Yds.
Erecting Handrail	80 Lin. Ft.
Erecting Right-of-Way Markers	30 Each
Erecting Structure Steel	25,000 Lbs.
Evergreens	20-25 Each
Excavation:	
Borrow	See Figure 8-501.02a
Earth	See Figure 8-501.02a

TABLE 8 (Continued)

CONSTRUCTION DAILY PRODUCTION TABLE

ITEM	PRODUCTION RATE PER DAY
Special	500 Cu. Yds.
Channel	650 Cu. Yds.
Cofferdam	75 Cu. Yds.
Earth (Shouldering, Widening)	500 Cu. Yds.
Rock	100 Cu. Yds.
Expansion Bolts	25 Each
Exploration Trench, 52" Depth	200 Lin. Ft.
Fabrication & Furnishing Structural Steel (Avg. 3 Span Structures)	
WF Beam	150 Calendar Days
Welded Plate Girder	180 Calendar Days
Gravel or Crushed Stone Base Course	800 Tons
Gravel or Crushed Stone Shoulders	800 Tons
Gravel or Crushed Stone Surface Course	
Granular Backfill	300 Cu. Yds.
Granular Embankment Special	800 Tons
Guard Rail	275 Lin. Ft.
Gutter Cracking	1,000 Lin. Ft.
Handholes (Electric)	4 Each
Handrail Concrete	1 Cu. Yds.
Hedge Removal	5-10 Unit
Holes Drilled	250 Each
Inlets	5 Each
Intermediate Trees	25-50 Each
Jute Matting	1,200 Sq. Yds.
Landscaping:	
Evergreens	20-25 Each
Intermediate Trees	25-35 Each
Seeding	10 Acres
Shade Trees	15-20 Each
Shrubs	250-350 Each
Sodding	800-1,000 Sq. Yds.
Top Soil	350 Cu. Yds.
Laying Signal Conduit	375 Lin. Ft.
Lightweight Structural Concrete	10 Cu. Yds.
Limestone Ground Aggregate	10 Tons
Manholes	3 Each
Median	300 Lin. Ft.
Median Surface (Concrete)	3,000 Sq. Ft.
Membrane Waterpoofing	500 Sq. Ft.
Metal Handrail	80 Lin. Ft.

TABLE 8 (Continued)

CONSTRUCTION DAILY PRODUCTION TABLES

ITEM	PRODUCTION RATE PER DAY
Moving, Fire Hydrants, Light Standards, Traffic Signals, Buffalo Boxes, etc.	2 Each
Patching	75 Sq. Yds.
Paved Ditch	300 Lin. Ft.
Pavement Removal	1,000 Sq. Yds.
Pavement Removal and Replacement	75 Sq. Yds.
Pipe Culverts	200 Lin. Ft.
Pipe Underdrains	500 Lin Ft.
P.C. Concrete Base Course	See Figure 8-501.02b
P.C. Concrete Base Course Widening	1,200 Sq. Yds.
P.C. Concrete Driveway	100 Sq. Yds.
P.C. Concrete Median	300 Lin Ft.
P.C. Concrete Pavement	See Figure 8-501.02b
P.C. Concrete Sidewalk	1,000 Sq. Ft.
Porous Granular Embankment	500 Cu. Yds.
Precast Concrete Bridge Deck	250-300 Sq. Ft.
Preparation of Base	4,000 Sq. Yds.
Prestress Concrete Beams	3 weeks for approval of shop, plans, then 3 beams @ 50'/day plus 3 days for curing
Protective Coat	10,000 Sq. Yds.
Raceway for Magnetic Detectors	50 Lin. Ft.
Reinforcement Bars (Culverts)	(Considered with Cl.X concrete)
Reinforcement Bars (Substructure)	2,500 Lbs.
Reinforcement Bars (Superstructure)	5,000 Lbs.
Relocate Existing Traffic Signal Posts	4 Each
Remove and Reset Metal Handrail	50 Lin. Ft.
Rock Excavation	100 Cu. Yds.
Seeding (Large Jobs)	10 Acres
Seedling Trees	2,000 (By Hand) Each 10,000 (By Machine)
Shade Trees	15-20 Each
Shrubs	250-350 Each
Sidewalk, P.C. Concrete	1,000 Sq. Ft.
Sidewalk Removal	1,500 Sq. Ft.
Slope Wall	50 Sq. Ft.
Sodding	800-1,000 Sq. Yds.

TABLE 8 (Continued)

CONSTRUCTION DAILY PRODUCTION TABLE

Item	Production Rate Per Day
Special Excavation	500 Cu. Yds.
Stabilized Shoulders	1,500 Sq. Yds.
Stabilized Subbase 4"	4,000 Sq. Yds.
Steel Plate Beam Guard Rail	250 Lin..Ft.
Storm Sewers	200 Lin. Ft.
Straw for Asphalt Coated Mulch	4-6 Tons
Subbase Granular Materials	800 Tons
Thermoplastic Pavement Marking	15,000 Lin. Ft.
Thermoplastic Pavement Marking Symbol	45 Sq. Ft.
Top Soil	350 Cu. Yds.
Traffic Signal Head Alternations	4 Each
Traffic Signal Posts	4 Each
Tree Removal (6" to 15")	110 In. Dia.
Tree Removal (Over 15")	110 In. Dia.
Tree Removal	1.5 Acres
Trench Excavation (52" Deep Exploration)	200 Lin. Ft.
Trench and Backfill	450 Lin. Ft.
Vines	2,000 Each
Woven Wire Fence	2,000 Lin. Ft.

Note: These figures are based on the output of one average construction unit in an 8 hour day.

