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Principles of designing monitoring information systems for small construction contractors

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Department:

PRINCIPLES OF DESIGNING MONITORING INFORMATION SYSTEMS FOR SMALL CONSTRUCTION CONTRACTORS

BY

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THESIS

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ABSTRACT

The object of this investigation was to develop a monitoring information system which would comply with the time and cost constraints of the small construction contractor. Every aspect of a monitoring system was considered and logically analyzed.

A suggested Monitoring Information System was developed and compared to other monitoring systems in existing literature and also the monitoring system of a local contractor. It was determined by this investigation and comparison that the suggested Monitoring Information System eliminated many disadvantages of existing systems such as: 1) inaccurate monitoring of progress, 2) large number of forms to process, 3) large time lag between the occurrence of an uneconomic situation and the reporting of this situation, 4) the inability to point out the cause of an uneconomic situation, and 5) the requiring of experienced construction personnel to perform progress monitoring. The time required for the suggested Monitoring Information System was not reduced but merely shifted from the pre-contract letting period to the post-contract letting period.

ACKNOWLEDGEMENTS

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I. INTRODUCTION

A. Present Day Construction Industry

Management's definition of business is; a commercial or industrial enterprise operating to make a profit. Any type of business that does not make a profit is not actually a business. In the construction industry today, there is one prime reason why contractors cannot maximize their profit on every project. This reason is competition. However, without competition our present day economic system would not exist.

In 1966, of the contractor failures, 77% and 37% had liabilities under $100,000 and $25,000 respectively.(1) Thus, the majority of contractor failures appear to be small contractors. Two reasons for these business failures are; 1) incorrect and unrealistic estimating and bidding; and 2) inadequate records and cost control.(2) These causes can easily be related to the need and especially the importance of an effective monitoring and control information system. Therefore, in order to minimize the chances of failure, a contractor should monitor and control his projects.

An effective monitoring and control system also has the added advantage of providing additional income with virtually no effort. According to W. Richard Jones, (3) every dollar that is saved on a construction project is equivalent to $20 on a contract price and is easier to obtain. A system which saves $5,000 on a project is just the same as having an additional $100,000 contract. Since approximately fourteen projects must be bid for every one brought to contract,(4) the value of cost savings can easily be seen.

B. Status of the Construction Contractor

Large construction contractors have elaborate and effective monitoring and control systems. This is largely due to the fact that they not only recognize the need but they can afford to employ personnel to manage and operate a monitoring and control system.

Small contractors, taken here as those grossing under two million dollars per year, are in a different situation entirely. Possibly one reason why a small contractor does not implement an elaborate monitoring and control system is cost. An effective monitoring and control system will require extra time and technical training for the estimating and field personnel for more planning and reporting. The small contractor cannot satisfy these requirements because of his cost constraints.

In the absence of an effective monitoring system, the president of the small company may waste a full day wading through invoices, sketchy and vague reports trying to determine if a project is under control, while he could be utilizing his time more effectively elsewhere. He may end up doing work that could be done more effectively be clerical personnel under a different system. In a more efficient system, only the exceptions to the plan would be pointed out to the president so that he could quickly make the decision as to which control measure to apply. If a system like this can be devised for the small contractor, the money saved and increased job control will more than adequately pay for the cost of the extra planning and personnel.

C. Purpose of the Investigation

It will not be questioned that an experienced small contractor can apply corrective control measures when a danger area is observed, however the process is informal in the absence of a proper monitoring

system and may allow many situations to go undetected. It is specifically the task of a formal system to collect the information from the field, transmit it to the office, and process it so that only the exceptions from the plan are presented to the company president for determination of the proper control measure. The goal of this investigation is to develop a monitoring system utilizing the principles of "management by exception". This monitoring system will comply with the following constraints which are significant to any contractor.

1. Minimum field and office time and personnel.
2. Simple and easy to understand.
3. Short time lapse between occurence of dangerous situation and its reporting.
4. Point out where to apply corrective action.

II. REVIEW OF LITERATURE

A. General

In reviewing other literature that has been published on monitoring systems, everything that has an effect upon a monitoring system should be considered. Basically the actions that are involved in a monitoring system are: The preparation of a standard, and the comparison of actual field data to this standard. The preparation of the standard normally occurs before the start of construction. This period will be referred to as the Pre-Construction Phase. Whereas, the comparison of actual field data occurs after construction on the project has begun. This period will be referred to as the Construction Phase.

B. Monitoring and Control System by Walker[5]

The Pre-Construction Phase procedure and the Construction Phase procedure are shown in Figure 1 and Figure 2, respectively. In the Pre-Construction Phase procedure, the method of preparing the standard and the bid estimate are the same. The actual construction data is compared to the Summary Sheet, item 12, and therefore also acts as the standard. The Summary Sheet also includes subbids, equipment, fees and overhead. The Construction Phase procedure is used to record field information, compare it to the standard and the reporting of this comparison as the job progresses. These procedures are used by many contractors. However, for the following reasons, it is not adaptable to the needs of the small contractor.

The Pre-Construction Phase procedure does not provide an estimated cost of a work classification to compare to its actual cost until the

PRE-CONSTRUCTION PHASE

Walker: "Practical Accounting and Cost Keeping for Contractors"

LEGEND

1 The Plans and Specification are inspected by the estimator.
2 From this, the items of work to be subcontracted out are determined.
3 Request for bids from subcontractors.
4 Fabricated material need is determined.
5 Major classes of work are listed for entire job. Such as: Concrete, Excavation, Earthwork etc.
6 Determine following conditions:
  a. General site conditions
  b. Soil conditions
  c. Location accessibility and Site size
  d. Available labor
7 Major work classes broken into subitems, then estimated material, dimensions, quantity unit cost material, cost of material, unit cost labor, cost of labor. Total cost of material and labor by major item.
8 Analyze subbids and place estimate on Summary Sheet.
9 Equipment estimated for total job and placed on Summary Sheet.
10 Fees include permits, taxes and insurance for entire job and placed on Summary Sheet.
11 Overhead items such as; supervisory personnel are priced and placed on Summary Sheet.
12 Shows: Total by class of work
  Total cost for all classes of work
  Profit
  Surety Bond
  Amount of Bid

SYMBOLS

Manual operation

Formal document

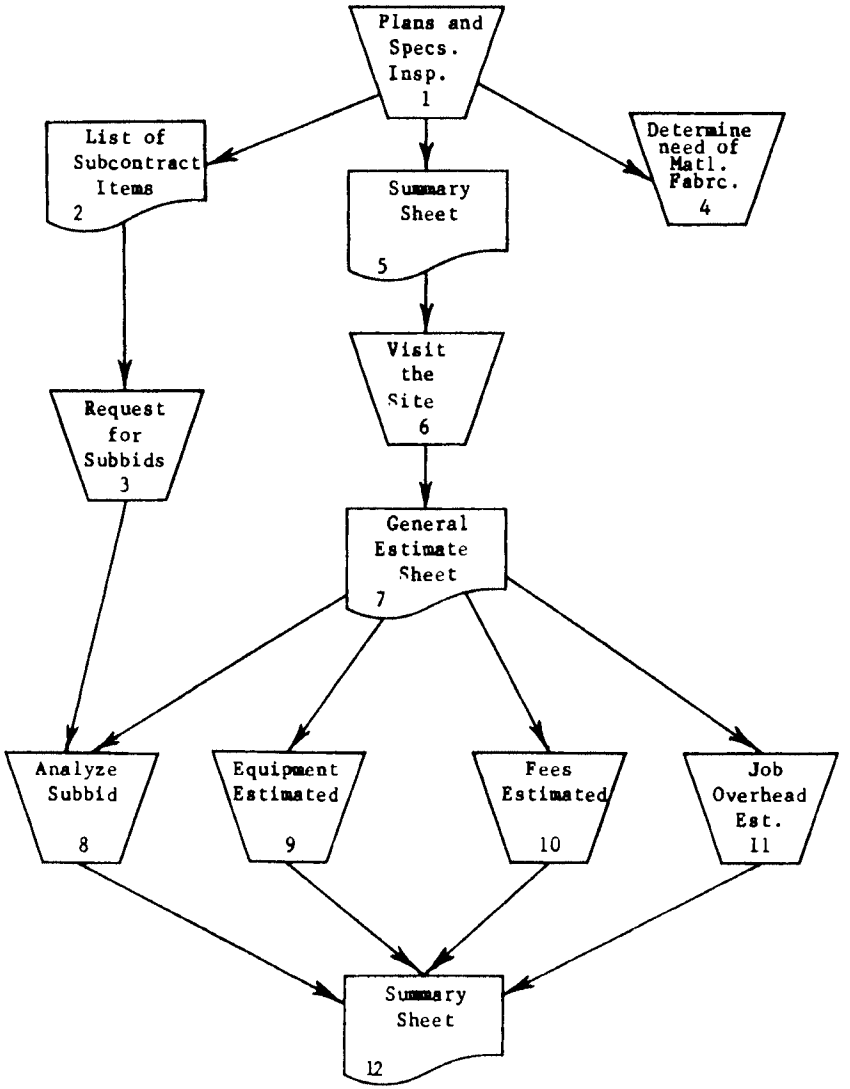

FIGURE 1-PRE-CONSTRUCTION PHASE BY WALKER

CONSTRUCTION PHASE

Walker: "Practical Accounting and Cost Keeping for Contractors"

