Effects of Delay Times on Production Rates in Construction

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Abstract: Factors that can be fairly easily identified and modified and can lead to significant improvements in production rates for activities in construction are considered in this paper. These factors are divided into four work categories. Two of the four work categories in which each construction activity was subdivided were idle and waiting times. Productivity measurements generally do not distinguish between the idle and waiting times. Conclusions can therefore be misleading, and more importantly, the attention of management is only vaguely and imprecisely directed to the cause of the inefficiencies. The breakdown of nonproductive time into two factors is therefore very important in directing the attention of management to the root causes of inefficient time. The variation in production rates used by contractors' estimators are given and compared with actual on-site production rates. The frequency of different sources of information used by contractors when estimating production rates, and the percentage use of production monitoring methods, are also given. A prototype expert system, using the Personal Consultant Plus shell program of 1987, was developed to assist in the acquisition and management of knowledge and data for the estimation of production rates.

INTRODUCTION

Productivity is extremely important in the construction industry. Governments and other owners are investing significantly less money into capital works and preventative maintenance programs, even though these programs would help curb the deterioration of the infrastructure. One of the reasons for this lack of financial commitment towards construction projects is that productivity and quality in the construction industry has not improved as much as in other industries, and construction is therefore regarded as a poor investment.

There are many factors that influence productivity in the construction industry. Some factors that create variations in production rates for certain activities are extremely difficult to control. There are other factors, however, that can be fairly easily identified and modified and can lead to significant improvements in production rates for activities. Some of these factors are determined and discussed in this paper.

Determining what these factors might be was the premise of Frederick W. Taylor's preliminary research in optimizing worker performance during the early 1900s. Taylor is most noted for the research he conducted in 1911 at Midvale Steel Inc. in Pennsylvania (Robbins 1986). By analyzing with stopwatch studies the efforts of a worker to load pig iron onto a railroad car, Taylor was able to show how the daily output per worker could be increased.

The success of Taylor's research inspired many others to study and develop new techniques of monitoring productivity by scientific means. For instance, Thomas has analyzed lost productivity at a construction site due to inefficient material management (Thomas and Sanvido 1989). Thomas's research work led to the development of an integrated material-management program that could be applicable to any construction site. The program consists of approximately 25 conditions or site factors that could have the potential to affect productivity on the construction site. The uniqueness of the program is that many of the factors are qualitative rather than quantitative. Factors such as disruptions, work content, constructability issues, construction methods, environmental conditions, and management aspects are just a few of the factors that are considered.

Thomas and Smith have further developed a more analytical approach for studying the mechanics of the problem (Smith et al. 1993). A productivity impact factor (PIF) has been developed that will allow more consistent comparisons to be made. This technique will therefore provide a means to gather a more homogeneous collation of information from a number of different sites. Consequently, this will permit useful comparisons of productivity from any number of construction sites used in further studies.

An international research project has been carried out by Handa and Thomas (1993) to standardize the measurement of construction labor productivity in some activities. The results of this research will obviate any disparities due to jobsite uniqueness and job complexity. The

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research described in this paper is indirectly linked to the focus of their research, but specifically examines the delay times of another construction activity—concrete placement.

Using similar scientific techniques, others have made notable contributions towards improvements in construction productivity. Olgesby et al. (1989), for instance, maintain that job satisfaction and worker productivity are related: an increase in either will have a positive influence on the other. To identify many of the influences that can affect worker productivity, Harris and McCaffer (1989) have utilized video recorded times studies to help recognize particular problems on site. Flow of men and materials, equipment utilization and balance, and safety and working conditions are examples of some of the problems affecting the progress of a worker that can be identified using this method. Similarly, a "foreman-delay survey" (FDS) that was developed by Tucker et al. (1982), was found to be useful as an effective low-cost method for determining the sources of delay not directly related to site worker productivity. Using the FDS, a foreperson is asked to identify sources of delay, length of delay, and the number of workers affected. A calculation of lost person hours is then made, giving a breakdown of lost productivity by category.

Collectively, these researchers and others have contributed useful knowledge that can be used to promote better construction practices in order to improve productivity. Their efforts have been recognized as an attempt to shape the construction industry so that cost efficient and more productive construction practices on jobsites will someday become the norm rather than the exception.