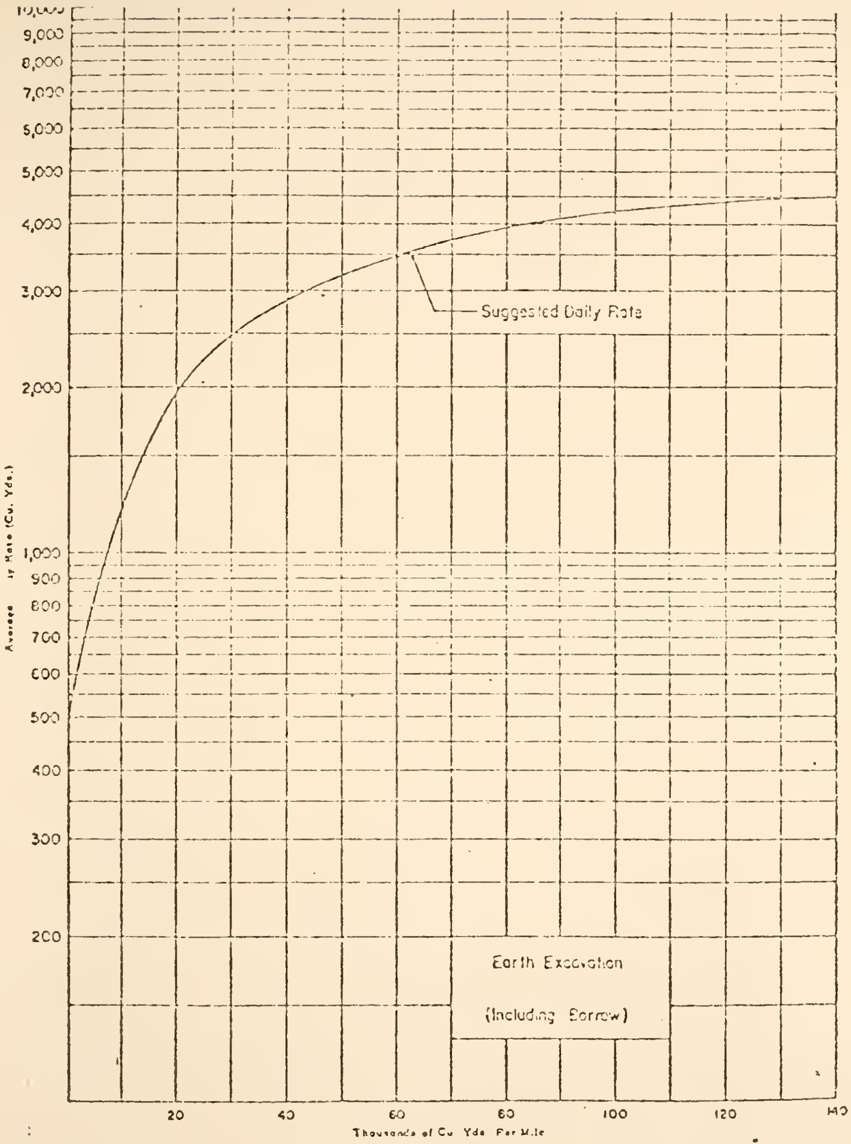


Figure 8-301.32a

Figure 5

Suggested Daily Rate for

Earth Excavation - Illinois

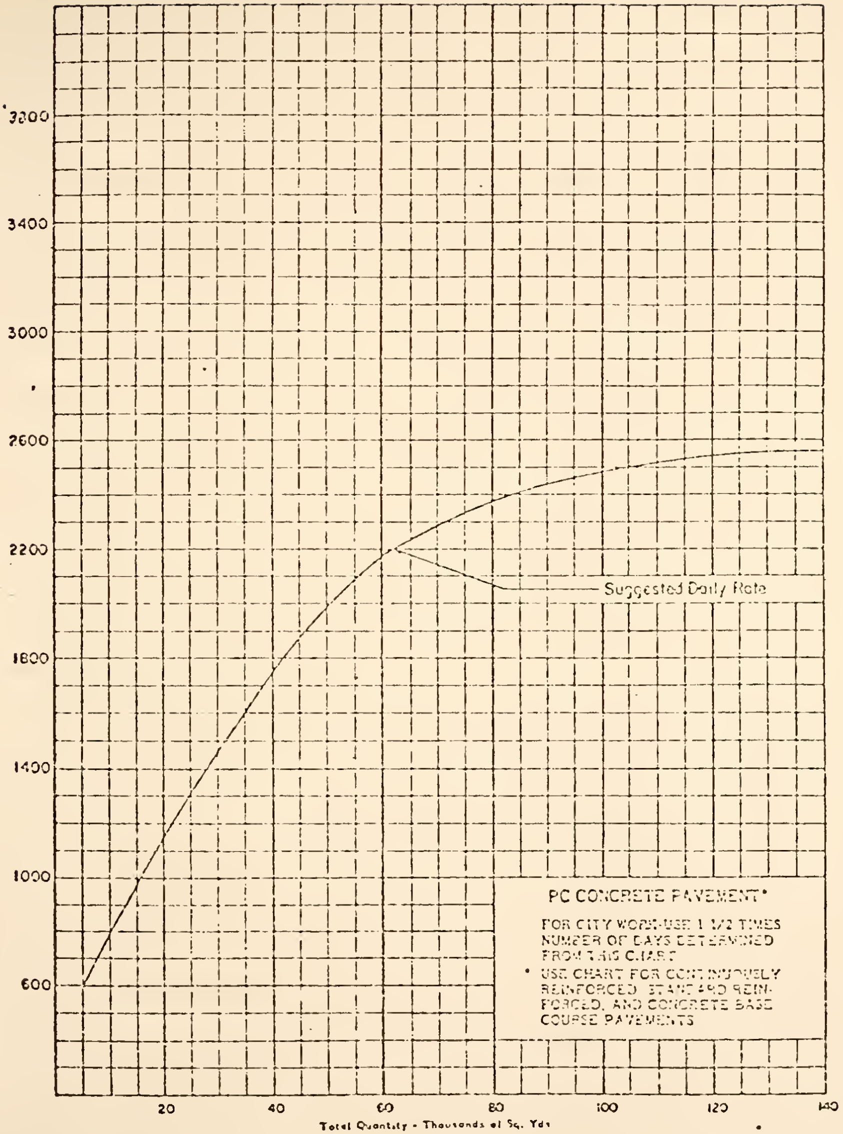


Figure 1-501.02b

Figure 6

Suggested Daily Rate for

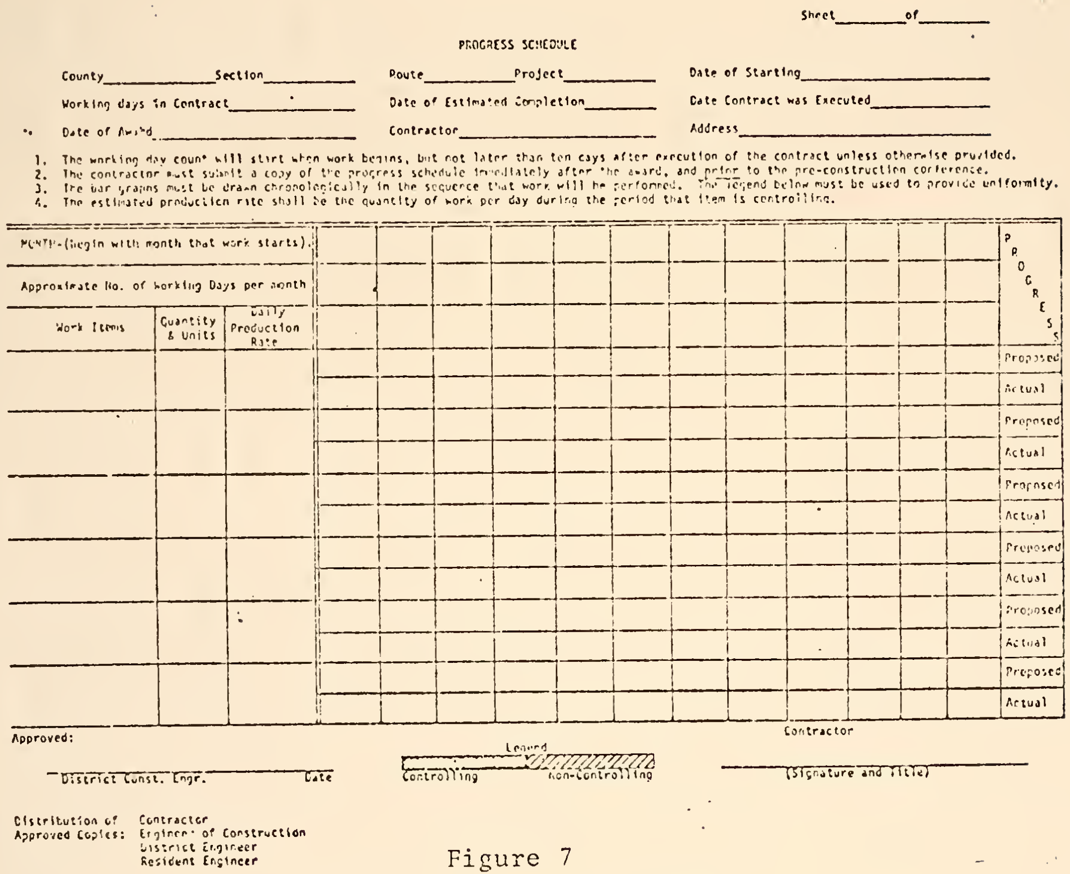
PC Concrete Pavement - Illinois

intermittently and to what degree the work item will be controlling the project schedule. Finally the last column is provided for the number of days which the work item will be the controlling operation. This number is computed by subtracting the value in the sixth column from the value in the fifth column. Finally the project engineer computes the total for column seven. This value is the total number of work days for the project. The guidelines specify that the minimum number of work days for a project should be fifteen and that work days should be specified in multiples of five. The guidelines also recommend the use of bar charts for more complicated projects where many activities may be performed concurrently.

The Illinois Department of Transportation requires the contractor to submit a progress schedule of the form shown in Figure 7 prior to the preconstruction conference. This progress schedule must reflect the contract time specified for the project and is the basis for establishing the controlling item of construction operations and for checking the progress of the work. Currently only about 10 percent of the highway construction projects in Illinois are completed late.

4.3 Michigan Methodology

The Michigan Department of Transportation has developed a comprehensive method of establishing contract durations. The contract durations are established by the



Sheet_____of_____

PROGRESS SCHEDULE

County_____Section_____ Route_____Project_____ Date of Starting_____

Working days in Contract_____ Date of Estimated Completion_____ Date Contract was Executed_____

Date of Award_____ Contractor_____ Address_____

1. The working day count will start when work begins, but not later than ten days after execution of the contract unless otherwise provided.
2. The contractor must submit a copy of the progress schedule immediately after the award, and prior to the pre-construction conference.
3. The bar graphs must be drawn chronologically in the sequence that work will be performed. The legend below must be used to provide uniformity.
4. The estimated production rate shall be the quantity of work per day during the period that item is controlling.

MONTH-(Begin with month that work starts).														PROGRESS
Approximate No. of Working Days per month														
Work Items	Quantity & Units	Daily Production Rate												
														Proposed
														Actual
														Proposed
														Actual
														Proposed
														Actual
														Proposed
														Actual
														Proposed
														Actual
														Proposed
														Actual

Approved:

____
District Const. Engr. Date

Legend
Controlling Non-Controlling

Contractor

____
(Signature and Title)

Distribution of Approved Copies:
Contractor
Engineer of Construction
District Engineer
Resident Engineer

Figure 7

Progress Schedule - Illinois

design squad. The design squad also has the responsibility for the cost estimates and the bid documents, due to their familiarity and understanding of the highway projects. Michigan utilizes a computerized drafting method and has developed a complete program for making the necessary scheduling calculations. The schedule produced by this process is incorporated into the bid documents and serves as the basis for measurement of progress and control of the highway construction projects.

The basis for the determination of contract time is a Critical Path analysis of the project. The scheduling program carries out a number of calculations necessary for the determination of the critical path. Following is an explanation of the methodology and computer program used for determination of contract time. The first step in this procedure is to identify the work activities which must be performed to complete the project. The design squad engineer refers to the listing of bid items to identify the necessary work activities. The engineer then makes a list of all of the activities from (and including) the award of the contract through the end of the project. After the list of activities is completed, the engineer considers each activity separately and identifies which of the other activities must be completed before the activity being considered can commence. Once this process is completed the engineer sketches a network diagram. The network diagram

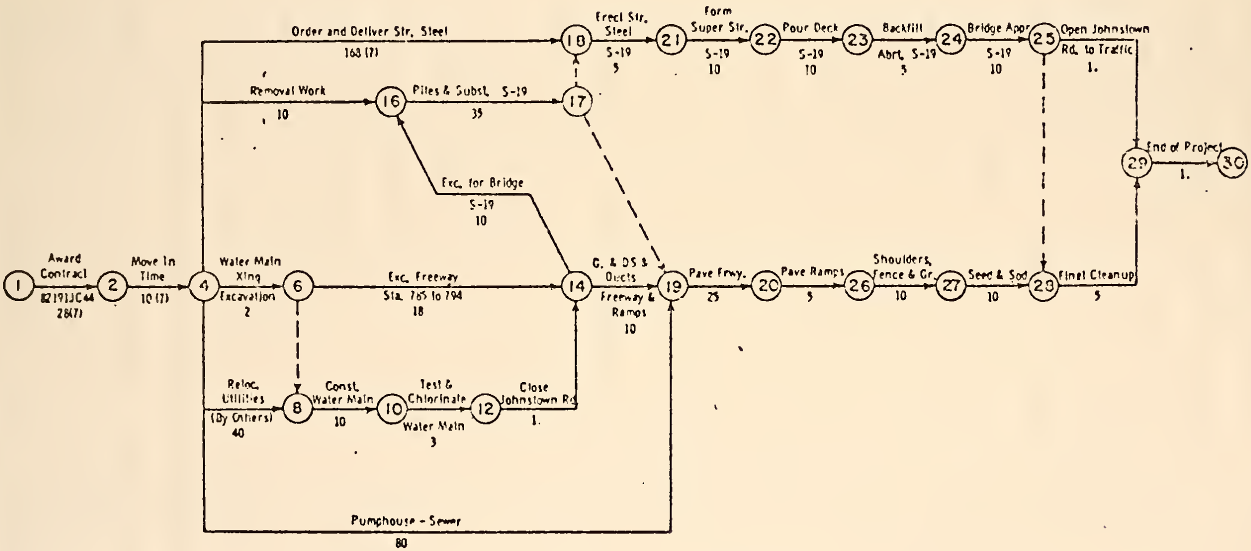


Figure 8

CPM Network - Michigan

shows each of the work activities and also the sequential relationships which were developed in the previous step. As this diagram is the basis for the calculations, the output will only be as valid as the model. The engineer must have a familiarity with the work and exercise sound judgment in preparation of the diagram. A typical example of a network diagram is shown in Figure 8. Each work activity is shown as a solid arrow on the diagram; the length of the arrow is not significant. If one activity follows another, the tail of the following activity is located next to the arrowhead of the preceding activity. The circles, or nodes, at the terminals of the arrows represent events. An event marks the time when all of the activities whose arrowheads end at the node are completed and all activities whose tails start at the node may begin. Dashed arrows represent "dummy" activities. A "dummy" activity is an artificial device with a zero-time duration used to indicate the correct relationships between activities and to ensure unique identification of activities. Each node, or event, is numbered so that work activities can be identified by a unique set of events.

The next logical step in the determination of contract time is the establishment of time estimates for each activity. The bid quantities are evaluated using average productivity rates developed by the Michigan Department of Transportation. The productivity rates are updated periodically to reflect new construction methods. Presented in Table 9 are the most recent productivity rates which have been established by the Michigan Department of Transportation. The bid quantities are divided by the productivity rates to establish the time estimates for each activity. With this information the design squad engineer prepares the input for the computer program. The input for the program consists of a few control cards and activity-specification cards. There is one card for each activity. The program can accomodate up to 400 cards. Information describing each activity is coded on each card.

The first two columns on the card are used to identify any restrictions on the working dates for the activity. Table 10 is a listing of the restrictions and codes used. These restrictions reflect a reasonable approach for identifying the seasonal weather constraints which exist for some activities. The third and fourth columns are used to identify any functional responsibilities for activities. These columns are optional and the engineer develops his own system of alphanumerical coding for functional responsibilities for activities. Column five through ten are used to identify the logical sequence of the activities. The unique node, or event numbers, from the network diagram are entered into these columns. The beginning node number is entered in columns five through seven and the ending node number is placed in columns eight through ten. "Dummy" activities are also identified in these columns.

TABLE 9

CRITICAL PATH

CONSTRUCTION TIME ESTIMATES

I. AWARD CONTRACT USE "WW" CODE	
A. For letting months with the 1st on Thur., Fri, or Sat.	14 days @ 7-day week
B. For all other letting months	21 days @ 7-day week
II. MOVE IN TIME (10 calendar days) USE "WW" CODE	10 days @ 7-day week
III. DRAINAGE	
A. Cross Culverts (generally included in G+DA)	
1. Rural Highways	120 L.F./Day
2. Expressways	150 L.F./Day
3. Large Headwalls	5 Days/Unit
4. Slab or Box Culverts	5 Days/Pour
B. Sewers	
1. 0'-14' (up to 60")	120 L.F./Day
2. 0'-14' (over 60")	80 L.F./Day
3. 14'-over (up to 60")	80 L.F./Day
4. 14'-over (over 60")	60 L.F./Day
5. Jacked-in-place	40 L.F./Day
Includ. Exc. Pit and Setup	Min. 5 Days
6. Tunnels Includ. Exc. Pit and Setup	30 L.F./Day
C. MHs	3 Units/Day
D. CBs	4 Units/Day
IV. UTILITIES	
A. Water Main (to 16")	300 L.F./Day
Flushing, Testing, Chlorination	4 Days

TABLE 9 (Continued)

CRITICAL PATH

CONSTRUCTION TIME ESTIMATES

	B.	Water Main (20" to 42")		80 L.F. Day
		Flushing, Testing & Chlorination		5 Days
	C.	Gas Lines		300 L.F./Day
V.	EARTHWORK AND GRADING		Expressway	Rural
	A.	Emb. CIP	2000	7000 Cyds/Day
	B.	Muck (Exc. Waste & Backfill		2000 Cyds/Day
	C.	Exc. and/or Emb. (Freeway)	2000	12000 Cyds/Day
	D.	Exc. and/or Emb. (Reconst.)	1000	5000 Cyds/Day
	E.	Exc. (Widening)		20 Stas/Day
	F.	Emb. (Light Weight Fill)	400	800 Cyds/Day
	G.	Grading (G&DS)		25 Stas/Day
	H.	Subbase and sel sub (24' or less)		20 Stas/Day
	I.	Subbase and sel sub (more than 20")		15 Stas/Day
	J.	Shoulders (Gravel) one side		25 Stas/Day
VI.	SURFACING ITEMS			
	A.	24 ft. Conc. Pav't. Includ. Forming and Cure		15* Stas/Day Min. 7 Days
	B.	24 ft. Bit Pav't. (per course)		40 Stas/Day
	C.	16 ft. Conc. Pav't. Ramps Includ. Forming and Cure		10* Stas/Day Min. 7 Days
	D.	Curb (one side)		25* Stas/Day
	E.	Conc. Shoulder Median		1500 Syds/Day
	F.	Bit Shoulders (one side per crse.)		25 Stas/Day
	G.	Sidewalk		2000 Sq. Ft./Day
	H.	Sidewalk (Patching)		700 Sq. Ft./Day
VII.	STRUCTURES			
	A.	Sheeting (Shallow)		100 L.F./Day
	B.	Gen. Exc. at Bridge Site		1000 Cyds/Day