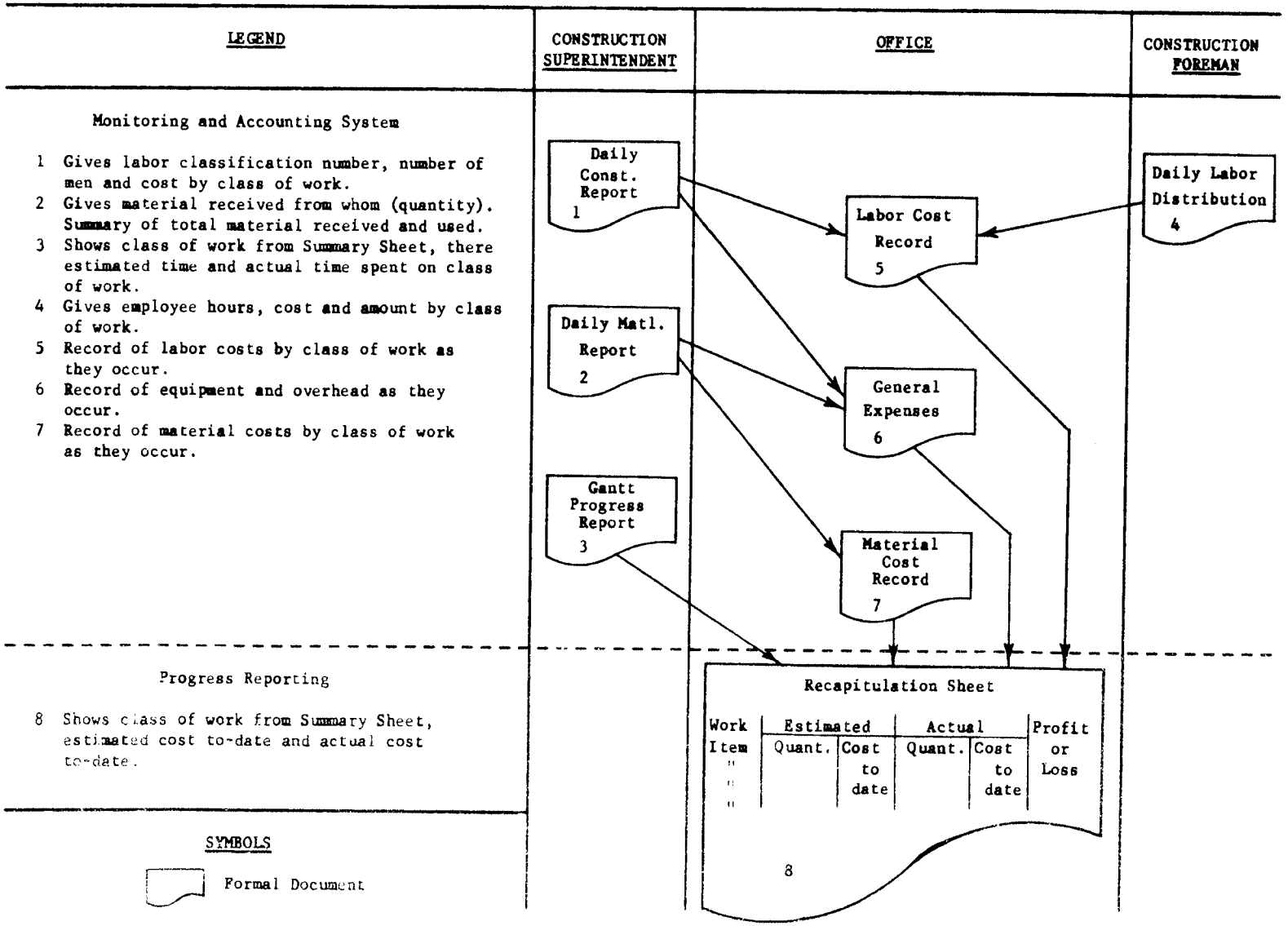

FIGURE 2-CONSTRUCTION PHASE BY WALKER

work classification is completed or nearly completed. The inability of the small contractor to make a reliable comparison between actual data and the standard inhibits his capacity to exercise an immediate and effective control measure.

In the Construction Phase procedure, the contractor must process seven forms before he knows if he is close to his estimate. This procedure gives a daily check on the progress of the project if seven forms could be processed daily, but this automatically eliminates the small contractor from using it because of his personnel limitations.

The Recapitulation Sheet, item 8, contains every class of work that is involved in the entire project. A few examples of classes of work are general excavation, rock excavation, millwork, plastering, and plumbing. After examining the percent completion, of each class of work on the Gantt Progress Report, item 3, the quantity of material that should be in place, according to the date, is estimated. The estimated unit cost, on the Recapitulation Sheet, is taken from the Summary Sheet and the estimated total cost for each class of work is then calculated. The actual quantity and unit cost to-date is recorded from field reports and the actual total cost by class of work is calculated. By comparing the estimated total cost to the actual total cost, the total gain or loss on the estimate is determined. This procedure is inaccurate because the quantity of material that is estimated from the Gantt Progress Report is a very rough estimate. This sheet does not point out specifically where corrective action should be applied. Even if the Recapitulation Sheet does point out a loss on a certain class of work, it is still unknown which element or elements (material, labor, and equipment) are responsible.

C. Monitoring and Control System by Deatherage

The Pre-Construction Phase procedure[6] is shown in Figure 3, and the Construction Phase[7] in Figure 4. In the Pre-Construction Phase procedure, the method of preparing the standard and the bid estimate are the same. The estimated data serves as a standard for the monitoring system. This procedure is primarily the same as the one suggested by Walker, except the number of forms is greater, which is a disadvantage to the small contractor. Each class of work, such as clear site, foundation backfill, and concrete piers are given a separate cost code number, which contains material, labor and equipment in the estimate. Each cost code estimate will include everything during the entire project duration that can be credited to that cost code. This procedure does not allow the contractor to compare actual costs to the cost code estimate until almost all of the work on the cost code is completed. This will naturally inhibit the small contractor's ability to exercise immediate control.

In the Construction Phase procedure, the major disadvantage, as in the procedure suggested by Walker, is the Recapitulation Sheet, item 9. To determine the quantities of material, that should be in place to-date, daily reports and the estimate sheet must be studied and a rough estimate made. This will result in a daily or weekly rough estimate of the standard by which the actual data are compared. Even if this rough comparison does show an uneconomic situation, it is still not known which cost code element or elements (material, labor, and equipment) are the cause.

PRE-CONSTRUCTION PHASE

Deatherage: "Construction Estimating and Job Preplanning"

LEGEND

1 The Plans and Specification are inspected by the estimator.
2 From this inspection, the classes of work to be subcontracted are determined.
3 Request for bids from subcontractors.
4 All subbids are analyzed and chosen.
5 From the Plans and Specifications inspection, the required work items are checked off.
6 Shows job access, labor conditions, soil etc.
7 Checklist of classes of work which apply to this job.
8 Checklist and estimate of Job Overhead (field supervision etc.)
9 Checklist and estimate of plant, tools and equipment.
10 Estimated quantity of labor, equipment and material by class of work (cost code). Last page totals all work items, subbids and profit to give bid price.

SYMBOLS

Manual operation

Formal document

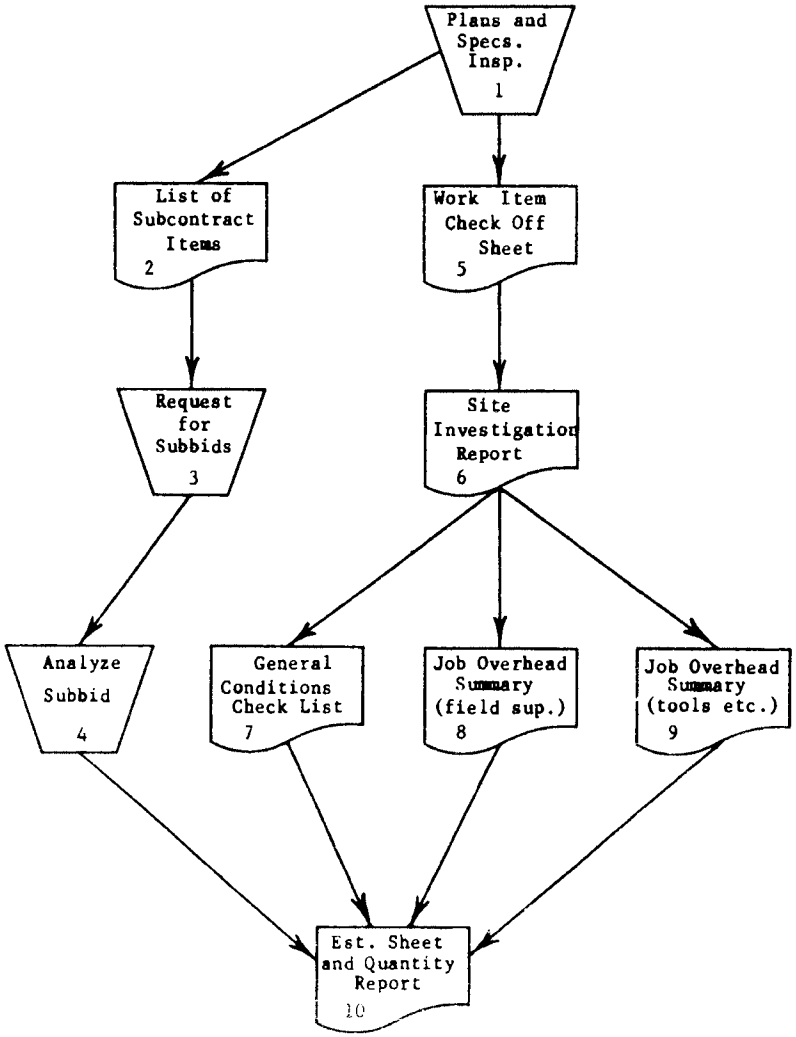

FIGURE 3-PRE-CONSTRUCTION PHASE BY DEATHERAGE

CONSTRUCTION PHASE

Deatherage: "Construction Office Administration"