Part of the uniqueness of the research described in this paper is the distinction between idle and waiting times, which create delays in construction activities. This breakdown of nonproductive time enables the attention of management to focus onto the causes of inefficient time and create efficient procedures. Maintaining efficient procedures, however, is difficult because most construction projects are unique and are prone to nonstandard building practices. This usually means that there are many factors to be considered. Material delay, management constraints, and adverse weather conditions are just a few of the factors that can affect the progress of an activity. To identify these and other factors that are not generally considered requires that the activity be monitored. The monitoring and measurement of the production rate of an activity then creates an effective means of showing where the progress of the activity can be improved. For the research described in this paper, a video camcorder was used to record concrete-placement activities at job sites in the Fredericton, New Brunswick, area in Canada.

To determine which factors adversely affected production, each activity was divided into four work categories: (1) Essential; (2) essential contributory; (3) idle; and (4) waiting. By noting whether lost productivity was due to "waiting" or "idle" time, it was recognized that many of the factors that affected an activity's progress (e.g., factors causing waiting time) could be rectified or improved by a response from management. Site managers with information on factors that created inefficiencies would therefore have a better ability to organize workers to achieve better production rates in the future.

Variation in Production Rates

Construction projects are generally unique and are built on sites with different work crews associated with different trades. The work is cyclical due to the weather, seasonal variations, and the economic climate. These factors affect production rates, and although there are many worthwhile measures that can prevent or reduce a loss in productivity, there are certain elements that cannot be eliminated to improve productivity. There are, however, many other factors that influence productivity that can be improved. It is these other factors that are identified and discussed in this paper.

Many of these factors can cause production rates for a given activity to vary considerably. To help understand why these variances occur, a questionnaire was sent to various construction companies in Eastern Canada requesting information concerning the production rates that they use in estimating and scheduling. The production rates for certain activities, shown in Table 1, are derived from 15 responses to the questionnaire. The wide range of production rates given in the table illustrates how difficult it is to estimate a particular production rate for any activity. The determination of the value of these rates is complex because productivity is difficult to analyze, and even if it is analyzed, the knowledge and data acquired are difficult and time consuming to interpret and evaluate.

When further clarification of the knowledge acquired was sought from respondents, it was discovered that some of the production rates, shown in Table 1, were modified later in the preparation of the estimate to reflect delay times and other time-consuming aspects of an activity. A strict comparison of each numerical value of the production rates should therefore be viewed with some caution.

In most construction companies the production rates are usually established by a combination of experts' opinions and the use of handbooks that contain productivity data. Although this data is often broken down to account for factors that significantly affect the production rates, little data and knowledge are acquired and stored for future use concerning the reasons for major reductions in productivity, such as waiting time.

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TABLE 1. Estimated Production Rates Used by Contractors

Source of information (1)	ESTIMATED PRODUCTION RATES (m³/person-h)					
	Reinforced Footings		Reinforced Foundation Wall		Reinforced Slab on Grade	
	Pumped (2)	Chute (3)	Pumped (4)	Chute (5)	Pumped (6)	Chute (7)
A	1.47	1.37	2.67	1.77	1.00	1.50
B	1.25	1.22	2.49	2.00	1.00	1.62
C	1.12	1.04	2.61	1.63	0.75	1.35
D	0.28	0.33	0.58	0.48	0.30	0.45
E	1.96	1.76	3.48	2.36	1.20	1.73
F	0.98	1.04	2.61	0.38	1.00	1.05
G	0.84	1.43	2.49	1.71	1.05	1.88
H	0.98	1.50	2.61	1.63	1.10	1.95
I	1.75	1.11	2.61	2.13	1.08	1.73
J	1.19	1.53	2.55	1.62	0.95	1.20
K	1.68	1.43	3.34	2.09	0.85	1.13
L	1.65	1.14	3.39	2.28	0.90	1.22
M	2.03	1.04	3.34	2.09	1.20	1.13
N	1.61	1.20	3.16	2.20	1.08	1.65
P	2.10	1.95	2.90	2.47	2.50	3.00
Average rate	1.39	1.27	2.72	1.79	1.06	1.51
Standard deviation	0.51	0.38	0.70	0.62	0.45	0.57