TABLE 9 (Continued)

CRITICAL PATH

CONSTRUCTION TIME ESTIMATES

C.	Ex. for Footings	1 Days/Unit
D.	Piles (40')	15 Piles/Day
E.	Substructure	5 Days/Unit
F.	Order and Deliver Str. Steel	
	1. Plate Girders	85 Days (5-day wk)
	2. Rolled Beams USE "BW"	85 Days (5-day wk)
	3. Conc. Beams CODE	50 Days (5-day wk)
G.	Erection of Str. Steel	3 Days/Span
H.	Form and Pour Deck Includ. Cure Time	5* Days/Span Min. 20 Days
I.	Two Course Bridge Decks	
	1. Add 9 Days for 2nd Crse. Latex	
	2. Add 12 Days for 2nd Crse. Low Slump	
J.	Sidewalk and Parapets	5 Days/Span
K.	Paint	5 Days/Span
L.	Clean-up	10 Days
M.	Overlay of Exist. Deck (1 or 2 at a time)	
	1. Entire Deck (Traffic removed)	15 Days
	2. 1/2 Deck (Maintain traffic)	13 Day Each 1/2
VIII.	RETAINING WALLS	1 Panel/Day Min. 10 Days
IX.	RAILROAD STRUCTURES	
A.	Grade Temp. Runaround	1000 Cyds/Day
B.	Ballast, Ties and Track	150 Ft./Day
C.	Place Deck Plates	5 Days/Span
D.	Waterproof, Shotcrete & Mastic	5 Days/Span
X.	TEMPORARY RAILROAD STRUCTURE	
A.	Order and Deliver Steel USE "BW" CODE	55 Days (5-daywk)

TABLE 9 (Continued)

CRITICAL PATH

CONSTRUCTION TIME ESTIMATES

	B.	Order & Deliv. Mechan. & Electrical Equip.	90 Days
	C.	Install Mechan. & Electrical Equipment	30 Days
XII.	MISCELLANEOUS		
	A.	Removing Old Pavement	200 Ln. Ft./Day
	B.	Removing Trees	
		1. Urban	15 Each/Day
		2. Rural	30 Each/Day
	C.	Clearing	2 Acres/Day
	D.	Sodding	2500 Syds/Day
	E.	Seeding	10 Acres/Day
	F.	Guard Rail	750 L.F./Day
	G.	Fencing Wovenwire	1200 L.F./Day
	H.	Fencing, Chain Link	500 L.F./Day
	I.	Clean-up	20 Stas/Day
	J.	Conc. Med. Barrier	1000* L.F./Day
	K.	Reroute Traffic (Add 4 days if 1st operation)	1 Day/Move
	L.	Conc. Glare Screen	1500 L.F./Day
	M.	Light Foundations	6 Each/Day
	N.	Remove Railing & Replace w/barrier (1 or 2 Decks at a time)	4 Days/Side

* Add 5 Days Cure Time.

TABLE 10

ACTIVITY CODES AND RESTRICTED DATES

The following codes entered in columns 1-2 of the activity specification record will imply that only dates within the limits of its restrictions will be considered in determining starting and finishing dates for the activity.

CODE	ACTIVITY	VALID WORK DATES
BLANK	WINTER WORK RESTRICTED	4-15 to 11-15
BC	BITUMINOUS CONCRETE	5-15 to 11-01
CP	CONCRETE PAVING	5-01 to 11-01
SE	SEEDING	4-15 to 10-15
SO	SODDING	5-01 to 6-01 and 8-15 to 11-15
SS	SUPERSTRUCTURE CONCRETE	5-01 to 11-15
WM	WATER MAINS	10-15 to 5-15
WW	WINTER WORK	ALL DATES VALID
BY	BY OTHERS, WINTER WORK RESTRICTED. DURATION OF ACTIVITY USED IN SETTING DATES, BUT DOES NOT AFFECT THE CRITICAL PATH.	4-15 to 11-15
BW	SAME AS "BY" BUT HAS NO WINTER WORK RESTRICTIONS	ALL DATES VALID
S(COL 1)	EARLIEST DATE THE ACTIVITY CAN BEGIN IS PRESENT IN COL 15-20 (MONTH, DAY, YR)	
C(COL 1)	DATE THE ACTIVITY WAS COMPLETED IS PRESENT IN COL 15-20 (MONTH, DAY, YR)	

The eleventh column on the data card is used to indicate the assumed number of days in each work week. This column is used only for those activities which will proceed on a different work week basis than identified on the control card for the project. The control card normally specifies a four day work week. The four day work week is assumed to incorporate typical poor weather conditions that are randomly encountered during the construction season. Table 10 also gives a guideline for the work week to be used for activities. The twelfth through fourteenth columns are used to input the activity durations in work days which were previously calculated. If an "S" or a "c" is coded into columns one and two, then columns fifteen through twenty are used to indicate the numeric month, day, and year that the activity starts or is completed. In the next thirty two columns a brief description of the activity is entered.

Once the activity-specification cards are completed, they are added to the control cards for the program. The control cards contain such information as the name of the user, account charge numbers, a description of the project, normal number of days in the work week, a letting or starting date, and identification of the sorts desired for the output. The program has the capacity to perform a variety of sorts. Those which may be selected are (1) Total Float (2) Earliest Start (3) Earliest Finish (4) Latest Start

(5) Latest Finish (6) Code (7) Node or (8) Responsibility. Normally in determining the duration the total float sort is used because it will produce a chronological ordering of the critical activities.

Once the calculations are complete, a comprehensive Critical Path network can be sketched utilizing a plotter. Together with the computer output this network shows the job logic, durations for activities, early start dates, late start dates, early finish dates, late finish dates, total float, and the critical path of activities for the project. From the output, the contract duration can be expressed either as working days or as calendar days. The Construction Division reviews the completed network for it's validity prior to it's inclusion in the bid documents. Michigan has found that the methodology has considerably reduced the number of contracts which are not completed on time. The computer program has significantly reduced the calculation time. The network has also helped in resolving differences between contractors and the state.

4.4 Kentucky Methodology

Kentucky has developed a computerized methodology for establishing contract completion times. The Roadway Plan Review Section is assigned the responsibility for making the computations of contract times for most projects. The computer program was designed as a Critical Path network model based on working days. The output takes the form of a time scaled bar graph. Fourteen controlling work items are included. Each controlling work item is represented by a bar on the graph. The length of each bar represents the time required for completion of the controlling work item. The time is computed by dividing the quantity by the applicable production rates. Expected production rates have been established from past construction experience. After the time for each controlling work item has been established, the time bars are arranged in their logical sequence and overlapped when appropriate. The degree of overlap for each work item is calculated from a delay formula based on logic and construction experience. Following is an explanation of the logic programmed for each of the fourteen controlling work items.

(1) Clearing and Grubbing

The unit of acres is used for clearing and grubbing. Listed in the table below are the production rates or work days for various ranges of quantity.

Quantity	Acres/Day mobilization	days (T_1)
0		10
0-10		10
11-25	1	
26-50	2	$\frac{\text{Quantity}}{\text{Acres/Day}} = T_1$
51-70	3	
71-100	4	
Over 100	5	

As can be seen, if there is no clearing and grubbing work item then ten days are allowed for mobilization. Similarly if there are 10 acres or less of clearing and grubbing then a minimum of ten days is used. For values greater than ten acres the appropriate acres/day is applied to the quantity involved. Since this work item marks the beginning of construction, there is no start lag or delay computed.

(2) Culvert Pipe

The unit of lineal feet is used for culvert pipe. The table below gives the applicable production rates for the quantity ranges.

Quantity	Lin. Ft./Day
1-2000	100
2001-7500	200
7501-15,000	300
over 15,000	400

$$\frac{\text{Quantity}}{\text{Lin. Ft./Day}} = T_2$$

The delay for this work item is as follows:

delay (D_2) - 10 days if clearing and grubbing time (T_1) is less than 15 days.

delay (D_2) - 15 days if clearing and grubbing time (T_1) is 15 days or greater.

(3) Class "A" Concrete

The unit for this work item is cubic yards. Below the applicable production rates are tabulated.

Quantity	Lin. Cyd/Day
1-200	10
201-500	20
501-1000	30
1001-2000	40
over 2000	50

$$\frac{\text{Quantity}}{\text{Lin. Cyd/Day}} = T_3$$

The delay is computed as follows:

$$\text{delay } (D_3) = D_2 + T_2 \text{ when } T_2 < 10 \text{ days}$$

$$\text{delay } (D_3) = D_2 + 10 \text{ when } T_2 \geq 10 \text{ days}$$

(4) Roadway Excavation

The unit for this item of work is cubic yards. Listed below is a table of expected production rates for various quantities.

Quantity	cyd/day
1-5000	200
5001-10,000	500
10,001-50,000	1000
50,001-100,000	2000
100,001-200,000	3000
200,001-500,000	5000
500,001-1 million	8000
1,000,001-2 million	10,000
2,000,001-3 million	15,000
over 3 million	20,000

$$\frac{\text{Quantity}}{\text{cyd/day}} = T_4$$

The delay is computed as follows:

$$\text{delay } (D_4) = D_3 + T_3 \text{ when } T_3 < 10$$

$$\text{delay } (D_4) = D_3 + 10 \text{ when } T_3 \geq 10$$

$$\text{delay } (D_4) = D_2 + 10 \text{ when } T_3 = 0$$

$$\text{delay } (D_4) = 10 \text{ days when } T_3 \,\&\, T_2 \text{ both} = 0$$

(5) Structural Steel

The unit for this work item is pounds. Listed below are the productivity rates and expected delay times for various quantities.

Quantity	lbs/day	Delay (D_5)*
1000-20,000	1000	50
20,001-50,000	2000	50
50,001-100,000	5000	60
100,001-500,000	10,000	70
500,001-1 million	15,000	80
1,000,001-2 million	20,000	90
2,000,001-3 million	30,000	100
3,000,001-4 million	40,000	120
over 4 million	50,000	150

$$\frac{\text{Quantity}}{\text{lbs/day}} = T_5$$

*The delay for structural steel generally depends upon fabrication and delivery time.

(6) Class "AA" Concrete

The unit for this item is cubic yards. The table below gives the productivity rates for various quantities.

Quantity	cyd/day
1-200	10
201-500	20
501-1000	30
1001-2000	40
over 2000	50

$$\frac{\text{Quantity}}{\text{cyd/day}} = T_6$$

The delay is computed as follows.

$$\text{delay } (D_6) = D_5 + T_5 - .5T_6 \text{ when } T_5 > T_6$$

$$\text{delay } (D_6) = D_5 + .5T_5 \text{ when } T_5 < T_6$$

when $T_5 = 0$

$$(D_6) = D_3 + T_3 - .5T_6 \text{ when } T_3 > T_6$$

$$(D_6) = D_3 + .5T_3 \text{ when } T_3 < T_6$$

(7) Aggregate Base

The unit for this work item is tons. The table below gives the productivity rate expected for various quantities.

Quantity	Tons/day
1-5000	500
5001-10,000	700
10,001-25,000	1000
25,001-50,000	1500
50,001-75,000	2000
75,001-100,000	2500
100,001-125,000	3000
125,001-200,000	4000
200,001-300,000	5000
over 300,000	6000

$$\frac{\text{Quantity}}{\text{Tons/day}} = T_7$$

The delay is computed as follows.

delay (D_7) = $D_4 + T_4 - .5T_7$ when $T_4 > T_7$

delay (D_7) = $D_4 + .5T_4$ when $T_4 < T_7$

(8) Cement Concrete Pavement

The unit for this work item is square yards. The table below lists the productivity rates for various quantities.

Quantity	syd/day
1-5000	500
5001-15,000	700
15,001-25,000	1000
25,001-50,000	2000
50,001-75,000	3000
75,001-100,000	4000
100,001-150,000	5000
150,001-200,000	7000
over 200,000	10,000

$$\frac{\text{Quantity}}{\text{syd/day}} = T_8$$

The delay for this work item is computed as follows.

if $T_4 \quad 0$ then

delay (D_8) = $D_7 + T_7 - .5T_8$ when $T_7 > T_8$

delay (D_8) = $D_7 + .5T_7$ when $T_7 < T_8$

if $T_4 = 0$ then

$D_8 = D_7 + T_7 - .25T_8$ when $T_7 > T_8$

$D_8 = D_7 + .75T_7$ when $T_7 < T_8$

(9) Curb and Gutter (All Types)

The unit for this work item is lineal feet. The table below relates the productivity rates to various quantities.