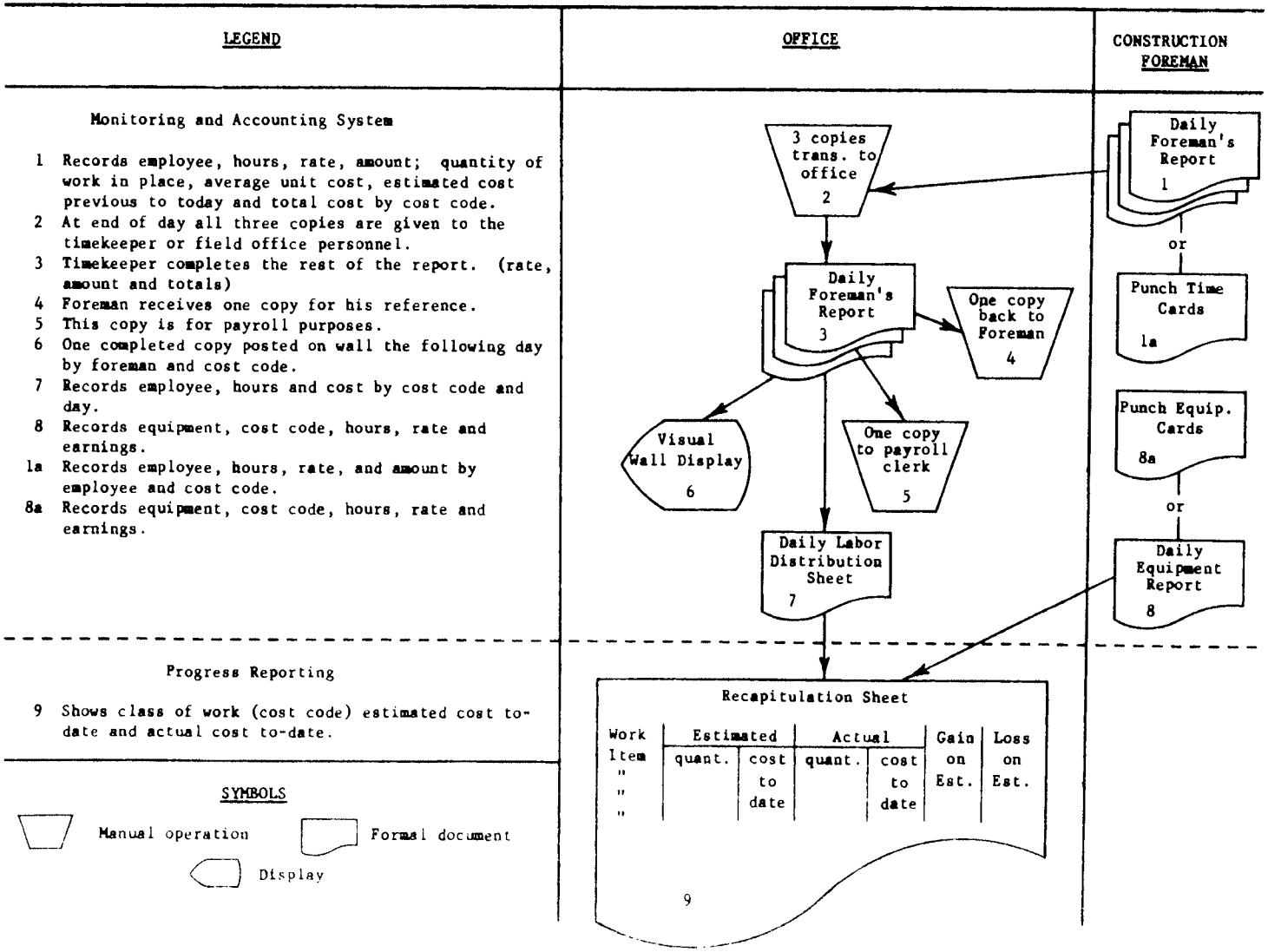

FIGURE 4-CONSTRUCTION PHASE BY DEATHERAGE

D. Local Small Contractor

The method shown in Figure 5 describes the Construction Phase procedure which is now in use by a local contractor. As stated in the thesis by Bailey,[8] from which this procedure is taken, this contractor has an annual gross income of about $750,000. The Pre-Construction Phase procedure is not shown because it is primarily the same as the one presented by Walker and also contains the same disadvantages.

The outstanding characteristic of the Construction Phase procedure is that the monitoring reports are processed through the accounting and bookkeeping procedure before progress reporting occurs. All labor, equipment, material, rental debts and credits are recorded and balanced with bookkeeping accuracy in the Job Cost Ledger, item 13. The person responsible for monitoring and controlling the project can compare the data of the Job Cost Ledger to the estimate or summary sheet. Using this procedure, however, a three to four week lag time will be present in the Job Cost Ledger. This lag time is caused by the time required to process the reports through the bookkeeping procedure and balance the accounts. Naturally this inhibits the contractor's ability to recognize an uneconomic situation in time to prevent a large loss.

By using the same Construction Phase procedure, this contractor sometimes utilizes another progress reporting method. The reports that are sent to the office daily can be reviewed and compared daily or weekly to the general estimate. This method, however, even though it is immediate, requires a very experienced person in all phases of construction to be able to recognize an uneconomic situation. Usually

CONSTRUCTION PHASE

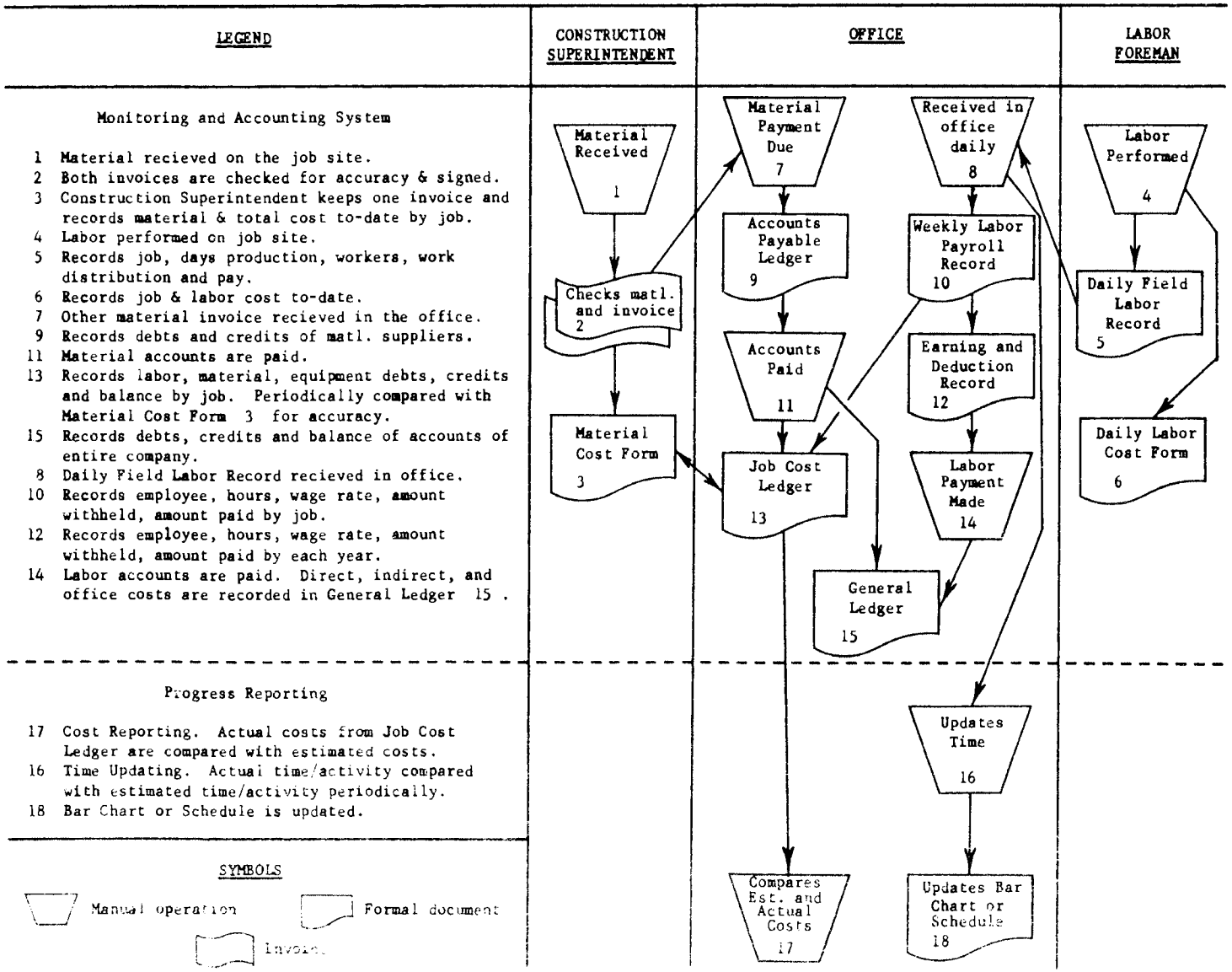

FIGURE 5-CONSTRUCTION PHASE BY LOCAL CONTRACTOR

in a small contractor's organization, the only person with this type of experience is the company president. As the company president, he could probably utilize his time better if he did not have to read and interpret daily reports.

