DEPARTMENT OF MATERIALS AND CONSTRUCTION

Construction Methods Improvement by Time-Lapse Movie Analysis

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Constant and systematic methods improvement is an area for possible cost reduction that construction contractors cannot afford to overlook. The details of daily operations, including selection of methods, tools, and sizing of crews, are often delegated to the craft foreman. It is proposed that construction management should assume more responsibility for the development and use of improved procedures. The use of time-lapse movies for analysis of operations is suggested as an additional technique besides the uses of stop-watch time studies and cost accounting data. The advantages of this technique are discussed. An actual example involving erection of tubular metal falsework for an elevated freeway structure is used to illustrate a movie analysis study. Both equipment and procedures are described.

• THE AWARD of construction contracts for public works in the United States is based solely on price competition. Detailed plans and specifications are made available when the project is advertised. Each contractor who bids is offering to build the same structure, to meet the same standard of quality for materials and workmanship, and to complete the project within the same time limit. By law the award is made to the lowest responsible bidder. Hence the distinguishing factor between the services offered by one contractor and those offered by another is the total price quoted.

Every contractor treads a narrow path. His prices must be low enough to obtain a share of the work available but high enough to make a sufficient profit to justify remaining in business. Success demands an active and continual search for methods to reduce costs. There are many areas that offer possibilities for cost reduction, and all are important. One of these is the improvement of field methods. Such improvements can be of the more spectacular type that result from a novel approach to a conventional problem, the discovery of a new technique, or a major equipment modification to meet job conditions.

Almost every issue of construction trade magazines contains examples of ingenious solutions that have given one contractor a competitive edge over others for a specific job. The possibility of these solutions makes construction works the exciting and challenging business that it is.

However, a less spectacular type of methods improvement offers even greater possibilities for cost savings. It consists of systematic and sustained efforts to accomplish the routine and detailed steps of each operation in a more economical manner. In view of their importance, the treatment accorded these efforts by construction management generally falls short of what seems justified. Management seems content to pass the responsibility for details on to the craft foreman or the worker himself. Once the general plan of operations has been determined and the major equipment has been selected, it is usually the foreman who chooses the tools, sizes the crew, schedules the daily routine, and selects the procedures to be followed. This delegation of management control is apparently based on the assumptions that the foreman has gained such a degree of "know-how" from past experience that he is the one best qualified to make these decisions and that he will be motivated to draw on the best practices he has learned. These assumptions are questionable. There are about as many ways to perform an operation as there are foremen that can be assigned to do it. The foreman is generally a temporary employee drawn from the union hiring hall. His experience and ability may vary greatly. Often he does contribute or develop better methods than those used previously by his employer, but unfortunately these usually leave with him at the end of the job.

A better situation would be for management to retain a greater share of responsibility for detailed performance as well as for over-all planning. The systematic and continual effort to improve methods should be conducted by permanent and dedicated personnel. The best practices that foremen and workers bring to the job should be retained and used by other crews on future jobs. More sophisticated procedures for analyzing operations and evaluating methods should be developed. When improvements have been developed, better ways of "selling" them to the foreman or worker who will execute them are required.

To justify much special attention and analysis, an operation should be a repetitive one. Highway construction offers greater opportunities for profitable study of methods than perhaps any other type of construction. The highly organized and mechanized paving spreads give proof that this opportunity has been appreciated by the industry. On the other hand, the structures contractor is inclined to feel that most of his operations are unique on each job. This is not as true as often imagined. Although an over-all operation may involve conditions that are not likely to be found in the same combination again, the individual steps required to accomplish the operation are likely to be very similar to the corresponding steps of many past and future jobs. So it is these steps, or sub-operations, that should be subjected to systematic analysis.