Quantity	lin.ft./day
1-1000	100
1001-3000	200
3001-5000	300
5001-10,000	400
10,001-15,000	500
15,001-20,000	600
20,001-30,000	700
over 30,000	800

$$\frac{\text{Quantity}}{\text{lin. ft./day}} = T_9$$

The delay for this work item is computed as follows.

$$\text{delay } (D_9) = D_8 + T_8 - .5T_9 \text{ when } T_8 > T_9$$

$$\text{delay } (D_9) = D_8 + .5T_8 \text{ when } T_8 < T_9$$

$$\text{if } T_8 = 0 \ (D_9) = D_7 + T_7 - .5T_9 \text{ when } T_7 > T_9$$

$$(D_9) = D_7 + .5T_7 \text{ when } T_7 < T_9$$

(10) Bituminous Concrete Pavement

The unit for this work item is tons. The table below lists the productivity rates for various quantities.

Quantity	tons/day
1-2000	400
2001-5000	500
5001-10,000	600
10,001-20,000	700
20,001-30,000	800
30,001-40,000	900
40,000-50,000	1000
50,001-60,000	1100
60,001-75,000	1200
over 75,000	1500

$$\frac{\text{Quantity}}{\text{tons/day}} = T_{10}$$

The delay for this work item is computed as follows.

if T_9 0: delay $(D_{10}) = D_9 + T_9 - .5T_{10}$ when $T_9 > T_{10}$
delay $(D_{10}) = D_9 + .5T_9$ when $T_9 < T_{10}$

if $T_9 = 0$: delay $(D_{10}) = D_8 + T_8 - .5T_{10}$ when $T_8 > T_{10}$
delay $(D_{10}) = D_8 + .5T_8$ when $T_8 < T_{10}$

If both T_9 & $T_8 = 0$ delay $(D_{10}) = D_7 + T_7 - .25T_{10}$ when $T_7 > T_{10}$
delay $(D_{10}) = D_7 + .75T_7$ when $T_7 < T_{10}$

(11) Removing Guardrail

The unit for this item is lineal feet. The table below indicates the productivity rates for various quantities.

Quantity	lin.ft./day
1-30,000	1000
30,001-75,000	1500
over 75,000	2000

$$\frac{\text{Quantity}}{\text{lin. ft./day}} = T_{11}$$

The delay for this work item is computed as follows.

delay $(D_{11}) = D_4 + T_4 - .5T_{11}$ when $T_4 > T_{11}$
delay $(D_{11}) = D_4 + .5T_4$ when $T_4 < T_{11}$

(12) Constructing Guardrail

The unit for this work item is lineal feet. The table below indicates the productivity rates for various quantities.

Quantity	Lin.ft./day
1-30,000	1000
30,001-75,000	1500
over 75,000	2000

$$\frac{\text{Quantity}}{\text{lin.ft./day}} = T_{12}$$

The delay for this work item is computed as follows.

delay $(D_{12}) = D_{11} + T_{11} - .5T_{12}$ when $T_{11} > T_{12}$

delay $(D_{12}) = D_{11} + .5T_{11}$ when $T_{11} < T_{12}$

(13) Seeding and Protection

The unit for this work item is square yards. The table below lists the productivity rates for various quantities.

Quantity	syd/day
1-100,000	5000
100,001-200,000	10,000
200,001-300,000	15,000
over 300,000	20,000

$$\frac{\text{Quantity}}{\text{syd/day}} = T_{13}$$

The delay for this work item is computed as follows.

delay $(D_{13}) = D_{12} + T_{12} - .25T_{13}$ when $T_{12} > T_{13}$

delay $(D_{13}) = D_{12} + .5T_{12}$ when $T_{12} \leqslant T_{13}$

when $T_{12} = 0$ $D_{13} = D_{10} + T_{10} - .25T_{13}$ when $T_{10} > T_{13}$

$D_{13} = D_{10} + .5T_{10}$ when $T_{10} \leqslant T_{13}$

when T_{12} & T_{10} both $= 0$ $D_{13} = D_8 + T_8 - .25T_{13}$

when $T_8 > T_{13}$ $D_{13} = D_8 + .5T_8$ when $T_8 \leqslant T_{13}$

when T_{12}, T_{10}, & T_8 all $= 0$ $D_{13} = D_4 + T_4$

(14) Final Clean-up

There are no units for this work item. The time allowance made for this item is computed as follows.

If the total time for all other items of work is:

A. 1-50 days, use 10 days for clean-up (T_{14})

B. 51-150 days, use 15 days for clean-up (T_{14})

C. over 150 days, use 20 days for clean-up (T_{14})

The delay for this item (D_{14}) is calculated by taking the maximum of ($T_i + T_i$) for all i and rounding back to the nearest five day increment.

The program is designed to allow the user to utilize either the overlap method or an end-to-end is often used. Although the computer program makes calculations based on working days it also has the capability of adjusting the duration to fit the construction season. An average value for the number of working days in a normal construction season is used for this adjustment. After the total contract time duration is established, the computer program makes adjustment as follows:

(1) If the time remaining in the construction season is 35 working days or less, the duration is extended to the end of the construction season.

(2) If the time computed extends into the next construction season by 25 working days or less, the completion date is the end of the previous construction season.

(3) If the time extends into the next construction season by 25 to 50 working days, then the duration is extended to a minimum of 50 working days into the next season.

CHAPTER 5

OTHER SCHEDULING AND CONTRACT TIME DETERMINATION METHODS

Contract time is an essential and critical part of the contract documents. It is vital that the contract time be reasonable with respect to the magnitude of the project. Care and sound engineering judgment must be exercised in establishing the working days or completion date for a project. Severe time limitations placed on contractors will probably be reflected in their bid prices, either through inclusion of overtime costs or expected liquidated damage charges. A realistic time limit will also help in avoiding differences and disputes between the contractor and the ISHC. For establishing feasible project time limits, a comprehensive analysis of the work involved in the project is the only valid approach. Development of an estimated schedule for the contract execution is the most logical method for the analysis.

There are several scheduling methods which have been developed and used in the construction industry. Probably the most widely used and one of the oldest methods is the bar (Gantt) chart. The bar chart shows each activity of the project plotted as a horizontal bar. The length of the bar indicates the time necessary to complete the activity. Normally the activities are listed in chronological order of their starting dates. An example of a typical bar chart is shown in Figure 9. The main advantage of the bar chart are related to its' simplicity. The bar chart shows the total project in a compact format that is easy to read and understand. Nearly all contractors have a familiarity with the bar chart and are quite comfortable in interpreting its logic.

The bar chart does, however, have some serious pitfalls and shortcomings that constrain its application to complex highway construction projects. These include:

1. A tendency to over simplify the breakdown of the project into component activities. Often bar charts are prepared with division of the project into gross, broadly scoped component activities. The result of this type of approach is a plan with very little information which can be used for control of the project.
2. A failure to include important time consuming items. Activities such as material procurement and delivery, preparation and approval of shop drawings, approval of temporary structure drawings, public utility modification support

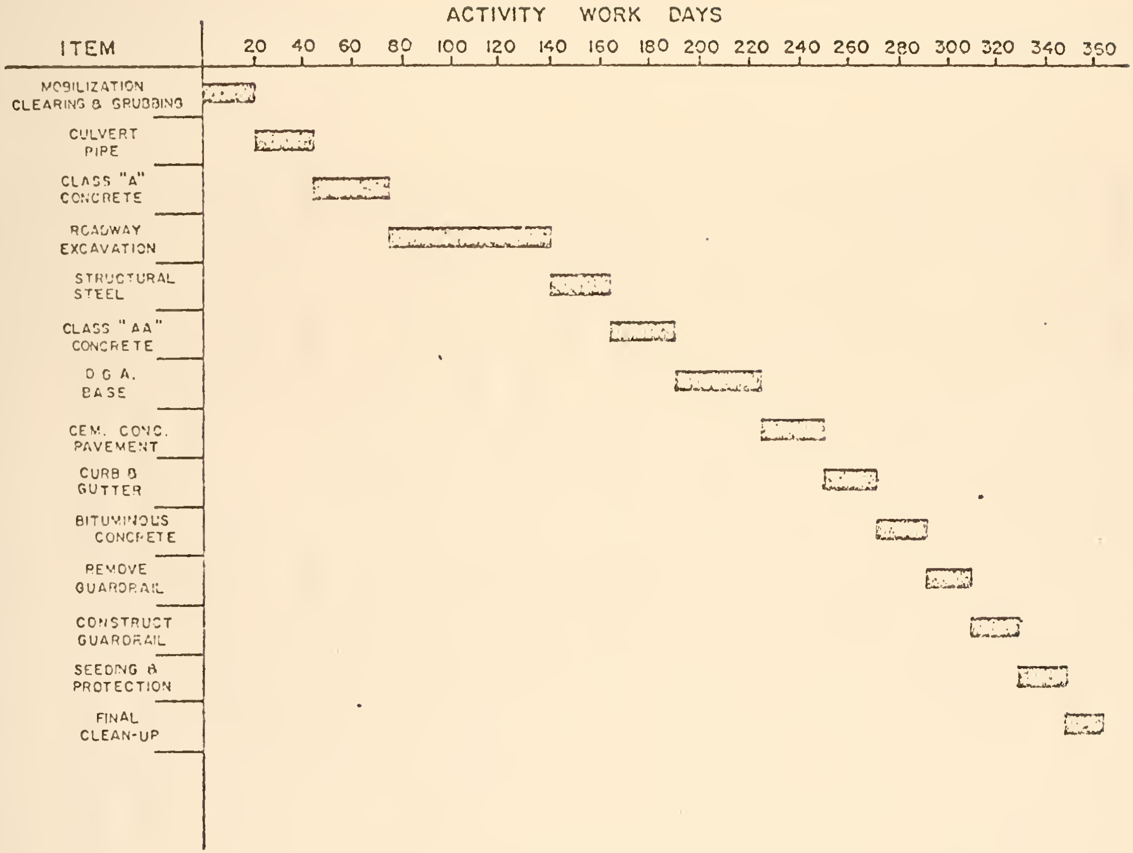


Figure 9

Typical Bar Chart - Small Paving Project activities, and license and permit procurement are often omitted from the bar chart.

3. *The interdependencies between activities in the construction plan for the project are not shown.* The necessary information to identify dependencies of one activity on others is not shown on bar charts. Although some relationships may be obvious, many others are not. An evaluation of the construction activity logic or the communication of the planned logic is not possible without the identification of the relationships between the activities needed for project completion.
4. *An inability to be adaptable to schedule deviations and updating.* Often the bar chart is used as the basis for measuring and controlling the contractor's performance. If actual performance varies from anticipated productivity the bar chart does not reflect the impact of the deviation on the overall project time. Also, the effects of deviations on later activities in the sequence of work items cannot be easily identified from a bar chart. Thus, updating requires a complete analysis of the remaining work each time a deviation occurs.

Due to the disadvantages of the bar chart, other methods have been developed. Probably the most popular of these is the Critical Path Method (CPM). This method can be classified as a network technique for scheduling. This method was developed over twenty years ago and has been used on many projects in the last two decades. The Critical Path Method requires that a project be broken down into component activities that can be presented in a form to show their sequential relationship. CPM utilizes a diagram made up of arrows and circles to identify activities and events. It also requires time estimates for each work item. Following is a description of the Critical Path Method of planning and scheduling.

A good CPM analysis must begin with sound project planning. The project planning should include identifying the necessary items of work and time consuming activities to achieve the completion of the project. Also it must involve establishing the most logical and economical order for the activities and present all of the information in a clear and understandable graphical model. The following factors are normally considered when deciding on the practical breakdown of the project into component time-consuming activities:

1. Area of Responsibility
2. Category of work by craft or crew requirements
3. Category of work by equipment requirement
4. Category of work by material requirement
5. Identifiable subdivision of work

6. Location of work
7. Bid or payment items

Activities may be classified into three major categories. The categories are procurement, production and management decision activities. Procurement activities are probably the most difficult and frustrating items for the construction planner. Typical procurement activities include material purchases, obtaining specialized labor, rental or purchase of equipment, and securing engineering approvals, licenses and permits. Production activities involve the consumption of resources such as material, labor and equipment. Management decision activities are those related to the options considered by the contractor for completion of the work. As an example, the contractor may decide to delay some operations until a later date so that he may make better utilization of his supervision on a project.