III. COST CONTROL PRINCIPLES APPLIED TO THE PRE-CONSTRUCTION PHASE

A. Principles of Cost Control

According to Pilcher,[9] the most important function of a cost monitoring system is to bring immediate attention to any activity on a contract which is uneconomical to the contractor. This is the common day-to-day use of the cost monitoring system. The secondary function of the cost monitoring system is to provide historical information or feedback to the estimator because he will be responsible for estimating future contracts. These functions are basic to a cost monitoring system of any contractor, large or small.

In order to provide the small contractor with the ability of bringing immediate attention to uneconomic activities, timely information must be supplied from the field. The information system should then monitor the defects of an activity soon after they occur. Likewise, to provide the small contractor with the ability of providing historical information to the estimator, current information should also be supplied. The estimator's prime responsibility is to produce estimates on future contracts. By this, he brings about the necessity to generate current information on all activities. Without this type of information, in the form of historical records, the ability of an estimator to produce an up-to-date estimate would be permanently handicapped.

Since both functions of a cost monitoring system are concerned with the same type of information, the providing of historical cost information could very easily be the end result of the monitoring system. The information in this monitoring system need only be accurate enough to point out an uneconomic situation and also sufficiently reliable to assure that actual costs are accredited to the

proper cost code for accurate historical records.

There is another function of a cost information system which is directed toward satisfying external constraints on the company. The system which will satisfy these constraints would be the bookkeeping or accounting system. The function of this system will be to pay material suppliers, labor trades and the Internal Revenue Service their correct amount of money. The cost information to fulfill this function must be accurate and able to balance with all the accounting books and ledgers of a project. If this accuracy of the cost information were not required, the company would soon fold-up and go out of business. The separation of the bookkeeping procedure from the monitoring procedure was brought out by Gillette and Dana,(10) in 1922.

B. Pre-Construction Phase Procedure

The Pre-Construction Phase entails all the activities that are necessary before the actual construction on the project is started. Some of these activities are such things as site investigation, the bid estimate, the securing of the contract, job site lay-out and project pre-planning. However, as far as the Monitoring Information System is concerned, the only part of the Pre-Construction Phase of importance, is the preparation of a standard. Later, in the Construction Phase, the standard will be compared to actual data which will form the basis of progress reporting.

1. Method of Preparing a Standard

The method used to prepare a standard is an important factor in the Pre-Construction Phase procedure. As was seen in the review of

literature, the primary purpose of the general estimate sheet is to serve as a project estimate before the contract letting. However, after the project is under contract, the secondary purpose of the general estimate sheet is to serve as the standard. With the primary purpose in mind during its preparation, the cost estimate of a class of work will contain all of that type of work over the entire project. Therefore, for the previous reasons stated in the review of literature, the use of these sheets is a very poor standard by which to compare actual construction data, daily or weekly.

A second method of preparing a standard is the use of the Critical Path Method or CPM. With CPM the project is broken up into many detailed activities. It also describes the activity precedence and points out the critical activities that will affect the duration of the entire project. This procedure not only enables the contractor to arrive at a more accurate cost estimate but a more detailed and accurate standard. Even though CPM, because of its detail, appears to be a more accurate method than the previous one, small contractors seem to shy away from its use because of the cost of extra planning and scheduling required. If CPM is used on every project before the contract letting, the added cost of this procedure would never be compensated by the one project out of every fourteen that is brought to contract. Therefore, it is almost mandatory to use CPM only on projects that have already been brought to contract.

However, the use of CPM only on the projects that are brought to contract, with the purpose of providing a guide and cost schedules to a contractor's personnel, will create some adverse effects. Since the project is already under contract, the answer to the CPM cost estimate

is already known. Instead of re-estimating the cost of each activity, the easiest way, according to O'Brien,[11] is to start with the contract price and work backward. Each class of work will be reapportioned to the appropriate activities according to the re-estimated quantities and kinds of material involved in that activity. Using this method, if an error in unit costs was present in the original estimate, it will also be carried over into the CPM estimate. However, if the re-estimating of the material quantities is carefully performed, any material quantity error that was present in the original estimate would be pointed out. The contractor can then correct his purchase order so he will not be short or have an over supply of materials. If the original material quantity estimate was under estimated to the extent that the contract price should have been higher, an added risk is involved in this project. However, the contractor will at least know there is an added risk involved and this amount must be made up somewhere else in the project if he hopes to obtain the profit originally anticipated.

2. Contents of the Standard

As previously stated, the purpose of the standard is to provide a comparison for actual construction data in order to determine an uneconomic activity. The standard could contain the costs of material, equipment and labor. The only costs that are absolutely necessary are the ones which will point out an uneconomic activity. The bare essential contents of the standard must be determined which will enable the contractor to isolate an uneconomic situation during construction.

By first examining the method of preparing the standard, two areas of concern can be seen. Each and every activity, developed

through the use of CPM, is described by an estimated cost and production rate. The production rate is represented by the activity description stating that a quantity of material will be placed within an estimated time duration. Both of these areas must be monitored. However, the detail of the standard when first produced must first be determined.

The different types of costs that might be included in the cost standard are; material, labor and equipment. The cost of materials was originally estimated to include the cost in the contract price. Since the project is under contract, the material cost cannot be controlled by any managerial technique or the field personnel. Therefore, as far as the field personnel are concerned, they have no control over the cost of material required. After the material is on the job site, it is not a variable cost, but only reflects the accuracy of the estimate. What remains to be developed as a cost standard is labor and equipment costs.

The second standard, that of production, can be described in either of the following two ways; 1) monitoring the cost of the material by activity, or 2) monitoring the quantity of material by activity. Suppose these two ways are compared to each other on the basis of accuracy. If the cost of a material quantity by activity were used, a variance in the quantity estimate and also a variance in the unit price estimate could be present. Therefore, the total cost of the material quantity could contain two variances. Whereas, if material quantities by activity were used to measure production, they would only contain one variance and thus be more accurate. Because of the character of the information involved in estimating material quantities, estimators are much better at estimating material quantities

than costs. Therefore, the following solution is adequately justified. The reapportioning of material quantities among the activities will then be the basis for the production standard or actually the production schedule.

3. The Form of the CPM Activities

One of the prime disadvantages of the monitoring systems, presented in the review of literature, is the inability to permit the contractor to accurately monitor his project daily or even weekly. This inability is primarily due to the fact that the estimated progress on one work classification was determined by the amount of time spent on that work classification. Thus, the actual costs and production rates might not be linear with the time spent on the class of work, and a false signal would result. To illustrate this point, suppose $1269 is the total estimate for placing a concrete floor which will take 20 days to perform. At the end of 15 days, according to the recapitulation sheet, we should have spent 75% of the money and still have 25% more material to place. However, according to actual construction data, we have spent 95% of the money and placed 100% of the material. The remaining 5 days are for the concrete curing and removing the formwork. In this situation, the recapitulation sheet would have shown that costs were 20% higher than what they should be when actually everything was under control.

In order to overcome this defect, the cost standard and production standard must be linear with time. This means that when the CPM activities are originally devised, the cost of labor and equipment, and the material placement must be linear with the activity duration. This action will cause the activities to be smaller in duration than normally

devised. However, without this requirement on the CPM activities, the capability to accurately conduct daily monitoring of a project would be impaired.

IV. COST CONTROL PRINCIPLES APPLIED TO THE CONSTRUCTION PHASE

A. General

The Construction Phase consists of everything performed on the project after the actual construction has begun. This will entail all activities from moving the equipment onto the job site to final inspection and turning the project over to the owner. However, the only activities involved in the Monitoring Information System are: 1) collecting and recording of field information, 2) comparing this information to the standard, and 3) the reporting of this comparison as progress monitoring. Each of these activities will be discussed in the following paragraphs.

B. Field Personnel Requirements on the Collection of Field Information

The collection of field information is of prime importance in monitoring a project. This activity of the Construction Phase is the source of all information that will be processed through the Monitoring Information System and the Bookkeeping or Accounting System. If the correct information is not acquired through this source, it will jeopardize the entire cost control system.

There is a basic requirement that the information system must conform to the limitations imposed by field personnel. The small contractor's field personnel are normally not highly trained in accounting procedures nor in the details of CPM. The small contractor does not have the time or the money to train his personnel in the details of these methods and procedures. The value of this type of field personnel is their experience in construction methods and the guidance of labor trades. Realizing this situation, it is mandatory that the method

used to collect field information be easy to understand, simple to use and require little time.

C. Field Information Requirements for the Standard

As stated previously, the standard is represented by the Labor and Equipment Cost Schedule and the Production Schedule. Both of these schedules demand specific information from the field for comparison. By examining the contents of the Labor and Equipment Cost Schedule, the following information is required.

1. The number of workers by trade
2. working on what activity, and
3. for what amount of time.
4. The number by type of equipment
5. working on what activity, and
6. for what amount of time.

By examining the contents of the Production Schedule, developed as a standard, the exact field information required cannot be determined. The schedule merely states the quantities of material that should be in place by the end of an activity. Subsequently, the information required from the field cannot be resolved until the method of measuring the material quantities is defined.

One procedure that could be used to monitor production is the actual physical measurement of material in place. However, this method would be very cumbersome to the small contractor because it would require additional qualified personnel and time to go through the calculations and paper work in the field.