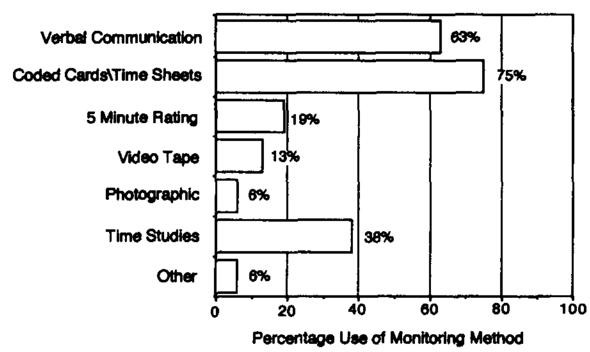

FIG. 1. Methods Employed to Monitor Productivity

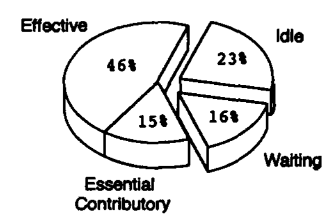

FIG. 2. Basic Time Components Used for Describing Effectiveness of Construction Worker

Although all construction projects are different, most construction activities have common parameters. For example, the concreting activity for a foundation wall involves delivery, placement, vibration, and finishing work. These basic steps are fairly consistent with this type of activity, no matter where, when, and how the concrete is being placed. However, variations in actual production rates among various sites are common. These variations, when analyzed, were found to be primarily caused by waiting and idle times.

In concreting activities it was found that the most significant reduction in the production rate was due to delays in the delivery of concrete to the site. This type of delay was often attributed to unexpected occurrences that appeared to be unrectifiable, and therefore was of secondary concern to a very busy management team.

Monitoring Productivity

Fig. 1 shows the various methods that are used by contractors to monitor progress on projects. The percentage use of each monitoring method by companies who responded to the questionnaire is given. Some of these methods capture the very important information concerning waiting time, but some do not. The two most effective methods are in the use of video tapes and time studies, because although many methods that are used can indicate the percentage efficiency, few methods are able to show where the root causes occur. It can be seen that, apart from two methods—verbal communication and time sheets that do not indicate efficiency, the percentage use of any method to monitor progress is less than 40%.

Acquisition and Measurement of Data and Knowledge

Seven construction sites in one city (Fredericton, New Brunswick, Canada) were monitored so that the factors affecting concrete placement operations could be determined. A total of 32 concrete-placement operations were recorded from these seven sites. The methods used to monitor these activities were video recording and stopwatch studies. Before the activity could be analyzed, it was subdivided into the four work categories: (1) Effective; (2) essential contributory; (3) waiting; and (4) idle. Effective work positively influences the progress of the activity, and work that has an indirect but positive influence on progress, such as the movement of materials or equipment for essential purposes, is considered essential contributory. Idle time represents a category in which the work could, but did not, progress, because the worker was not working. However, if a worker is unable to perform a task because of an uncontrollable external delay, such as late concrete delivery, then the lost time is considered waiting time, not idle time. This procedure was the method used to calculate the production rates published by Christian and Hachey (1992) (see Table 2).

Fig. 2 shows how a worker's time can be divided into the four work categories. Information presented in this fashion emphasizes the inefficient factors that affect the progress of a worker that may not be apparent during normal observations. This information permits management to clearly identify inefficient factors that are revealed during analysis, and therefore utilize a worker's time more effectively.

The information obtained from the answers given in the questionnaire was further enhanced by knowledge obtained from experts and practitioners in the field. By conducting interviews with site personnel while field recordings and measurements were being performed, heuristic knowledge was gradually gathered. If the expert being interviewed referred to supervisors or colleagues from previous projects who were more familiar with certain aspects, then these persons were often contacted for further knowledge acquisition.

To help explain features of an activity that were not apparent from the video analysis, interviews were repeated again with some experts. The various sources used for the gradual progression of knowledge and data elicitation and acquisition, are shown in Fig. 3.