Depending on the desired use of the CPM schedule, different levels of detail for activities will be chosen. If the activity breakdown is not sufficient to identify the important dependencies, the plan will not yield valid and useful information. When activities are broken out in too great of detail, obscurity in the work plan will result. Activities should only be broken down to a level where the dependencies can be shown clearly. After the component activities have been determined the relationships between the activities must be identified. The sequence of activities is often termed the "job logic". To establish the job logic one basic question needs to be answered and that is "what activities must be finished before this activity can start"? After the preliminary activity list is prepared and each activity numbered, it is a simple matter to assign preceding activity numbers to each activity by answering the one question. It should be noted here that when using the Critical Path Method it is not possible for an activity to begin before the preceding activity is completed. If in the development of the job logic this situation occurs then a further breakdown of the activities is necessary to show the job logic properly. After each activity has been analyzed and the preceding activities determined, it is possible to graphically represent the job logic through the use of a network diagram (see figure 10). The graphical representation for an activity in the network diagram using the Critical Path Method is an arrow. The length of the arrow has no significance. The start and end of each activity are represented by nodes or circles on the CPM network; these are often referred to as "events". An event is a point in time and therefore does not have a duration. Event numbers, or node numbers, are used to identify activities

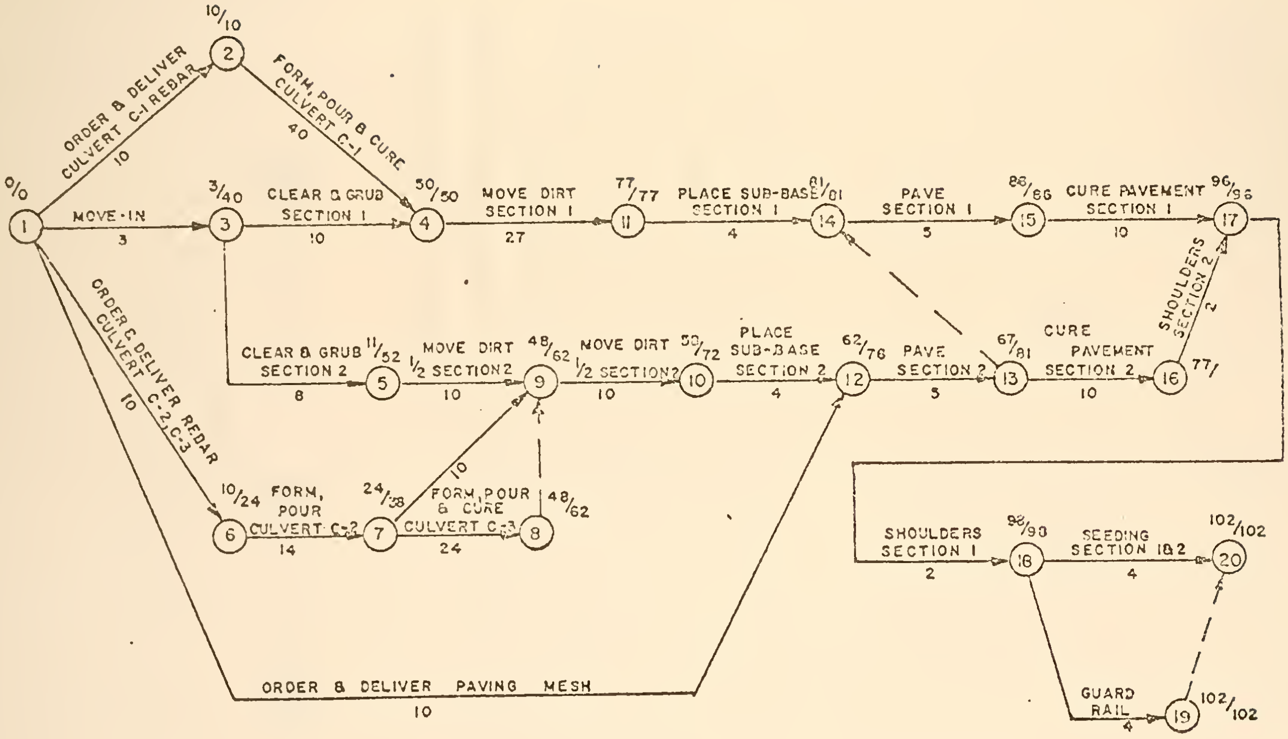


Figure 10

Critical Path Network - Road Project

since separate events, or nodes, occur which mark the start and end of each activity. Figure 11 shows the representation of an activity and events.

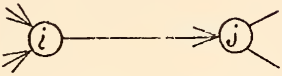


Figure 11

Activity and Event Representation

The event at the head of the arrow is designated as the "j event" or end of the activity. The "i event" occurs at the tail of the activity arrow and represents the point in time at which the activity may start.

If two activities are independent of each other they will be represented by two separate arrows with no connection as shown in Figure 12.

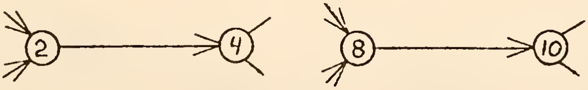


Figure 12

Independent Activities

When an activity is dependent on the completion of another activity the connecting point or event will be shared by the two activities. The common event will be the "j event" for the preceding activity and the "i event" for the dependent activity. This type of relationship is illustrated in Figure 13.

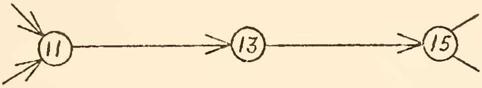


Figure 13

Dependent Activity

Often an activity is dependent on the completion of more than one activity. This situation is called a "merge" and is illustrated in Figure 14.

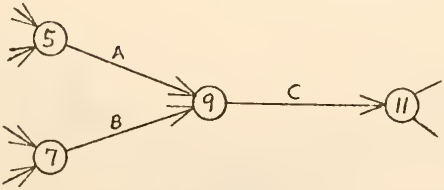


Figure 14

A Merge

In this case the start for activity C (9-11) is dependent on the completion of both activity A and B. Similiarly more than one activity may be dependent on the completion of one activity. This situation is called a "burst" and is shown in Figure 15.

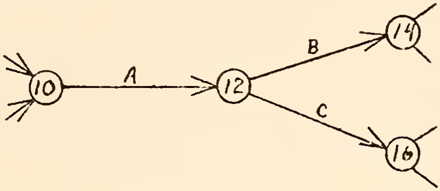


Figure 15

A Burst

In this case both activities B and C are dependent on the completion of activity A, therefore, neither may begin until activity A is completed. Sometimes the logic will establish that more than one activity will be dependent on two or more preceding activities. This case is termed a "cross" and is illustrated in Figure 16.

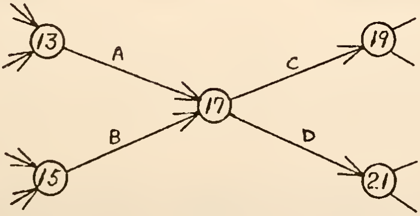


Figure 16

A Cross

The diagram indicates that neither activity C or D may begin until both activities A and B are complete.

If one activity is dependent on the two preceding activities and another activity depends on only one of the two activities then a "cross" representation would not be correct. To illustrate this situation assume activity C is dependent on the completion of activities A and B. The cross representation shown in Figure 16 would not be correct. The correct representation is shown in Figure 17.

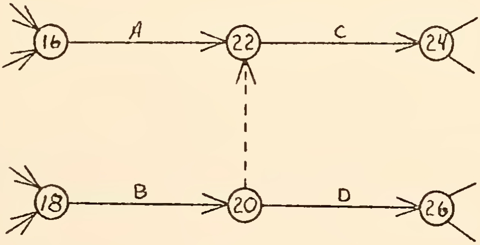
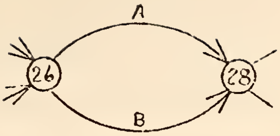


Figure 17

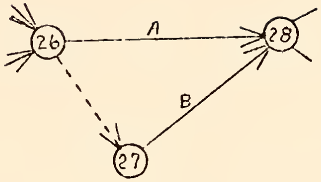
Dummy Activity

Figure 17 shows the use of an activity called a "dummy". A "dummy" activity is a fictitious activity with no time duration. In this case it is added to represent the correct logic that activity C must wait until activity B is completed.

Another use of the dummy activity is shown in Figure 18 (b).



(a) Incorrect



(b) Correct

Figure 18

Representation of Two Activities with the
Same Starting and Ending Events

If figure 18 (a) were used to represent the logic of activities A and B then both activities A and B would have identical event numbers. This representation is not correct because it's ambiguity leads to confusion in the computations that must be performed. To avoid this situation a dummy activity is used so that activity A and B will have unique event or node numbers. After the complete diagram has been drawn it should be carefully checked to eliminate any unnecessary dummies which may have been included. The network diagram must begin with one event and end with one event.

The next phase involves the establishing of durations for each activity. A time interval must be selected as a basis for measurement. Any time interval may be chosen that will be convenient for use with the anticipated activities. Normally, in construction, an eight hour work day is chosen since this is the common employment period for construction labor. Sometimes calendar days are used for procurement activities. Regardless of the choice, the time interval selected should be used consistently throughout the diagram. For an accurate presentation of the project it is imperative that time durations be based on a sound engineering analysis of the work. Assuming that the quantities of work are known accurately, a multitude of factors such as work method, crew size, and type or size of equipment must be estimated to determine the activity duration. Assumptions must be made about these factors and a choice made for the productivity rates. The productivity rate chosen should be a reasonable compromise between speed and cost.

The following guidelines are generally applied in establishing productivity rates.

1. The activity duration should be based on a "normal" level of manpower and equipment similar to that assumed in preparing the cost estimate.
2. Each activity should be evaluated separately.

3. Where possible productivity rates on projects of a similar scope and magnitude should be utilized.
4. Contingency allowances for strikes, fire, accidents or late material deliveries should not be included in activity durations. Weather may be included because it is predictable to some degree.

The activity duration is determined by dividing the quantity of work by the productivity rates. Procurement activity durations normally can be determined by contacting the suppliers or from experience. Management decision activity times are based solely on experience from past projects. Dummy activities have a zero-time duration.

Once the Critical Path network diagram has been drawn showing the activities, their interrelationships, and their durations, it is possible to make several calculations. For each activity computations are made to determine the earliest and latest times and the earliest and latest finish times. The early start time of an activity is defined as the earliest time at which the activity can commence which is also the time at which all the preceding activities have been completed. The early finish time is the earliest possible completion time for the activity. This is obtained by adding the activity duration to the early start time. The late start time for an activity is defined as the latest possible time at which the activity can commence and not delay the project completion. The late finish time is the latest time for completion of the activity which will not delay the overall project completion. Two other terms are used in the computations. These are the "early event time" and the "late event time". The early event time is the earliest possible time at which all activities terminating at the event, or node, can be completed. The late event time is the latest possible time at which all activities terminating at the event can be completed without delaying the overall project. The procedure for making these computations involves two major steps. These two steps are known as the "forward pass" and "backward pass". A complete description of the calculations can be found in nearly all textbooks covering scheduling techniques. The computations for CPM can be accomplished easily by hand calculations.

The critical path method provides a useful tool for analyzing the work involved in the project. It can also be used for financial planning, cost control, project monitoring and evaluation of the impact of changed quantities.

There are several other methods which have been developed to model the work activities involved in a construction project. Precedence diagramming and PERT (Program Evaluation and Review Technique) are two of these.

In the Precedence method activities are represented by nodes rather than lines. Another feature of precedence diagramming is the use of "lag factors" for overlapping activity durations. This method tends to be more complicated than the basic Critical Path Method. PERT is a method based on a probabilistic approach. It required multiple time estimates for each activity. Due to the excessive data requirements the PERT approach has not been utilized widely on construction projects. Both of these methods were evaluated, however, their application to the determination of contract time offers little advantage over a basic CPM approach.

CHAPTER 6

A RECOMMENDED METHODOLOGY FOR DETERMINING CONTRACT DURATION

The various methods of contract time determination used by the surrounding states, as well as other scheduling methods used in construction have been discussed previously in this report. While many of the more complex methods offer advantages in project control and monitoring, it appears they offer only a minimal, if any, improvement in contract time determination. The primary advantages of CPM, Precedence, and PERT methods can only be realized by contractors who have a sound basis for the assumptions required in their use. For the Indiana State Highway Commission to effectively utilize these more complex methods and gain the full benefits would require radical changes in contracting philosophy, changes in legislation relating to contracting, an increase in construction staffing, and a comprehensive staff training program in the use of the methods. These changes appear to be prohibitive at the present time due to the current economic and political conditions. Therefore, as a practical solution, the following recommendations are made which incorporate some of the advantages of the CPM and Precedence methods with respect to contract time determination.

It is hoped that the recommendations presented in this section will improve the method currently used to establish contract times. The recommendations will be listed as steps for a methodology to be used in determining the contract time and will incorporate many of the steps now used. At the end of this section is a discussion of how this methodology can be effectively utilized by the Indiana State Highway Commission. Examples of the methodology are also included. Following is a step-by-step approach which can be used to establish the completion date, and document the key assumptions and construction logic which will be used for a highway construction project.