Another procedure that could be used is accounting for the material

as it is taken out of the stockpile. The production could be monitored by measuring the material left in the stockpile and assuming that what is not in the stockpile is in the project. But this too would be very cumbersome for the small contractor. It would require again extra personnel to maintain a check on each stockpile and its records.

A third procedure is simply eye-balling the amount of material put in place. Even though this procedure is normally considered to be very rough and inaccurate, it would not be in this case. As previously stated, the activities that were developed, using the CPM technique, are designed so the material placement is linear with time. In essence, this will cause each activity production to be visually observed and distinct from other activity productions and thus the foreman will be able to estimate the material in place with reasonable accuracy. This procedure would not require extra qualified personnel, time or paper work which is ideal for the small contractor.

Using the last method of measuring production for the Production Schedule, the following information is required from the field for comparison to the Production Schedule.

1. The amount
2. of what material placed daily
3. on what activity or activities.

The Monitoring Information System requirements of this information are basic to enable effective monitoring of the project. Trying to reduce this amount of information, to lessen the time needed in the field to gather this information, would directly inhibit the effectiveness of the monitoring function.

D. Forms for Field Information

The printed form is the method most widely used to record and transmit field information to the office. This method is an important tool in every business firm. Even though the importance of this transmission line can never be stressed enough, it is a costly transmission media. According to the Systems and Procedures Association,[12] every dollar's worth in paper and printing cost of the form will require twenty dollars in clerical costs to completely process them. This fact alone is enough to encourage every contractor to re-examine the effectiveness of his forms. The design of the form is an important consideration. If the form is not easy to understand and simple to use, the time needed to fill it out will increase. To the field personnel, a complicated form will seem like an endless crossword puzzle, which will eventually lead to confusion and the recording of false information.

To determine the best type of form or forms to use in the Monitoring Information System, the total information requirements from the field must first be determined. The information needed for the Monitoring Information System has already been given. However, the information required by the Bookkeeping or Accounting System, which will account for the necessary cash disbursements might be as follows:

1. The individual workers name,
2. trade, and
3. hours of work performed,
4. on what activity cost code.
5. Number by type of equipment,
6. used on what activity cost code,

7. for what amount of time.
8. Amount of
9. what material received on the job site.
10. Cost of
11. any overhead cost codes.

In comparing the two system lists for required data, it is seen that the information needed to satisfy both systems are similar in nature. This certainly suggests the possibility of having one form contain all the information needed for both systems.

A second consideration, in the forms design and procedure, was exactly who will supply what information. The idea behind this is to reduce the time required to fill out the forms by distributing the origin of information amoung as many responsible field personnel as possible. By considering all the information needed for both the Monitoring Information System and the Bookkeeping or Accounting System, the following distribution of information was devised and illustrated in Figure 6.

In order to satisfy the monitoring information required, one form which contains all the information from the individual worker and labor foreman would be simplest and less time consuming. Since each worker must supply his name and trade or type of equipment he is operating, the least time consuming method would be that of individual cards for each worker. As each worker reports to the job site in the morning, he would be given this card to complete and therefore supply this information along with his Social Security Number. After the worker has completed the card, he then gives it to the foreman to fill out the hours that the individual works

INFORMATION SOURCE	INFORMATION REQUIRED
INDIVIDUAL WORKER	Name or Equipment Operator Trade or Type of Equipment
LABOR FOREMAN	Hours worked on what activities. Amount of what material placed.
JOB SUPERINTENDENT	Cost of overhead cost codes. Amount of what material received on job.

FIGURE 6. INFORMATION DISTRIBUTION

on an activity. The foreman will then have one card for every worker on the job. With a large number of cards it would be very time consuming if the foreman had to write in the hours the individual worked on which activities. One way to satisfy this limitation is to have half of the card set up, so a hand punch can be used.

As stated by Gillette and Dana,[10] the punch card possesses many advantages over the written card. One advantage would be that of duplicate copies. With many workmen working on the same activity, time is saved by simply aligning all the cards with the same activity and punching them all at once. If a copy is desired for the foreman's records a thin sheet of press paper, which requires no carbon, would be attached on the back of each card to not only record the written information but also the punched information. A second advantage is that punch records are absolutely clear and legible at all times.

A third advantage is the time required to punch a hole in a card is much less than to record the same information with a pencil. A fourth advantage, is that a hole can be punched accurately in a card while riding in a car or truck whereas a man's handwriting would be greatly distorted.

By analyzing these considerations for the punch card form, and also the possibility of a worker working on more than one activity in a day, a suggested format is illustrated in Figure 7. Of course using the capabilities of a printing machine, the card could be condensed into even a smaller size for convenience.

After this form is completed daily and sent to the office, more information would still be required from the field. This information is the amount of material placed (for the Production Schedule), the amount of material received on the job daily and comments on any situation which may effect the cost of the project. The amount of material received on the job daily is easily transmitted to the office by merely sending a copy of the invoice received on the job to the office. The other information varies from day to day and can only be recorded on a handwritten form because of its variability. A suggested format is illustrated in Figure 8. For convenience to the foreman or superintendent, whoever fills out the form, it should be about the same size as the Workman Time Card. This will enable all the forms to be carried easily and their copies or originals to be stored in the same place.

E. Recording of Progress

The last action entailed in the Monitoring Information System

WORKMAN TIME CARD

Name _____

Trade or Type of Equip. _____

S. S. Number _____ Date _____

Reg. Hourly Rate _____ Amount _____

O. T. Hourly Rate _____ Amount _____

Third Activity						Fourth Activity					
HOURS WORKED ON 3rd ACTIVITY		Thous. 1	Hundreds 1 2 3 4	Tens 1 2 3 4 5 6 7 8 9	Units 1 2 3 4 5 6 7 8 9	HOURS WORKED ON 4th ACTIVITY		Thous. 1	Hundreds 1 2 3 4	Tens 1 2 3 4 5 6 7 8 9	Units 1 2 3 4 5 6 7 8 9
.5						.5					
1.0						1.0					
1.5						1.5					
2.0						2.0					
2.5						2.5					
3.0						3.0					
3.5						3.5					
4.0						4.0					
4.5						4.5					
5.0						5.0					
5.5						5.5					
6.0						6.0					
6.5						6.5					
7.0						7.0					
7.5						7.5					
8.0						8.0					
8.5						8.5					
9.0						9.0					
9.5						9.5					
10.0						10.0					
10.5						10.5					
11.0						11.0					
11.5						11.5					
12.0						12.0					
12.5						12.5					
ACTIVITY	I					ACTIVITY	I				
	J				ACTIVITY COST CODE		J				ACTIVITY COST CODE

Second Activity						First Activity					
HOURS WORKED ON 2nd ACTIVITY		Thous. 1	Hundreds 1 2 3 4	Tens 1 2 3 4 5 6 7 8 9	Units 1 2 3 4 5 6 7 8 9	HOURS WORKED ON 1st ACTIVITY		Thous. 1	Hundreds 1 2 3 4	Tens 1 2 3 4 5 6 7 8 9	Units 1 2 3 4 5 6 7 8 9
.5						.5					
1.0						1.0					
1.5						1.5					
2.0						2.0					
2.5						2.5					
3.0						3.0					
3.5						3.5					
4.0						4.0					
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9.0						9.0					
9.5						9.5					
10.0						10.0					
10.5						10.5					
11.0						11.0					
11.5						11.5					
12.0						12.0					
12.5						12.5					
ACTIVITY	I					ACTIVITY	I				
	J				ACTIVITY COST CODE		J				ACTIVITY COST CODE

FIGURE 7-SUGGESTED FORM FOR REPORTING WORKMAN INFORMATION

DAILY PRODUCTION CARD

Project _____

Location _____ Date _____

Activity I	Activity J	Material Placed Today	Quantity

Circumstances which may effect the job cost _____

_____

_____

_____

_____

_____

Foreman or Superintendent signature _____

FIGURE 8-SUGGESTED FORM FOR REPORTING PRODUCTION

is the comparing and recording of construction information to the standard. All the required construction information has been recorded in the field and transmitted to the office by daily reports. After the information, required by the Monitoring Information System, has been taken from the daily reports, these reports can be stored for further processing through the Bookkeeping or Accounting System. All that remains is to determine a method of recording the cost and production comparison.

The Labor and Equipment Cost Schedule contains each CPM activity that will be performed on the project. Each activity is made up of one or more cost codes and each cost code is divided into its labor and equipment costs. Since these costs are linear with the duration of the activity, it would be very simple to use the actual time accredited to the cost code as the basis for determining an estimated cost, if the activity has not been finished. Using this method a reliable comparison can be made at any desired time interval, whether it be daily or even weekly.

The Production Schedule states the material quantity, which must be placed, for each cost code by activity. By comparing the actual material in place to the material quantity for each cost code, the percentage of completion can easily be calculated. A method of illustrating the percentage of work completed is a simple bar graph. A complete suggested format for the Construction Progress Report is illustrated in Figure 9.

CONSTRUCTION PROGRESS REPORT

PROJECT _____ LOCATION _____ DATE _____

Percentage Completed										Actual Production	Scheduled Production	ACTIVITY I - J	Dur-ation	Cost Code	Labor & Equip. Cost Allow.	Actual Time	Scheduled Cost	Actual Cost	Loss	Profit
100	90	80	70	60	50	40	30	20	10											
Actual ————																				
Scheduled ----------																				

FIGURE 9-SUGGESTED FORM FOR REPORTING PROGRESS

V. EXAMPLE

Company A has prepared a General Estimate, Table I, using the AGC Uniform System[13] for Building Construction cost code. After a value had been added on for a profit margin, the bid was submitted to the owner. After bids from other companies and the competency of each company was considered, the contract was awarded to Company A.