A prototype expert system was developed to handle and store the knowledge and data from all of the sources of intelligence, and also to create a decision support system that would enable a user, through a simple question and answer routine, to obtain a much more accurate estimate of the probable production rate.

The fairly simple prototype system leads the user to an estimate of the production rate that depends upon the answers that are given in the questions posed. The answers were used as a link to the knowledge and databases. In this particular system, the cumulative knowledge and

TABLE 2. Sample of Production Rates Measured at Various Project Sites

Location/ site (1)	Crew size (persons) (2)	Method of placement (3)	Volume concrete placed (m^3) (4)	Activity duration (min) (5)	Delay (min) (6)	Production rate (m^3/person-h) Average (7)	Production rate (m^3/person-h) Modified (8)
1 B	3	chute	5	75	20	1.33	1.82
2 A	3	chute	7.8	73	46	2.14	5.78
3 A	4	chute	4	43	15	1.40	2.14
4 A	4	chute	5	57	9	1.31	1.56
5 A	4	chute	5.5	105	49	0.79	1.47
6 C	4	chute	12	94	6	1.91	2.06
7 C	4	chute	16	140	5	1.71	1.78
8 A	5	pump	19	124	28	1.84	2.37
9 A	5	pump	32	154	50	2.49	3.69
10 A	7	pump	24	185	78	1.11	1.92
11 D	7	pump	27.5	98	18	2.41	2.94

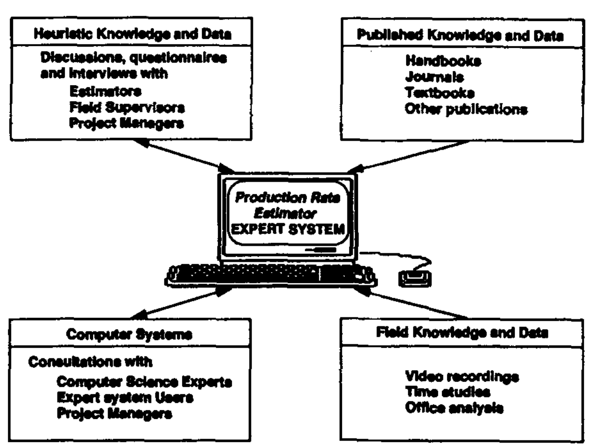

FIG. 3. Knowledge and Data Elicitation for Expert System

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database were derived not only from many experts, but also from the knowledge and data gathered in the field.

Providing such a wide array of knowledge permits the user to make reasonable assumptions on worker density, learning rate, weather conditions, crew experience, potential delays, and other relevant factors affecting the progress of an activity. Using these parameters to help estimate the production rate for an activity therefore provides a more realistic prediction of what the rate should be for that particular jobsite.

Analysis of Data

A comparative analysis of production rates from the various sites was possible because most construction activities have common parameters. For example, as mentioned earlier, the concrete operation for a foundation wall requires delivery, placement, vibration, and finishing work. In spite of these common parameters, it was found, not surprisingly, that there were differences in production rates between the various sites. These differences were found to be caused mainly by the waiting and idle times.

Several control parameters were identified prior to the collection of the data. This was done to ensure that each site and each project contained the same parameters for the purposes of comparative analyses. The following parameters were selected: (1) The construction of commercial buildings; (2) the application of similar equipment and methods; (3) the same general location (Fredericton, New Brunswick), (4) the same type of construction contract; and (5) a nonunionized labor force.

Information obtained from the site video recordings was analyzed so that inefficiencies reducing the productivity of a worker could be revealed. One such analysis was the categorization of time utilization for each separate worker at each site. The proportion of time spent on productive and nonproductive work was thus evaluated for each worker. Fig. 4 shows typical data.

Additional analysis of the information involved the determination of the rate of the volume of concrete placed at each job site. The data for this analysis were plotted on a graph, as shown in Fig. 5. The graph illustrates that the maximum time duration for concrete placement at each site for this particular sample varied from 90–135 min, and that the volume of concrete placed at each site ranged from 10–16 m^3. In this type of graph, the crew efficiency is represented by the magnitude of the slope. When a crew was able to work uninterrupted, their work rate gradually improved (increasing slope). A momentum was therefore built up, and efficiency improved.