Unfortunately the contractor's principal formal tool for evaluating his work is not a very effective one for sub-operation analysis. A good cost accounting system is invaluable for control purposes. However, the unit costs obtained are generally for unique operations composed of many steps. To obtain costs for these separate steps is beyond the capabilities of a cost accounting system. Such a system is based on the time distributions made on foremen's report cards at the end of each day. A too detailed breakdown of accounts would destroy the value of the results obtained rather than increase it. This limits its usefulness in comparing operation methods on one job with those used on another. For the job where the lower unit cost is obtained, there is no conclusive means of pinpointing the reasons for the improvement. The many steps that make up the operations compared are usually present in entirely different proportions and several of them, rather than just one, may have been performed in different ways.

A procedure for effective methods analysis and improvement may be summarized as follows:

1. An operation must be broken down into its separate steps.
2. Quantitative data that may be converted to dollars and cents must be collected for each of these steps.
3. The performance of the steps should be analyzed systematically for possible improvements, using both common sense and any formal work simplification technique available.
4. The best method determined, including any improvements developed, must be "sold" to the men responsible for their execution.
5. A follow-up is desirable to determine if changes made do really result in improvements.

The basic data for such an approach can be obtained by stop-watch time studies. The purpose of this paper is to suggest a different approach that has several advantages over stop-watch time studies.

TIME-LAPSE MOVIES, PROCEDURE AND EQUIPMENT

Many contractors record some of their more interesting operations on movie film. This is often done in an informal manner by job superintendents or engineers and sometimes in a more professional manner by hired photographers. In some cases these films are shown at meetings of company management personnel to pass good ideas from job to job. Such interchange and interest has value but fails to furnish the quantitative working data necessary for detailed study. With little additional effort and equipment, much more useful information may be obtained.

Short-interval, time-lapse movies can often provide the basic data for effective method improvement studies practically and economically. A number of such studies have indicated that 3-sec intervals between exposures generally produce the most useful results. This is a compromise between micromotion studies on the one hand and long-interval time-lapse pictures on the other. Micromotion studies, where movies are taken at normal or accelerated speeds, are useful in studying assembly-line manufacturing operations where hand motions, for example, are highly repetitive. Their use seems hardly justified for most construction operations, and the film produced would be too voluminous for economical analysis. Long-interval time-lapse movies, where individual exposures may be made every 5 min, 30 min, or 6 hr, for example, are useful for progress studies and general analysis. They do not provide sufficient data for detailed analysis.

The field equipment for short-interval, time-lapse studies can simply include a movie camera, a tripod, and a stop watch. These are items that are often already present on the job. A conscientious operator can trip a movie camera manually every 3 sec with sufficient precision to obtain effective data. Precise tripping on each exposure is unimportant as long as the total number of exposures for each minute is correct. However, a battery-operated timing circuit controlling a tripping solenoid eliminates the tediousness of manual operation and permits the operator to devote his efforts to improved documentation. Figure 1 shows the field equipment used for a study. The 16-mm camera was tripped by a solenoid actuated by the small, transistor timing circuit housed in a box mounted on the camera base plate. Power was supplied by a small 24-v storage battery hung from the tripod in a carrying case. The storage battery may be recharged nightly or less frequently as required. The camera may be removed from the tripod and held by the operator to obtain close-up pictures or to get into tight quarters. The timer will continue to operate from the power supply hung from the operator's shoulder.