The first step to prepare this project for construction is to construct a CPM diagram and perform the network calculations, Table II. In originally devising each activity, it was kept in mind that the activity duration must be linear to the cost of labor and equipment, and the material quantity placement. This requirement caused some actions, which are normally thought of as one activity, to be broken up into two or more activities. This is illustrated by the action of clearing the site which is normally considered as one activity. Whereas here it is broken up into two activities, one containing the demolition of the structure and the second containing the moving of the structure.

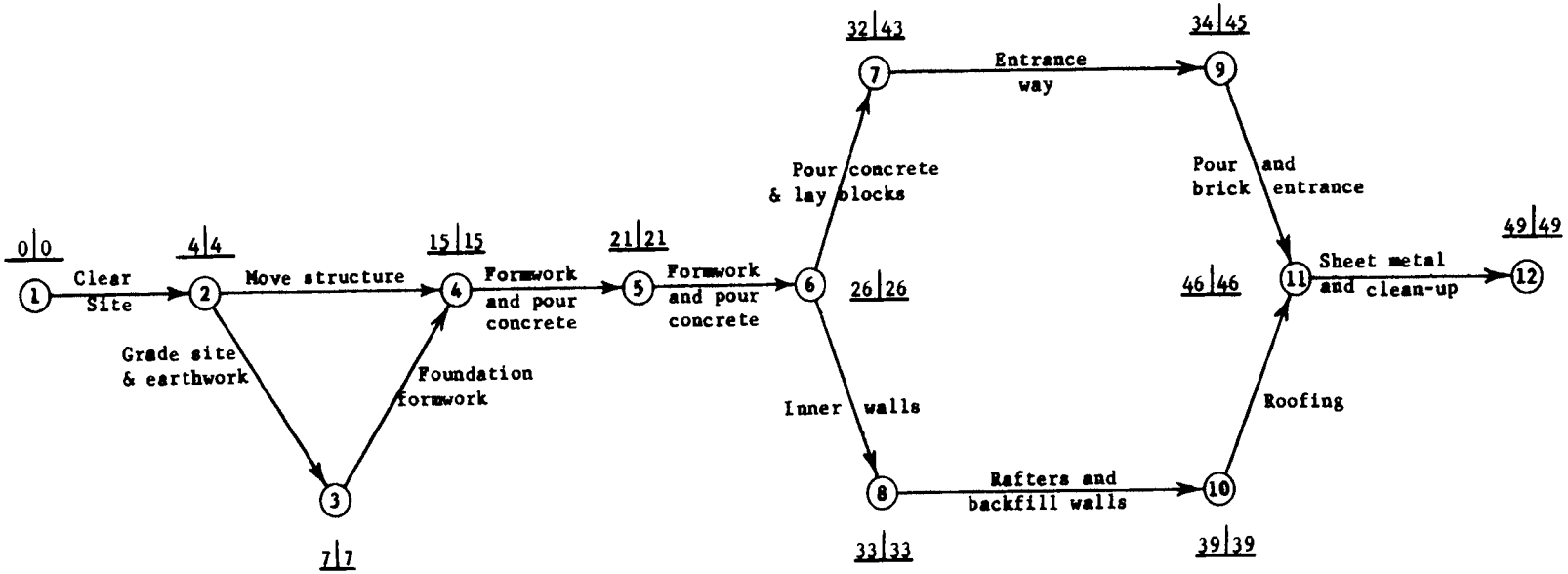
At the top of Table II, the diagram calculations were performed using a seven day work week. However in the table calculation of Early Start (ES), Early Finish (EF), Late Start (LS) and Late Finish (LF), the times were converted to a normal five day work week, with construction beginning on May 4, 1970.

The second step is to group and list all the activities and their work classification cost codes, of the General Estimate Sheet Table I, which will end in the same week. This is illustrated in Columns 1 and 2 of Table III. Then the material quantity for each activity work

GENERAL ESTIMATE

	Work Classification	Cost
0211	Demolition	$ 401.32
0212	Structure moving	387.14
0213	Clearing and grubbing	534.83
0221	Site grading	516.40
0222	Excavating and backfill	3,144.59
0310	Concrete formwork	1,319.49
0311	Concrete formwork unassigned	662.87
0320	Concrete reinforcement	464.76
0331	Heavyweight aggregate concrete	1,484.99
0411	Mortar	373.21
0420	Unit masonry	640.36
0421	Brick masonry	150.48
0611	Framing and sheathing	89.41
0612	Heavy timber work	260.82
0731	Asphalt shingles	743.16
0763	Gutters and downspouts	194.76
0782	Metal-framed skylights	98.44
0141	Clean-up	107.53
	Total	$11,574.56

Table I-EXAMPLE GENERAL ESTIMATE SHEET



I - J	ACTIVITY DESCRIPTION	DURATION	E S	E F	L S	L F	FLOAT
1 - 2	Clear site	4	04 May 70	08 May 70	04 May 70	08 May 70	0
2 - 3	Grade site and earthwork	3	08 May 70	13 May 70	08 May 70	13 May 70	0
2 - 4	Move structure	2	08 May 70	12 May 70	21 May 70	25 May 70	9
3 - 4	Foundation formwork on West and South wall	8	13 May 70	25 May 70	13 May 70	25 May 70	0
4 - 5	Formwork on North wall and pour West and South concrete	6	25 May 70	02 Jun 70	25 May 70	02 Jun 70	0
5 - 6	Formwork on East wall and pour North wall concrete	5	02 Jun 70	09 Jun 70	02 Jun 70	09 Jun 70	0
6 - 7	Pour East wall concrete and lay concrete blocks	6	09 Jun 70	17 Jun 70	22 Jun 70	30 Jun 70	9
6 - 8	Inner wall carpentry	7	09 Jun 70	18 Jun 70	09 Jun 70	18 Jun 70	0
7 - 9	Entrance way	2	17 Jun 70	19 Jun 70	30 Jun 70	02 Jul 70	9
9 - 11	Pour and brick entrance way	1	19 Jun 70	22 Jun 70	02 Jul 70	03 Jul 70	9
8 - 10	Rafters and backfill walls	6	18 Jun 70	24 Jun 70	18 Jun 70	24 Jun 70	0
10 - 11	Roofing	7	24 Jun 70	03 Jul 70	24 Jun 70	03 Jul 70	0
11 - 12	Place gutters and clean-up	3	03 Jul 70	08 Jul 70	03 Jul 70	08 Jul 70	0

TABLE II-EXAMPLE CPM NETWORK AND CALCULATIONS

I - J	Column 1 ACTIVITY	2 Cost Code	3 Total Cost Allowance	4 Cost Schedule Labor	 Equipment	5 Production Schedule Material Quantities	E F
1 - 2	Clear site	0211	401.32	246.66	103.48	15 # dynamite	08 May 70
1 - 2	" "	0213	113.60	78.40	35.20	4.8 acres	"
1 - 2	" "	0222	721.36	478.20	243.16	460 cu.yd. earth	"
				803.26	381.84		
	Cost Schedule for activities ending WEEK 1						
2 - 3	Grade site and earthwork	0213	421.23	304.10	117.13	10.7 acres	13 May 70
2 - 3	" " " "	0221	516.40	411.20	105.20	15.5 acres	"
2 - 3	" " " "	0222	914.78	704.32	210.46	684 cu. yds. earth	"
2 - 4	Move structure	0212	387.14	268.04	119.10	0.0	12 May 70
2 - 4	" "	0222	1347.72	814.32	533.40	894 cu. yds. earth	"
				2501.86	1085.29		
	Cost Schedule for activities ending WEEK 2						
	No activities ending WEEK 3						
3 - 4	Foundation formwork	0310	617.95	411.40	6.55	1040 sq. ft. of forms	25 May 70
3 - 4	" "	0320	223.16	35.76	11.16	316 # re-bar	"
				447.16	17.71		
	Cost Schedule for activities ending WEEK 4						
4 - 5	Foundation formwork and concrete pour	0320	116.84	12.14	10.38	151 # re-bar	02 Jun 70
4 - 5	" " " " "	0310	386.47	381.02	5.45	567 sq. ft. of forms	"
4 - 5	" " " " "	0331	704.46	193.42	90.14	43 cu. yds. concrete	"
				586.58	105.97		
	Cost Schedule for activities ending WEEK 5						
5 - 6	Foundation formwork and concrete pour	0320	124.76	13.86	12.16	155 # re-bar	09 Jun 70
5 - 6	" " " " "	0310	315.07	289.15	8.14	509 sq. ft. of forms	"
5 - 6	" " " " "	0331	310.18	94.86	46.91	21 cu. yds. concrete	"
				397.87	67.21		
	Cost Schedule for activities ending WEEK 6						
6 - 7	Concrete pour and lay concrete blocks	0331	324.16	96.43	49.17	22 cu. yds. concrete	17 Jun 70
6 - 7	" " " " " "	0420	640.36	214.48	0.00	3968 blocks	"
6 - 8	Inner wall carpentry	0611	89.41	24.80	9.11	211 sq. ft. plywood	18 Jun 70
6 - 8	" " "	0612	70.38	21.48	4.42	48 board ft.	"
7 - 9	Entrance way	0311	662.87	248.78	78.89	494 sq. ft. forms	19 Jun 70
				605.97	141.59		
	Cost Schedule for activities ending WEEK 7						
9 - 11	Concrete pour and brick entrance way	0331	146.19	42.16	24.43	10 cu. yds. concrete	22 Jun 70
9 - 11	" " " " " "	0411	373.21	167.94	0.00	1009 # mortar	"
9 - 11	" " " " " "	0421	150.48	58.16	0.00	1018 red brick	"
8 - 10	Rafters and backfill walls	0222	160.73	108.13	52.60	94 cu. yds. earth	24 Jun 70
8 - 10	" " " "	0612	190.40	58.14	10.29	116 board ft.	"
				434.53	87.32		
	Cost Schedule for activities ending WEEK 8						
10 - 11	Roofing	0731	743.16	214.86	31.16	1635 sq. ft. shingles	03 Jul 70
10 - 11	"	0782	98.44	10.19	0.00	2 skylights	"
				255.05	31.16		
	Cost Schedule for activities ending WEEK 9						
11 - 12	Gutters and clean-up	0763	194.76	48.74	4.98	114 ft. of gutters	08 Jul 70
11 - 12	" " "	0141	107.53	97.35	10.18	0.0	"
				146.09	15.16		
	Cost Schedule for activities ending WEEK 10						

TABLE III-EXAMPLE COST AND PRODUCTION SCHEDULE

classification cost code is re-estimated, Column 5. The re-estimating of the material quantities will bring out any errors that may be present in the General Estimate so corrections can be made. The material quantities, in Column 5, represent the Production Schedule or what must be placed before the activities can end.