Step 1

The first step involves examination of the drawings, specifications, and contract documents. This step is necessary to familiarize the engineer with the existing conditions, the scope of the work planned, and identification of special requirements or procedures which are incorporated in the contract. From this investigation the field engineer can determine all of the necessary work activities which will be performed to complete the project. Items such as constraints on traffic disruptions or closures are identified for incorporation in the overall plan. This step also will give an indication of the magnitude and technical specialties of the project. This information will provide the engineer with an indication of the type of contractor who will be bidding for the contract and thereby indicate the range of expected productivities for the project.

Step 2

Identify all of the time consuming work activities necessary for completion of the project. The criteria for establishing work activities can be any of the following:

1. Area of responsibility
2. Craft or crew requirements
3. Equipment requirements
4. Material requirements
5. Subdivision of work
6. Location of work
7. Bid or payment items

The activity list should include all bid items but may include several in one activity. Figure 19 can be used to list each activity. Activities should be listed in chronological order in the second column. The quantity for each of the bid items should be entered in the third column. Special attention should be given to incorporating procurement activities for critical materials such as

No.	Work Item	Quantity	Daily Productivity	Duration	Preceding Activity(s)	Start Time	Finish Time

Figure 19

Contract Time Determination Worksheet

structural steel or other materials which are not shelf items. Depending on the size and complexity of the project different activity breakdowns and levels of detail can be used. It should be remembered that the intent of the method is to establish a reasonable project duration and not to schedule the day-to-day activities of the contractor. Therefore, a level of detail should be chosen which will identify major work activities which must be completed before other activities may begin. Once the activity list is complete, identification numbers (1, 2, 3, 4,...) should be entered in column 1 of Figure 19.

Step 3

Establish the construction logic for the project and identify the relationships between work activities. This step involves identifying, for each activity, the other activities which must be completed before it can begin. All time consuming preceding activities should be noted. The preceding activities can be entered in the sixth column on Figure 19. Sometimes activities can begin before the preceding activity is completely finished. As an example, form, pour, and cure culvert C-2 can begin five days before form, pour and cure culvert C-1 is complete because the five days required for curing culvert C-1 does not restrict the forming and pouring of culvert C-2. As in the CPM methods this relationship can be indicated by showing the overlap, in work days, in brackets ( ) after the preceding activity number in column 6. Often times this step may identify activities which may have been omitted from the initial work item list. To accurately represent the project logic it may also be necessary to create two or more activities from one larger activity to show the actual constraints which exists. In other instances it may become clear that several activities can be combined without clouding the project logic. For standard types of construction contracts, such as bridge deck repair, the project logic will not vary. In these types of projects standard sequences can be developed for use on future projects. However, care should be exercised in using standard sequences since minor deviations in work items or existing jobsite conditions can alter the most effective construction logic. Often the standard sequence can be altered slightly to incorporate the minor differences which may exist.

Step 4

Establish the activity duration for each activity which has been identified. The activity duration should be expressed in work days wherever possible. To determine activity durations a daily productivity needs to be established. As a guide for use in establishing activity durations Table 11 lists average values of daily production for most of the bid items used by the Indiana State

TABLE 11

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Excavation Common 0000-1999	CYS	500	350
Excavation Common 2000-4999	CYS	2000	400
Excavation Common 5000-9999	CYS	2000	750
Excavation Common 10000-24999	CYS	2000	1000
Excavation Common 25000-49999	CYS	3000	2000
Excavation Common 50000-99999	CYS	6000	3000
Excavation Common 100000-OVER	CYS	8000	4000
Excavation for Subgrade Treatment	CYS	1000	500
Water Way Excavation	CYS	500	500
Rock Excavation	CYS	1000	1000
Unclassified Excavation 000-1999	CYS	500	350
Unclassified Excavation 2000-4999	CYS	2000	400
Unclassified Excavation 5000-9999	CYS	2000	750
Unclassified Excavation 10000-24999	CYS	2000	1000

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Unclassified Excavation 25000-49999	CYS	2000	2000
Unclassified Excavation 50000-OVER	CYS	3000	3000
Class "Y" Excavation 350-500	CYS	500	
Peat Excavation 0000-1999	CYS	800	
Peat Excavation 2000-4999	CYS	1000	
Peat Excavation 5000-9999	CYS	1000	
Peat Excavation 10000-24999	CYS	1000	
Peat Excavation 25000-49999	CYS	1000	
Peat Excavation 50000-OVER	CYS	1000	
Surcharge 0-4 FT	LFT	2000	
Surcharge 4-8 FT	LFT	2000	
Surcharge 3-12 FT	LFT	2000	
Surcharge 12-16 FT	LFT	2000	
Surcharge 16-20 FT	LFT	2000	
Surcharge 20-24 FT	LFT	2000	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Estimated Daily Production Rate Contractors
Surcharge 24-30 FT	LFT	2000	
Surcharge 30-36 FT	LFT	2000	
Borrow 0000-1999	CYS	500	350
Borrow 2000-4999	CYS	2000	400
Borrow 5000-9999	CYS	2000	750
Borrow 10000-24999	CYS	2000	1000
Borrow 25000-49999	CYS	3000	2000
Borrow 50000-99999	CYS	6000	3000
Borrow 100000-OVER	CYS	8000	4000
B Borrow 0000-1999	CYS	500	350
B Borrow 2000-4999	CYS	1000	400
B Borrow 5000-9999	CYS	1000	750
B Borrow 10000-24999	CYS	2000	1000
B Borrow 25000-49999	CYS	2000	1000

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Contractors
B Borrow 50000-99999	CYS	2000	1000
B Borrow 100000-OVER	CYS	2000	1000
B Borrow for Structure Backfill	CYS	500	500
Plowing	ACRE	5	2
Embankment	CYS	100	750
Pavement Removal	SYS	800	650
Surface Removal	SYS	2400	2000
Breaking Pavement	SYS	1000	1000
Concrete Curb Removal	LFT	500	500
Bitum Curb Removal	LFT	2000	1300
Center Curb Removal	SYS	100	500
Walk Removal	SYS	300	750
Retaining Wall Removal	LFT	100	
Guard Rail Removal	LFT	1000	625
Shoulder Drains	EA	10	4
Sand Drains	LFT	2	
Mail Boxes - Resetting	EA	15	8
Tree Removal 6 in.	EA	100	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Tree Removal 10 in.	EA	60	
Tree Removal 18 in.	EA	50	
Tree Removal 30 in.	EA	30	
Tree Removal 48 in.	EA	25	
Paved Side Ditch Removal	LFT	500	300
Removal of Bituminous Surface	SYS	1000	1000
Gabions	CYS	200	
Exploratory Excavation 000-7500	CYS	500	500
Exploratory Drilling	LFT	500	300
Exploratory Cores 500-750	LFT	200	
Piezometers	EA	2	
Linear Grading	MILE	¼	
Pipe Group A 12" - 24"	LFT	300	100
Pipe Group A 30" - 54"	LFT	200	75
Pipe Group A 60" - 108"	LFT	100	25
Pipe Group B 12" - 24"	LFT	300	100

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Pipe Group B 30" - 66"	LFT	200	75
Pipe Group C 12" - 24"	LFT	300	100
Pipe Group C 30" - 48"	LFT	200	75
Pipe Group D 12" - 24"	LFT	300	100
Pipe Group D 30" - 66"	LFT	200	75
Pipe Group E 12" - 24"	LFT	300	100
Pipe Group E 30" - 48"	LFT	200	75
Pipe Group F 12" - 24"	LFT	300	75
Pipe Group G-1 Min Area 1.1 - 4.1	LFT	300	70
Pipe Group G-1 Min Area 4.4 - 12.9	LFT	200	50
Pipe Group G-1 Min Area 14.3 - 35.0	LFT	100	20
Pipe Group G-2 Min Area 2.2 - 6.4	LFT	300	50
Pipe Group G-2 Min Area 7.4 - 12.9	LFT	200	35

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Contractors
Pipe Group G-2 Min Area 14.3 - 40.0	LFT	100	10
Pipe Group G-3 Min Area 6.3 - 12.9	LFT	200	30
Pipe Group G-3 Min Area 14.3 - 28.0	LFT	100	25
Pipe Group H-1 Min Area 1.1 - 4.1	LFT	300	70
Pipe Group H-1 Min Area 4.4 - 14.3	LFT	200	50
Pipe Group H-2 Min Area 6.4 - 7.4	LFT	200	40
Pipe Group H-3 Min Area 4.1 - 6.3	LFT	300	50
Pipe Group L 6" - 24"	LFT	500	150
Pipe Group L 27" - 66"	LFT	200	75
Pipe Group M 6" - 24"	LFT	500	150
Pipe Group M 30" - 54"	LFT	200	75
Pipe Group P 6" - 24"	LFT	500	150
Pipe Group P 27" - 60"	LFT	200	75

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Pipe Reinforced Concrete Culvert 12" - 30"	LFT	300	100
Pipe Reinforced Concrete Culvert 36" - 72"	LFT	200	75
Pipe Reinforced Concrete Culvert 78" - 114"	LFT	50	20
Pipe Reinforced Elliptical Concrete Culvert 3.3 - 10.2 sq. ft.	LFT	300	40
Pipe Reinforced Elliptical Concrete Culvert 12.9 - 29.5 sq. ft.	LFT	200	30
Pipe Reinforced Elliptical Concrete Culvert 34.6 - 40.1 sq. ft.	LFT	100	25
Pipe Heavy Duty Reinforced Concrete Culvert 36" - 72"	LFT	100	25
Pipe 18 Corrugated Steel 6" - 24"	LFT	500	150
Pipe 16 Corrugated Steel 20" - 72"	LFT	100	25
Pipe with Paved Invert 12" - 24"	LFT	500	100
Pipe with Paved Invert 30" - 84"	LFT	100	75
Pipe Concrete Sewer 6" - 24"	LFT	500	150

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Pipe Reinf. Conc. Sewer 12" - 24"	LFT	500	100
Pipe Reinf. Conc. Sewer 27" - 66"	LFT	200	75
Plastic Pipe 1"	LFT	500	500
Pipe Galv. Steel 3"	LFT	500	60
Pipe Vit. Clay Sewer Standard Strength 4" - 15"	LFT	700	150
Pipe Vit. Clay Sewer Standard Strength 18" - 36"	LFT	300	75
Pipe Perf. CS for Underdrains 6" - 18"	LFT	500	100
Pipe Draintile Class Standard 6" - 24"	LFT	500	100
Aggregate for Underdrains	CYS	350	50
Aggregate for Underdrains (Size no. 7)	CYS	350	150
Catch Basin Type A 1	EACH	3	
Catch Basin Type A 2	EACH	3	
Catch Basin Type A 3	EACH	3	
Catch Basin Type A 4	EACH	3	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Estimated Daily Production Rate Contractors
Catch Basin Type A 7	EACH	3	
Catch Basin Type A 8	EACH	3	
Catch Basin Type A 9	EACH	3	
Catch Basin Type A 15	EACH	3	
Catch Basin Type C 5	EACH	3	
Catch Basin Type C 8	EACH	3	
Catch Basin Type D 6	EACH	3	
Catch Basin Type E 7	EACH	3	
Catch Basin Type H 5	EACH	3	
Catch Basin Type J 10	EACH	3	
Catch Basin Type J 11	EACH	3	
Catch Basin Type K 10	EACH	3	
Catch Basin Type K 11	EACH	3	
Catch Basin Type R 13	EACH	3	
Catch Basin Type S 14	EACH	3	
Catch Basin Type W 8	EACH	3	
Pipe Catch Basin 12" - 24"	EACH	20	
Inlet A 1	EACH	5	
Inlet A 2	EACH	5	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Inlet A 3	EACH	5	
Inlet A 4	EACH	5	
Inlet A 7	EACH	5	
Inlet A 8	EACH	5	
Inlet A 9	EACH	5	
Inlet A 10	EACH	5	
Inlet A 15	EACH	5	
Inlet B 1	EACH	5	
Inlet B 2	EACH	5	
Inlet B 8	EACH	5	
Inlet B 9	EACH	5	
Inlet C 5	EACH	5	
Inlet D 6	EACH	5	
Inlet D 10	EACH	5	
Inlet E 7	EACH	5	
Inlet E 8	EACH	5	
Inlet F 7	EACH	5	
Inlet G 7	EACH	5	
Inlet Type "H"	EACH	5	
Inlet Type H 5	EACH	5	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Contractors
Inlet Type 1 4	EACH	5	
Inlet J 10	EACH	5	
Inlet J 11	EACH	5	
Inlet K 10	EACH	5	
Inlet K 11	EACH	5	
Inlet M 10	EACH	5	
Inlet M 11	EACH	5	
Inlet N 12	EACH	5	
Inlet P-12	EACH	5	
Inlet P-12A	EACH	5	
Inlet R-5A	EACH	5	
Inlet R-13	EACH	5	
Inlet S-14	EACH	3	
Inlet T-14	EACH	3	
Inlet Type U-A	EACH	3	
Inlet Type W-A	EACH	3	
Inlet Type A-2	EACH	3	
Manhole A-2	EACH	1	
Manhole A-4	EACH	1	
Manhole A-7	EACH	1	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Estimated Daily Production Rate Contractors
Manhole A-1772-CVH	EACH	1	
Manhole A-15	EACH	1	
Manhole B-1	EACH	1	
Manhole B-2	EACH	1	
Manhole B-3	EACH	1	
Manhole B-4	EACH	1/2	
Manhole C-1	EACH	1/2	
Manhole C-2	EACH	1/3	
Manhole C-4	EACH	1/3	
Manhole C-7	EACH	1/3	
Manhole C-15	EACH	1/3	
Manhole D-2	EACH	1/6	
Manhole D-4	EACH	1/6	
Manhole D-15	EACH	1/6	
Manhole E-4	EACH	1/6	
Manhole F-4	EACH	1/6	
Manhole G-4	EACH	1/6	
Manhole H-4	EACH	1/6	
Manhole J-4	EACH	1/6	
Manhole T-60	EACH	1/6	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Estimated Daily Production Rate Contractors
Casting Furn. & Adj. To Grade Type 2	EACH	10	
Casting Furn. & Adj. To Grade Type 4	EACH	10	
Casting Furn. & Adj. To Grade Type 7	EACH	10	
Casting Furn. & Adj. To Grade Type 8	EACH	10	
Casting Furn. & Adj. To Grade Type 10	EACH	10	
Casting Furn. & Adj. To Grade Type 13	EACH	10	
Casting Furn. & Adj. To Grade Type 15	EACH	10	
Casting Furn. & Adj. To Grade Pipe Catch Basin 12 in.	EACH	10	
Inlets Using Casting In Place Type "A"	EACH	15	
Inlets Using Casting In Place Type "E"	EACH	15	
Inlets Using Casting In-Place Type "R"	EACH	15	
Inlets Using Casting In-Place Type "J"	EACH	15	
Conc. Class A in Structure	CYS	20	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Estimated Daily Production Rate Contractors
Conc. Class F. in Structure	CYS	20	
Conc. Class A for Integral Curb Walk	CYS	15	
Conc. Class "A" for Guard Rail	CYS	15	
Conc. Class "A" for Sidewalk Ramps	SYS	10	
Conc. Steps	CYS	8	
Reinf. Conc. Spring Box	EACH	2	
Reconstructured Inlet	LFT	7	
Reconstructured Catch Basin	LFT	7	
Reconstructured Manhole	LFT	7	
Casting Adjusted to Grade	EACH	10	
Pipe Jacked 15" - 36"	LFT	30	
Portland Cement Conc. Base 8 in.	SYS	5000	
Portland Cement Conc. Base 9 in.	SYS	5000	
Portland Cement Concrete for Patching	SYS	10	
Bituminous Mixture for Patching Pavement	TON	100	40