This effect can be seen in Fig. 5. Crews on sites C6 and C7, which did not experience work interruptions, improved their work rate as time passed. The slope of the graphs of quantity against time increased. However, crews at sites E12 and E13, which did experience a work interruption, did not improve their work rate as time passed, and therefore did not produce an increasing slope of quantity against time.

Idle and Waiting Times

Many of the measurements of production rates revealed that waiting time delays were an extremely significant part of reduced productivity. Fig. 4 clearly shows this problem. A measure of how inefficiencies reduce productivity is the labor utilization factor (LUF). The LUF categorizes the amount of effective, essential contributory, and idle work performed by a tradesperson during a particular construction activity. This measurement is sometimes used as a guide to determine if a crew has performed work efficiently. However, the labor utilization factor does not generally distinguish between the idle and waiting times. Conclusions can therefore be misleading, and more importantly, the attention of management is only vaguely and imprecisely directed to the cause of the inefficiencies. The breakdown on nonproductive time into

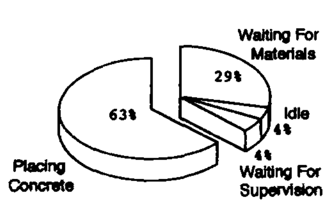

FIG. 4. Time Utilization for Typical Concrete Worker

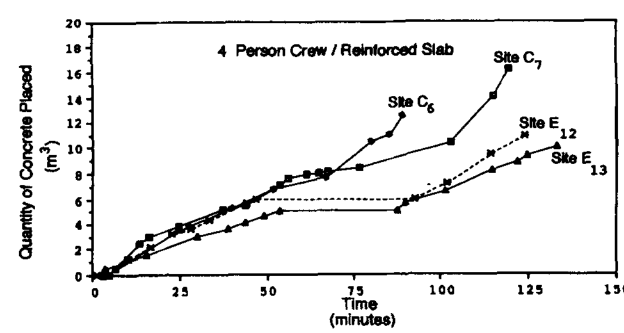

FIG. 5. Effects of Crew Momentum on Concrete Placement Operations

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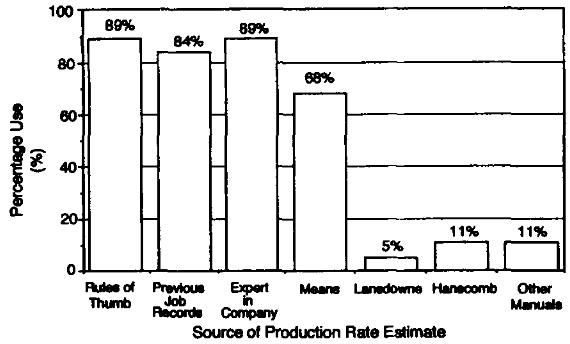

FIG. 6. Sources of Information when Estimating Production Rates

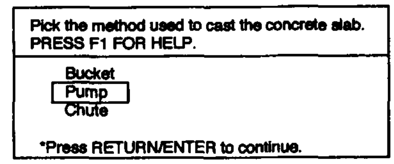

FIG. 7. Typical Question Posed by Expert System

TABLE 3. Average Production Rates

	AVERAGE PRODUCTION RATES (m³/person-h)					
	Reinforced Footings		Reinforced Foundation Wall		Reinforced Slab on Grade	
Method (1)	Pumped (2)	Chute (3)	Pumped (4)	Chute (5)	Pumped (6)	Chute (7)
Used by estimators	1.40	1.30	2.90	1.90	1.00	1.50
Measured in field	1.39	1.27	2.72	1.79	1.06	1.51

two factors, the idle and waiting times (Fig. 2), is therefore very important in order to direct the attention of management to the root cause of the nonproductive time.

Production Rate Estimates

The different sources for estimating production rates that are used in construction offices are shown in Fig. 6. Few of the sources contain information and knowledge derived from previous projects, and therefore a reduction in productivity due to waiting time is not adequately addressed in practice. Although there appears to be substantial agreement between the average actual production rates measured in the field and the overall average of those rates used by estimators (Table 3), there are few data available that enable the contractor to determine where the significant inefficiencies occurred. This, of course, means that there is no system to improve the inefficiencies on future projects.