The third step is to reapportion the work classification costs of the General Estimate Sheet among the CPM activity cost codes. These costs are reapportioned according to the re-estimated material quantities of Column 5. This procedure will produce a total cost allowance, Column 3, which includes labor, equipment and material costs. Cost code 0320 (concrete formwork) was reapportioned among activities 3-4, 4-5, and 5-6 because of the different amount of formwork required for each activity. If the work classification cost code does not require material, such as clearing and grubbing, the cost can be divided among the activities according to the acres cleared for each activity. However, if necessary each activity should be weighted to reflect the difficulty of performance among the areas to be cleared.

The fourth step is to determine the cost of labor and equipment for each activity cost code, Column 4 of Table III. The cost of labor and equipment is based on the quantity of material, Column 5, or work performed in each activity cost code. The Cost Schedule, Column 4, is calculated by totaling the labor and equipment costs of the activities that end in the same week. This procedure will form a weekly cost of labor and equipment. By continuing this procedure throughout the project, the standard in the form of the Cost Schedule, Column 4, and the Production Schedule, Column 5, was derived.

The construction of the project was started on May 4, 1970 and

proceeded as scheduled. Construction data was collected from the field daily. The Workman Time Card, as illustrated in Figure 7, was completed by each individual worker and his foreman daily. The Daily Production Card, as illustrated in Figure 8, was filled out by the Job Superintendent. Both types of forms were sent to the office daily.

The first week of construction passed and a comparison to the standard was made on activities ending in week one, which was only activity 1-2. As shown in Table IV, the estimated duration of activity 1-2 was 4 days and the actual time accredited to each cost code was 4 days. Within this time period 100% of the production was completed. The cost of this production was very close to the estimated cost. Cost code 0211 was $7.98 cheaper than estimated, 0213 was $5.82 higher than estimated and 0222 was $6.20 cheaper than the estimate.

However, now it is wished to make a comparison for the activities ending in week two. Activities 2-3 and 2-4 both end during this week. According to the daily reports, both activities are 100% complete. However, cost code 0222 in activities 2-3 and 2-4 was $43.62 and $59.40, respectively, higher than originally estimated. By looking at the Actual Production column, more cubic yards of earth was moved than was originally calculated. This points out that the cause of the extra money required to finish these activities was an error in the calculated earth quantities. The error caused a total deficit of $103.02, which must be compensated for somewhere in the project.

According to the actual construction data, activity 3-4 has been progressing for 3 days. Since this activity is eight days long and will not end until week four, the company president required a check

CONSTRUCTION PROGRESS REPORT

PROJECT _____ LOCATION _____ DATE May 15, 1970

Percentage Completed (100 90 80 70 60 50 40 30 20 10)	Actual Production	Scheduled Production	ACTIVITY I - J	Dur-ation	Cost Code	Labor & Equip. Cost Allow.	Actual Time	Scheduled Cost	Actual Cost	Loss	Profit
	15 #	15 #	Clear site 1 - 2	4	0211	350.14	4	350.14	342.16		7.98
	4.8 acres	4.8 acres	" "	4	0213	113.60	4	113.60	119.42	5.82	
	460 cu.yd.	460 cu.yd.	" "	4	0222	721.36	4	721.36	715.16		6.20
	10.7 acres	10.7 acres	Grade site and earthwork 2 - 3	3	0213	421.23	3	421.23	410.16		11.07
	15.5 acres	15.5 acres	" "	3	0221	516.40	3	516.40	512.10		4.30
	706 cu.yd. earth	684 cu.yd. earth	" "	3	0222	914.78	3	914.78	958.40	43.62	
	0.0	0.0	Move structure 2 - 4	2	0212	387.14	2	387.14	381.07		6.07
	938 cu.yd. earth	894 cu.yd. earth	" "	2	0222	1347.72	2	1347.72	1407.12	59.40	
	312 sq.ft. forms	390 sq.ft. forms	Foundation formwork 3 - 4	8	0310	417.95	3	156.73	224.16	68.43	
	95 # re-bar	118.5 # re-bar	"	8	0320	46.92	3	17.60	22.48	4.88	
									Total	182.15 -35.62	35.62
									Deficit	146.53	
Actual ———— Scheduled ----------											

TABLE IV-EXAMPLE PROGRESS REPORT

on this activity May 15, 1970. By having a close check on all activities, he hoped to compensate for the $103.02 deficit of activities 2-3 and 2-4. With 3 days accredited towards activity 3-4, 3/8 of the cost allowance for cost code 0310 and 0320 should have been spent. Therefore, the scheduled cost of 0310 is $417.95 (3/8) = $156.73 and the scheduled cost of 0320 is $46.92 (3/8) = $17.60. The scheduled production was also calculated in the same manner, 1040 (3/8) = 390 sq. ft. and 316 (3/8) = 118.5 #. By comparing these scheduled costs and productions to actual data, an uneconomic activity was easily pointed out. The activity is in progress and a chance to correct the situation is still present. The apparent cause of this situation is the extra workmen and equipment that are present on the job site. Even with these extra men and equipment, the scheduled production rate is still not attainable. These facts would point to bad labor-management relations or ineffective management or even a crowded job site as the cause for the situation.

VI. DISCUSSION OF THE MONITORING INFORMATION SYSTEM

The Pre-Construction Phase, as developed in the previous section, is illustrated in Figure 10. Many differences can be seen by comparing this suggested procedure with the ones suggested by Walker and Deatherage in the review of literature. The most outstanding difference is the additional planning which occurs only after the project is brought to contract. Neither Walker or Deatherage suggest any form of pre-construction planning after the project is under contract. In the suggested procedure, the Summary Sheet (item 1) can be prepared by either Walker's method or Deatherage's method. According to the suggested procedure, only after the project is under contract does the additional planning occur. Even though this planning will require extra time of the planning and scheduling personnel, the benefits will be in the Construction Phase.

Another difference, in the Pre-Construction Phase, is the suggested procedure actually produces a cost code standard of labor and equipment costs and material quantities placed. Since the standard is linear with the activity duration, a reliable comparison can be made at any time during this duration. Whereas in the method by Walker or Deatherage, if the production involved in a work classification which was not near completion, a very rough and inaccurate guess must be made of what portion of the work classification should be in place. However, the suggested procedure removes all guessing from the providing of the standard and therefore less risk is involved.

There are also differences between the suggested Construction Phase, Figure 11, and the procedures suggested by Walker, Deatherage and the local contractor. One prominent difference is the number of forms that must be processed before progress reporting can take place.

PRE-CONSTRUCTION PHASE

LEGEND

1 Contains the cost of each work classification and the amount of the bid. Submitted to the owner for letting.
2 The contractor may or may not bring the project to contract.
3 Activity cost of labor and equipment, and material placement is linear with the duration.
4 Each work classification cost of the Summary Sheet is reapportioned among the activities.
5 The cost of labor and equipment for each cost code is determined.
6 The material quantities which are placed for each cost code is determined.
7 This is the standard in the form of a Cost and Production Schedule.