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Bituminous Mixture for Patching Pavement	TON	150	40
Widening with Bituminous Mixture	TON	1000	600
Widening with Compacted Aggregate	TON	750	750
Conc. Patches	SYS	10	
Conc. Widening 8 in.	SYS	4000	
Conc. Widening 9 in.	SYS	4000	
Filling Cracks and Joints in Conc. Pavement or Base	TON	50	3
Sealing Cracks and Joints in Bituminous Pavement	TON	50	4
Driller Holes for Underseal	EA	200	
Subbase 0000-4999	CYS	400	
Subbase 5000-9999	CYS	400	
Subbase 10000-24999	CYS	400	
Subbase 25000-49999	CYS	700	
Subbase 50000-99999	CYS	1000	
Subbase 100000-OVER	CYS	1000	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Bituminous Stabilized Subbase	TON	3000	1350
Bituminous Base	TONS	2000	1100
Bituminous Surface	TON	1500	1100
Hot Asphalt Concrete Base	TON	2000	1100
Hot Asphalt Concrete Binder	TON	2000	1200
Bituminous Binder	TON	2000	1200
Bituminous Mixture for Wedge and Levelling	TON	700	850
Type O Compacted AGC for Base (Size No. 53)	TON	2000	1100
Type O Compacted AGC for Shoulder (Size No. 73)	TON	2000	700
Type O Compacted AGC for Surface (Size No. 73)	TON	1000	900
Type P Comp. AGC for Base (Size No. 53)	TON	2000	1000
Type P Comp. AGC for Surface Size No. 73)	TON	1000	900
Type P Comp. AGC for Shoulder (Size No. 73)	TON	1000	700

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Hot Asph. Conc. Surface Type B	TON	1500	1100
Scarifying and Reshaping	SYS	400	1000
Bituminous Coated AGC for Base Widening	TON	1000	800
Bituminous Mixture for Shoulders	TON	1000	600
Bituminous Mixture for Crossovers	TON	300	250
Bituminous Mixture for Approaches	TON	300	200
Bituminous Mixture for Park Roads	TON	1000	700
Bituminous Mixture for Parking Area	TON	1000	525
Bituminous Material for Prime Coat	TON	200	7.5
Bituminous Material for Tack Coat	TON	200	2
Bituminous Material for Seal Coat	TON	200	7.5
Covering Aggregate	TON	400	175
AGC for Shoulder Drains	TON	200	20
Reinf. Cement Conc. Pavt. 7 in.	SYS	7000	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Estimated Daily Production Rate Contractors
Reinf. Cement Conc. Pavt. 8 in.	SYS	7000	
Reinf. Cement Conc. Pavt. 9 in.	SYS	7000	
Reinf. Cement Conc. Pavt. 10 in.	SYS	7000	
Reinf. Cement Conc. Pavt. 11 in.	SYS	7000	
Reinf. Cement Conc. Pavt. 12 in.	SYS	7000	
Plain Cement Conc. Pavt. 6 in.	SYS	7000	
Plain Cement Conc. Pavt. 7 in.	SYS	7000	
Plain Cement Conc. Pavt. 8 in.	SYS	7000	
Plain Cement Conc. Pavt. 9 in.	SYS	7000	
Plain Cement Conc. Pavt. 10 in.	SYS	7000	
Plain Cement Conc. Pavt. 11 in.	SYS	7000	
Plain Cement Conc. Pavt. 12 in.	SYS	7000	
Cement Conc. Pavt. for Driveways	SYS	500	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Estimated Daily Production Rate Contractors
Continuously Reinf. Cem. Conc. Pavt. 7 in.	SYS	7000	
Continuously Reinf. Cem. Conc. Pavt. 8 in.	SYS	7000	
Continuously Reinf. Cem. Conc. Pavt. 9 in.	SYS	7000	
Terminal Joints	LFT	96	
Contraction Joint Typd. D-1	LFT	2500	
Expan. Joint Performed with Load Transfer 1 in.	LFT	500	
Reinforcing Steel for Pavt.	LFT	3800	
Riprap	SYS	800	
Slopewall 4 in.	SYS	800	
Slopewall 5 in.	SYS	800	
Standard Lip Gutter	LFT	300	
Paved Side Ditch Type A	LFT	300	
Paved Side Ditch Type B	LFT	300	
Paved Side Ditch Type C	LFT	300	
Paved Side Ditch Type D	LFT	300	
Paved Side Ditch Type E	LFT	300	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Contractors
Paved Side Ditch Type F	LFT	300	
Paved Side Ditch Type G	LFT	300	
Paved Side Ditch Type H	LFT	300	
Paved Side Ditch Type J	LFT	300	
Paved Side Ditch Type K	LFT	300	
Paved Side Ditch Type L	LFT	300	
Paved Side Ditch Type M	LFT	300	
Integral Conc. Curb	LFT	250	
Integral Conc. Curb Type B	LFT	250	
Integral Conc. Curb Type C	LFT	250	
Bituminous Curb	LFT	1000	650
Cement Conc. Curb	LFT	300	
Cement Conc. Gutter	LFT	300	
Combined Conc. Curb and Gutter	LFT	300	
Reinf. Conc. Gutter	LFT	300	
Reconstructued Conc. Curb	LFT	300	
Conc. Center Curb Type A - D	LFT	400	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Conc. Median Barrier	LFT	400	400
Bituminous Center Curb	SYS	700	825
Guard Rail Type A	LFT	600	450
Guard Rail Type B	LFT	600	600
Guard Rail Type C	LFT	600	300
Guard Rail Type D	LFT	600	275
Guard Rail for Railroad Signal Protection, Median	EACH	4	2
Guard Rail for Railroad Signal Protection, Shoulder	EACH	4	1.5
Resetting Guard Rail	LFT	400	350
47 in. Fence Farm Field	LFT	500	750
Resetting Farm Field Type Fence	LFT	500	500
48 in. Fence Chain Link	LFT	400	325
Resetting Chain Link Type Fence	LFT	400	200
Gates Farm Field 47 in. x 12 ft.	EACH	10	3
Gates Farm Field 47 in. x 30 ft.	EACH	10	3

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Gates Chain Link 48 in. x 12 ft.	EACH	10	3
Flexible Delineator Post (B-8)	EACH	200	
Delineator with Post Type D-1 - D-3	EACH	150	75
STD Barricades Type I-V	EACH	50	
Permanent Barricades Type III - V	EACH	50	
Typical Sign Stds. (Constr. Sign Type A & B)	EACH	50	
Conc. Header Type A - D	LFT	1/2	
Conc. Sidewalk	SYS	100	
Reconstructed Sidewalk	SYS	50	
Conc. Sidewalk Removal	SYS	200	
Expansion JT for Sidewalk	LFT	500	
Temp. Crossover Type A & B	EA	1/5	
Lighting for Temp. Crossover Type "A"	EA	1/2	1/5
Right-of-Way Markers	EACH	50	17.5
Monument Type A - D	EACH	50	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Bench Mark Post	EACH	50	
Conduit 2 in.	LFT	500	400
Sodding	SYS	2500	
Lime Stabilization	TON	800	
Mulched Seeding	SYS	40,000	
Stop Sign	EACH	100	25
Speed Limit	EACH	100	25
Control R-10-R	EACH	100	25
Do Not Pass Sign	EACH	100	25
Pass with Care	EACH	100	25
Wrong Way	EACH	100	25
Yield Sign	EACH	100	25
Curve Sign	EACH	100	25
Reverse Curve Sign	EACH	100	25
Side Road Signs	EACH	100	25
T Symbol Sign	EACH	100	25
Flashing Arrow Sign (Single)	EACH	10	
Flashing Arrow Sign (Double)	EACH	10	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate ISHC	Estimated Daily Production Rate Contractors
High Intensity Flashing Yellow Light Type "B"	EACH	100	
Large Arrow Sign	EACH	20	20
Stop Ahead Sign	EACH	100	25
Signal Ahead Sign	EACH	100	25
Road Narrows Sign	EACH	100	25
Lane Ends	EACH	100	25
Divided Highway Sign	EACH	100	25
Railroad Advance Warning Sign	EACH	100	25
Railroad Crossbuck Sign	EACH	100	11.5
Advisory Speed Sign	EACH	100	20
School Sign	EACH	100	20
School Crossing Signs	EACH	100	20
Dead End Sign	EACH	100	20
Rumble Strip	LFT	500	
Painted Line	LFT	10,000	
Removal of Line - Solid 4 in.	LFT	4000	
Temporary Pavement Marking (Paint)	LFT	10,000	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Temporary Pavement Marking (Tape)	LFT	6000	1300
Parking Barriers (Conc) 7 ft. Long x 8 in. Wide	EACH	100	
Wood Post Barriers	EA	60	30
Line Skip White 4 in.	LFT	10,000	
Line Skip Yellow 4 in.	LFT	10,000	
Line Skip White 4 in.	LFT	10,000	
Line Skip Yellow 4 in.	LFT	10,000	
Thermo-Plastic Special Markings 6 in.	EACH		
Straw Bales in Place	EACH	100	
BRIDGE ITEMS			
Concrete, Class C in Superstructure	CYS		
Below 200 Above 200		30 cys	
Concrete, Class A in Substructure			
Above 200		10 cys	
Concrete, Class B Above Footings		10 cys	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Concrete, Class B in Footings		10 cys	
Pile Encasement (Concrete)	LFT	40 lft	
Concrete, Class A in Structures	CYS	10 cys	
Reinforcing Steel	LBS	20,000 lbs.	
Structural Steel Beams		30,000 lbs	
75000-300000			
3000001-500000			
Above 500000			
Anchor Rods	EACH	20 ea	
MK-AR 7			
Deck Drains	EACH	10 ea	
Cast Iron Drain Pipe 6"	LBS	3000 lbs	
Cast Iron Grates, Basins & Fittings	LBS	3000 lbs	
Steel Conduit 2 in.	LFT	200 lft	300
Tie Down Assemblies	EACH	10 ea	
Steel H Piles	LFT		
8 in.		600 lft	
10 in.		500 lft	
12 in.		500 lft	