The prototype expert system was developed to assist in the acquisition and evaluation of knowledge and data for the estimation of production rates. Personal Consultant Plus was the shell program used to construct the rules in the expert system. This computer-aided decision support system helps estimators to calculate production rates more accurately by prompting users to consider factors that will make production rates vary, and to show where and why inefficiencies might occur. The system will alleviate the current problem of production rates often being estimated by less-experienced personnel in contractors' organizations.

The system will allow an estimator an alternative method for estimating production rates. It simulates a consultation between the computer, as the knowledge and data source, and the user, who answers certain questions when prompted. The questions and answers formulated were compiled from the knowledge acquired from field analyses and from experts' opinions. Responses to the questions are in the form of single valued, ask-all, or yes/no type of format. For instance, the format of a question relating to the casting of a concrete slab is shown in Fig. 7. By choosing "pump" as the technique employed to place the concrete, as shown in Fig. 7, a link is then established to questions associated with this concreting procedure. Depending on how the questions are answered, a probable, more realistic production rate is given to the user, which will reflect conditions specified for the jobsite. The system therefore utilizes the equivalent cumulative knowledge of many specialists, and also enables the estimator to use production rates that more closely reflect actual job conditions.

CONCLUSIONS

The attention of management personnel should be focused on the sources and causes of delays. A major problem at present is that several methods that measure and monitor productivity on construction sites are unable to direct attention to the cause of the delay. The breakdown of nonproductive time into two factors, the idle and waiting times, is therefore very important in order to direct the attention of management to the root causes of the nonproductive time. For instance, the delays associated with "waiting for supervision" were found to be very considerable. The managers on a construction site (the project manager, the construction engineer,

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the superintendent/foreperson), however, often have severe time constraints and problems with time management.

This leads on to an obvious conclusion. During the estimating stage of a project, an insufficient number of supervisors and managers are generally allocated to the construction site, because of budgetary problems. The resulting lack of sufficient supervision on the site, however, generally lowers productivity, and therefore increases overall project cost. Consequently, an increase rather than a decrease in site supervision is needed in order to help reduce the overall cost of a project.

The use of an expert system to predict production rates will enable contractors to capture and retain specific knowledge and data from past projects and use them as a support system for future projects under consideration. The prototype model provides the user with probable production rates for specific activities for given circumstances. The system will enable contractors to not only predict more realistic production rates but also to provide a list of possible delays, and instructions on what might be done to prevent them from occurring. It will also allow contractors to utilize their project manager's time more effectively by allowing them to access the necessary information required to estimate the production rate of an activity more quickly.

APPENDIX. REFERENCES

Christian, J., and Hachey, D. (1992). "Production rates in construction." *Proc., Conf.*, Can. Soc. for Civ. Engrg., Quebec City, Quebec, Canada.

Handa, V. K., and Thomas, H. R. (1993). "International study on construction site productivity." *CIB W-65 Symp. 93*, Nat. Tech. Information Service, Springfield, Va., Vol. 2, 999–1002.

Harris, F., and McCaffer, R. (1989). *Modern construction management.* BSP Professional Books, Osney Mead, Oxford, England, 68–73.

Oglesby, C., Parker, H., and Howe, G. (1989). *Productivity improvement in construction.* McGraw-Hill Book Co., Inc., New York, N.Y.

Personal Consultant Plus. (1987). *Reference guide manual.* Texas Instruments, Austin, Tex.

Robbins, S., and Stuart-Kotze, R. (1986). *Management concepts and practices.* Prentice-Hall, Inc., Englewood Cliffs, N.J.

Smith, G., Shumway, J., and Thomas, H. R. (1993). "Productivity influence factors for baseline comparisons." *CIB W-65 Symp. 93*, Trinidad, (2), 989–997.

Thomas, H. R., and Sanvido, V. (1989). "Impact of material management on productivity—a case study." *J. Constr. Engrg. and Mgmt.*, ASCE, 1(115), 370–384.

Tucker, R., Roggie, D., Hayes, W., and Hendrickson, F. (1982). "Implementation of foreman delay surveys." *J. Constr. Div.*, ASCE, 4(108), 577–591.

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