SYMBOLS

Formal document

Manual operation

Decision

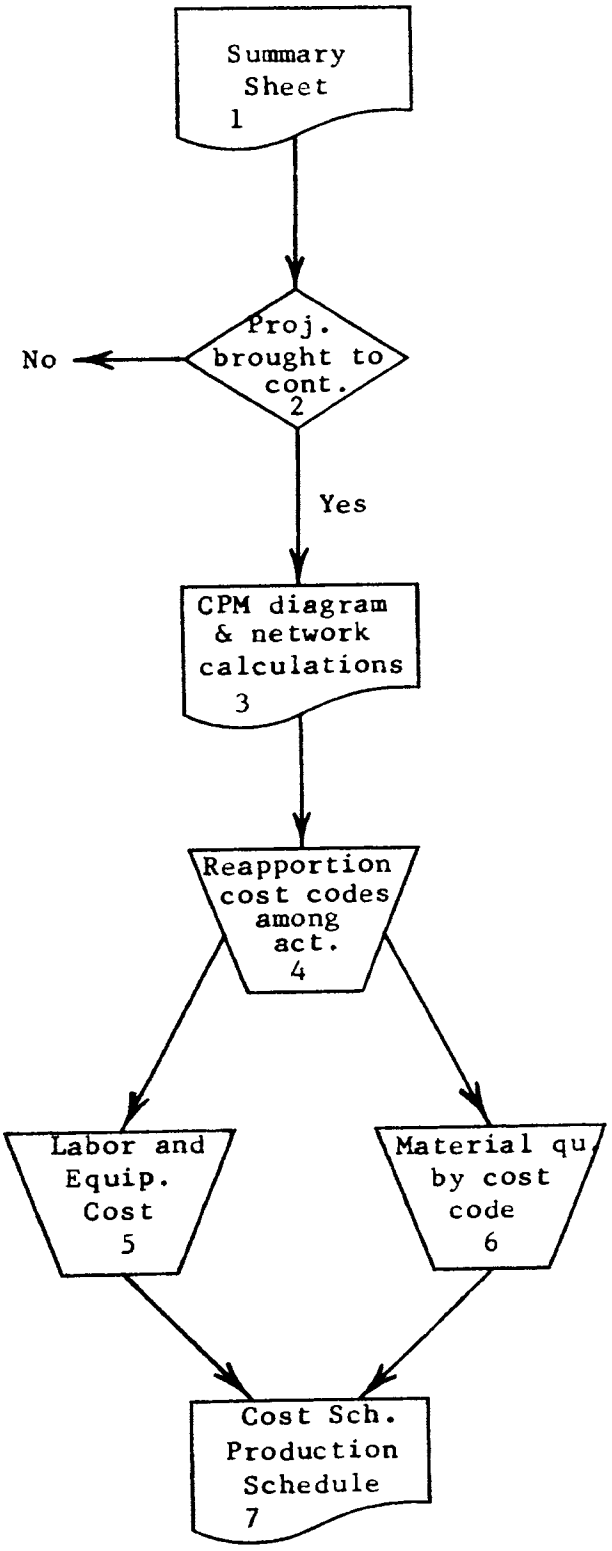


FIGURE 10-SUGGESTED PRE-CONSTRUCTION PHASE

CONSTRUCTION PHASE

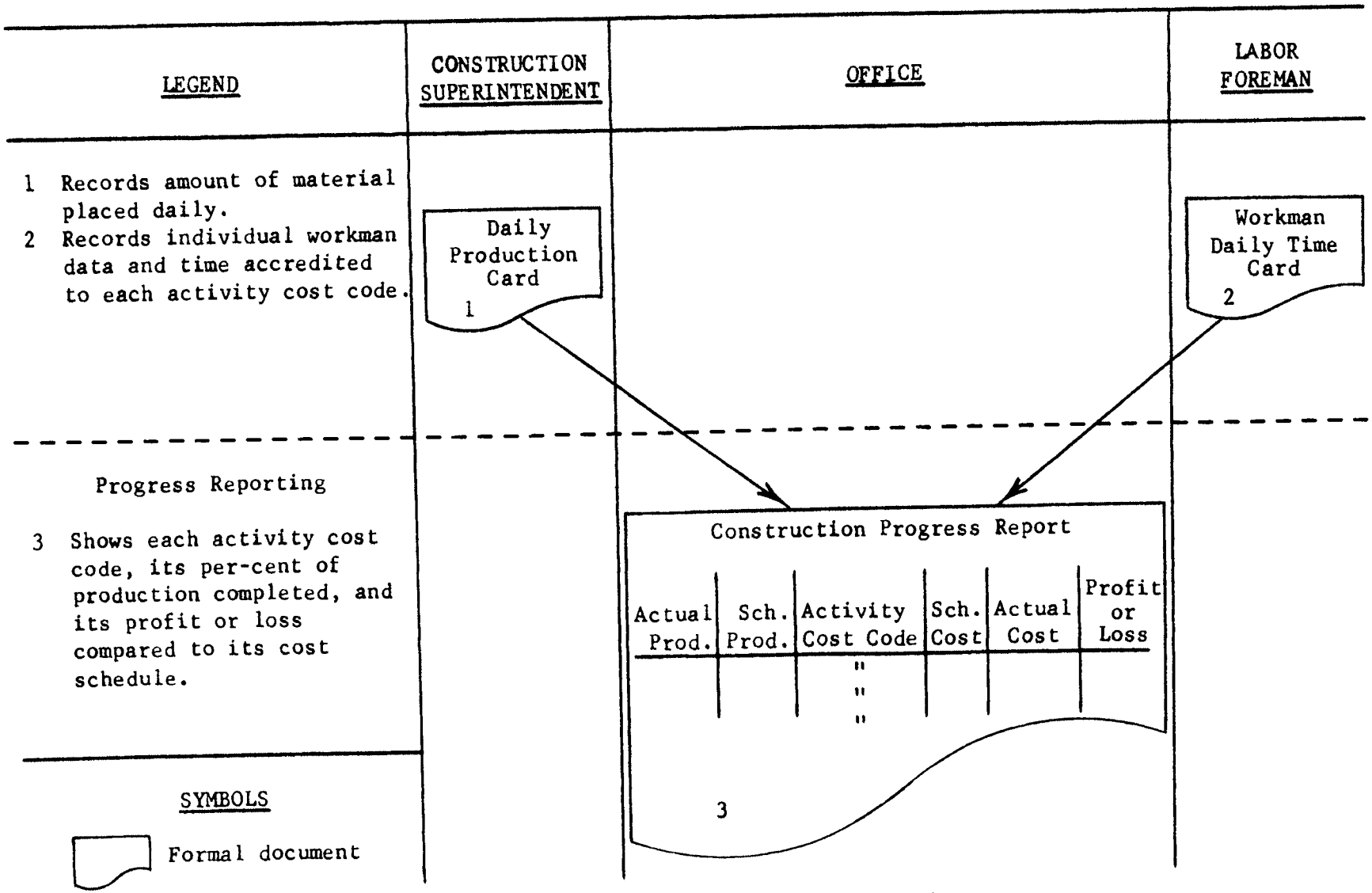


FIGURE 11-SUGGESTED CONSTRUCTION PHASE

The suggested procedure has two types of forms that must be processed whereas, Walker has seven, Deatherage three and the contractor six. With only two forms to be processed, this suggested procedure will be simple, require less time of the personnel and therefore cheaper to operate.

Another difference, in the suggested Construction Phase procedure, is the forms are not processed through other books, accounts and ledgers before progress reporting takes place. This fact alone will prevent a three or four week lag in the information, as was present in the local contractor's method. By preventing this time lag, information for progress reporting will be almost immediate and a remedial action, for an uneconomic activity, can be applied before the situation has passed and a permanent loss occurred.

In the Construction Phase procedure by Walker, Deatherage and the contractor, if an uneconomic situation was pointed out, the cause of this situation, whether it be labor or equipment problems of which activity, was still unknown. This problem was corrected, in the suggested procedure, by the detailed manner in which the standard is produced and monitored. By isolating the labor and equipment costs and the material quantities of each activity cost code, the exact cause of an uneconomic activity is easily exposed.

Walker's, Deatherage's and the contractor's Construction Phase procedure almost made it mandatory of the person responsible for completing the Recapitulation Sheet, to be well experienced in the construction field. In the local contractor's case, this requirement was absolutely necessary to be able to point out the cause of an uneconomic situation. However, in the suggested procedure, a timekeeper

or even a secretary can perform the required calculations and expose the cause of an uneconomic activity.

VII. CONCLUSION

The purpose of this investigation was to develop a monitoring information system which would comply with the time and cost constraints of the small contractor. An effort was made to reduce the time required, by a small contractor, to monitor a project. By looking at the suggested Monitoring Information System in its entirety, it can be seen the time required for monitoring is not reduced, but merely shifted from the Construction Phase procedure to the Pre-Construction Phase procedure. Even though the amount of time is not reduced, the overall effectiveness of the monitoring system is greatly increased. This point can easily be seen by analysing the advantages of having additional planning in the Pre-Construction Phase and its effect on the Construction Phase.

1. The suggested System will allow progress to be monitored at any time during an activity duration. This feature will allow the contractor to apply an immediate control measure if needed.
2. By transferring the actual construction data directly to progress reporting, a shorter time lag will be present between the occurrence of an uneconomic activity and the reporting of the situation. This will enable a faster and therefore more effective corrective action to be applied if the cause is due to inefficient job operation.
3. By having each activity cost code described by a labor and equipment cost and a material quantity, the cause of the inefficient job operation and uneconomic situation can be easily pointed out.
4. Although total time is not reduced, the smaller number of forms

in the Construction Phase procedure will make the collection of data simpler, easier to understand and less time consuming in the Construction Phase.

5. In the Construction Phase procedure, the calculations are simple and straightforward enough to enable any clerical personnel to perform progress monitoring.

If this Monitoring Information System were installed in a small contractor's environment, he would have a more accurate, simple and reliable monitoring system. With this type of monitoring system in operation, the risk of not making a profit will be reduced and subsequently the chance of making a planned profit will be greatly increased.

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VITA

Dan Richard Pellegrino was born on January 20, 1945, in Wood River, Illinois. He is the son of Mr. and Mrs. Sam Pellegrino. He received his primary and secondary education in Wood River, Illinois. In September, 1964, he entered the University of Missouri-Rolla and completed the requirements for a Bachelor of Science in Civil Engineering in May, 1969. He chose to continue at the University of Missouri-Rolla seeking a Master of Science in Civil Engineering.

Mr. Pellegrino is married to the former Jo Ann Bishop of Sullivan, Missouri.