TABLE 11 (Continued)

DAILY PRODUCTION RATES

Work Item Description	Units	Estimated Daily Production Rate	
		ISHC	Contractors
Steel Pile Shells	LFT		
12 in.		300 lft	
14 in.		300 lft	
16 in.		200 lft	
Timber Piles Driven	LFT	200 lft	
Waterway Excavation	CYS	1500 cys	
Wet Excavation	CYS	60 cys	
Foundation Excavation, Unclassified	CYS	100 cys	
Class X Excavation	CYS	20 cys	
Dry Excavation	CYS	100 cys	
Slopewall	SYS	100 sys	
Concrete Slopewall 5 in.	SYS	100 sys	
Concrete Slopewall 4 in.	SYS	100 sys	
Riprap	SYS	300 sys	
Hand Laid Riprap 12 in.	SYS	200 sys	
Dumped Riprap	TON	1000 Ton	
Hand Laid Riprap 6 in.	SYS	250 sys	
Revetment Riprap	TON	1000 Ton	

Highway Commission. These rates were established from data collected from the ISHC construction staff and many contractors who perform construction work for the ISHC. It should be emphasized that these rates are average values and should be reviewed periodically to ensure that they reflect technological improvements within the construction industry. The estimated daily production rate is entered in the fourth column of Figure 19. Once the productivity rates are known the activity durations are determined by dividing the quantity given in the contract documents by the daily production rate. The duration should be rounded up to the nearest whole day. If the activity involves more than one bid item or other time consuming work items a close evaluation is necessary to set a reasonable time duration. As an example the activity might be "form, pour and cure, culvert C-1." In this case the quantity is divided by the production rate (expressed in cubic yards per day) to give the number of days required for forming and pouring the culvert. To this number of days the minimum curing time should be added to set the duration for the activity. The activity duration is entered in the fifth column of Figure 10.

Conversion from calendar days to work days is necessary for activities such as curing concrete. The conversion is made on the basis of five work days for every seven calendar days. In a few instances this may not be exactly correct but due to the overall project duration the difference will be minimal. In projects involving a large number of calendar day activities it would be prudent to make the project duration determination by using calendar days for activity durations.

Step 5

Establish the start time and finish time for each activity. The approach which will be followed in this step is similar to the early start time and early finish time calculations performed in the critical path method. First it is assumed that the project begins at work day 0. All activities which have no preceding activities will have a start time of 0. This should be entered in the seventh column of Figure 19. The finish times for these activities, therefore, are simply the durations. Next the work items which are preceded by the initial activities are considered. For each of these work items the finish times of the preceding activities are compared and the largest of these becomes the start time and is entered in the seventh column. The finish time is derived by adding the activity duration to the start time. In cases where one or more preceding activities have bracketed numbers following them, the number in the bracket should be subtracted from the finish time of the preceding activity before being compared with the finish times of the other preceding activities. The procedure of comparison and computation is followed until the start times and finish times for all activities are established.

Step 6

Draw a time scaled bar graph to represent activity durations. A typical example of a time scaled bar graph is shown in Figure 20. At the top of the bar graph, information identifying the contract and its location should be identified. On the far left hand column space is provided to number the various activities. The second column is used to name the work activity and describe the specific task to be performed. The upper row across from each activity will be used to identify the proposed quantity, proposed daily production rate, and proposed duration. The lower row across from each activity will be used later to reflect the actual quantity, actual daily production rate, and actual activity duration. In the third column the quantity of work which will be used for bidding purposes is filled in on the upper half. The upper half of the fourth column should be used to identify the proposed daily productivity. In the space provided on the right hand portion of the graph, the activity duration is represented by a bar. The length of the bar is the number of work days allocated for the activity. The starting point of the bar is the earliest possible time

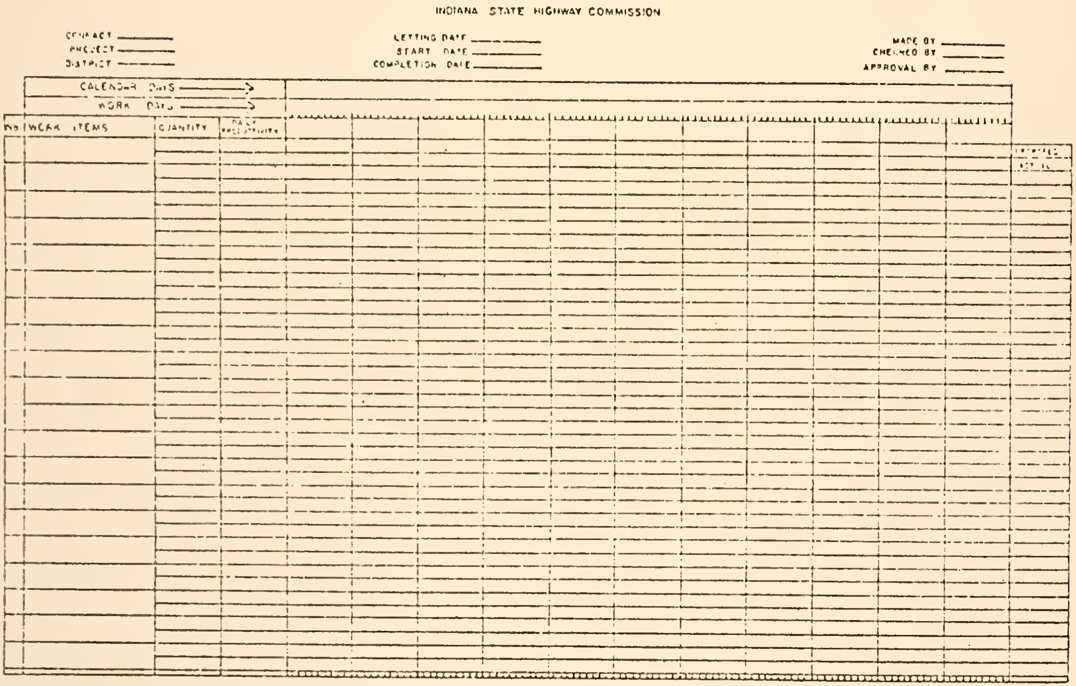


Figure 20

Time Scaled Bar Graph

which the activity can begin, determined by the completion of any activities which must preceed it.

Activities normally are listed in chronological order of their start times. This can be done simply from column seven in Figure 19. Although this is not absolutely necessary it certainly simplifies reading of the chart.

As an aid in clearly identifying the construction logic, the preceding activities are noted on the bar graph to the left of each activity bar. With the construction logic clearly shown, deviations from the proposed daily productivity or changes in the quantities can be evaluated for their overall impact on the total project duration.

The scale used to plot the activity durations is in work days. A row is provided above this scale to identify calendar days (or calendar dates). This can be added by applying the work day correlation tables 4, 5, 6, and 7.

Finally, a contingency time allowance may be added to the total project duration to reflect the possibility of strikes, late material deliveries, unusual weather, equipment breakdowns, or other unforeseen circumstances. Depending on the size and scope of the project and the degree of urgency, this contingency allowance may vary from zero to ten percent of the estimated total project duration. The contingency allowance should be treated as the final activity commencing after the completion of the project.

To illustrate the use of the recommended methodology, worksheets and time scaled bar graphs for a bridge project are shown in Figures 21, 22 and charts 1, 2, and 3 on page 131.

- Bridge Project -

No.	Work Item	Quantity	Daily Productivity	Duration	Preceding Activity(s)	Start Time	Finish Time
1	Move-in	-	-	5	-	0	5
2	Remove Existing Structure	-	-	5	1	5	10
3	Order & Deliver Piling	-	-	21	-	0	21
4	Construct Fill	8,000 cyd	500 cyd/day	16	2	10	26
5	Bent 1 Cofferdam	1 ea.	-	3	4	26	29
6	Bent 1 Piling	1500 lft	500 lft/day	3	3,5	29	32
7	Bent 1 Form & Pour Footing	10 cyd	10 cyd/day	1	6	32	33
8	Bent 1 Cure Footing	-	-	1	7	33	34
9	Dewater, Form & Pour Bent 1 Stem	20 cyd	10 cyd/day	2	8	34	36
10	Bent 1 Cap	10 cyd	10 cyd/day	2	9	36	38
11	Bent 2 Cofferdam	1 ea.	-	3	5	29	32
12	Bent 2 Piling	1500 lft	500 lft/day	3	6,11	32	35
13	Bent 2 Form & Pour Footing	10 cyd	10 cyd/day	1	7,9,12	36	37
14	Bent 2 Cure Footing	-	-	1	13	37	38
15	Dewater, Form & Pour Bent 2 Stem	20 cyd	10 cyd/day	2	9,14	38	40
16	Bent 2 Cap	10 cyd	10 cyd/day	2	15	40	42
17	North End Bent Drive Piling	1000 lft	500 lft/day	2	12	35	37
18	North End Bent Form & Pour	30 cyd	10 cyd/day	3	15,17	40	43
19	North End Bent Cure	-	-	4	18	43	47
20	South End Bent Drive Piling	1000 lft	500 lft/day	2	17	37	39
21	South End Bent Form & Pour	30 cyd	10 cyd/day	3	18,20	43	46

Figure 21

Contract Time Determination

Worksheet - Bridge Project

(partial)

No.	Work Item	Quantity	Daily Productivity	Duration	Preceding Activity(s)	Start Time	Finish Time
22	South End Bent Cure	-	-	4	21	46	50
23	Order & Deliver Beams	-	-	45	-	0	45
24	Set Beams	-	-	2	10,16,19,22 23	50	52
25	Form & Pour Diaphrams	15 cyd	5 cyd/day	3	24	52	55
26	Cure Diaphrams	-	-	4	25	55	59
27	Form Deck & Coping	-	-	4	26 [3]	56	60
28	Rebar	60,000 lbs	20,000 lbs/day	3	27 [2]	58	61
29	Pour Deck W/O Support Cuttouts	150 cyd	150 cyd/day	1	28	61	62
30	Remove Bulkheads & Place Concrete	20 cyd	10 cyd/day	2	29	62	64
31	Cure Deck	-	-	4	30	64	68
32	Form & Pour Top Wall	30 cyd	15 cyd/day	2	31 [1]	67	69
33	Cure Top Wall	-	-	4	32	69	73
34	Reinforced Concrete Approaches	180 cyd	30 cyd/day	6	32	69	75
35	Cure Approaches	-	-	4	34	75	79
36	Place Compacted Aggregate	450 tons	2000 tons/day	1	34	75	76
37	Place Bituminous Mix	250 tons	1300 tons/day	1	36	76	77
38	Bridge Rail	800 lft	600 lft/day	2	33,35,37	79	81
39	Guard Rail	1200 lft	600 lft/day	2	37	77	79
40	Seeding & Sodding	5000 syd	2500 syd/day	2	37	77	79
41	Clean-up	-	-	9	38,39,40	81	90

Figure 22

Contract Time Determination

Worksheet - Bridge Project

(continued)

CHAPTER 7

CONCLUSIONS

The goal of this investigation was to develop an improved methodology for contract time determination. The methodology described in Chapter 6 has many advantages over the current system used to determine contract durations. Adoption of the methodology would provide more consistency in the determination of contract times by the field engineers. The assumptions and judgments made about the project prior to bidding, should be well documented for use in evaluating and prequalifying bidders, monitoring construction progress, and settling disputes over time extensions. The project logic is identified clearly so that a determination of the controlling work activities can be made on a "work day" contract. The effects of delays on the completion date for the project can be determined through analysis of the time scaled bar chart. This would be a useful tool in persuading the contractor to take the necessary remedial action to bring the project back onto schedule. The time scaled bar chart would also provide a method of communication between the field engineer and the estimator who will compile the engineer's estimate for the State Highway Commission. The estimator should have knowledge of productivity rates in his evaluation and projection of the cost of construction.

Another advantage to this method is that procurement items and other nonpay items will be identified and their importance to a timely completion of the project highlighted. The time scaled bar chart can also serve a purpose in the field where the work is going on. Progress can be plotted and productivity rates noted for comparison with the original bar chart. This information can be used to give a more accurate representation of the progress than the current system used for the monthly construction report.

The Indiana State Highway Commission prepares many contracts which are similar in nature. With this method it would be possible to develop basic logic diagrams for these similar projects. Modifications could be made to the standard activity list when unusual or peculiar conditions existed. This would greatly reduce the time spent by field engineers in determining contract durations.

It should be noted that the methodology still requires sound engineering judgment. The suggested daily productivity rates should be checked with actual productivities periodically and be updated or revised to include new work items or new technology.

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