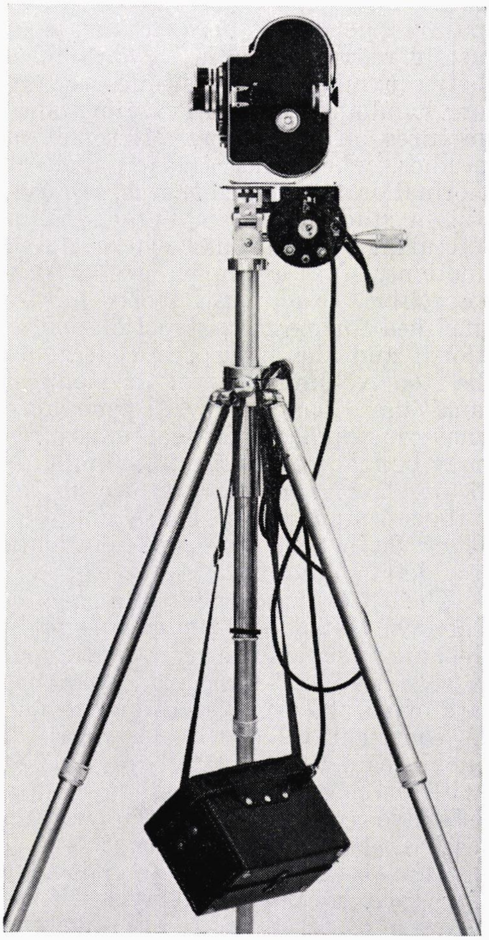

Figure 1. Field equipment for time-lapse movies, including electronic timer and battery power supply.

The office equipment for analysis work includes a conventional film viewer, or editor, equipped with a frame counter (Fig. 2). This enables the analyst to observe single frames as long as he wishes and to advance or reverse the film as slowly as he desires. Having selected cycle end points he may take frame counter readings at the beginning and end of each operation step and obtain time data. Other types of equipment are available for group presentations. Specially equipped stop-motion projectors permit observation of single frames without film damage and allow films to be advanced or reversed a frame at a time as well as at varying continuous speeds. These may range from simple hand-crank projectors to more elaborate, automatically controlled ones such as those sometimes used by football coaches to analyze plays.

ADVANTAGES OF MOVIE ANALYSIS

It was indicated that this approach can have several advantages over the more conventional stop-watch study for analyzing construction operation. Some of these advantages may be described as follows:

1. Most construction operations involve crew activity and one or more pieces of equipment. The simultaneous activities of each man and piece of equipment is important to record. Crew balance studies often indicate the most significant opportunities for improvement. Data for such studies require about as many stop-watch observers as crew members; however, a movie study permits a single observer to record all of the simultaneous activities accurately. By repeated observation of a cycle on film, the analyst may follow the ac-

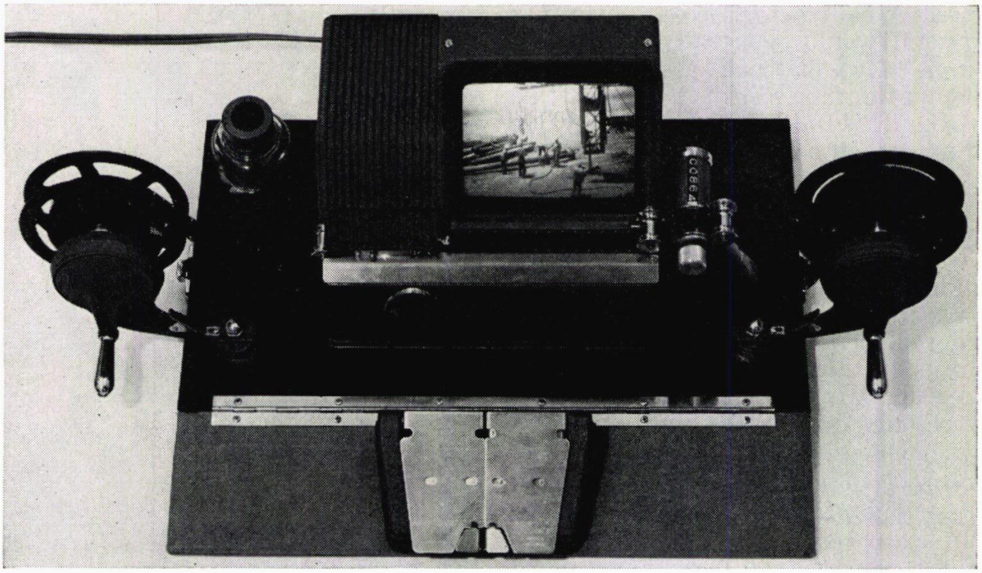

Figure 2. Office analysis of films by means of standard editor with frame counter.

tivities of one man at a time and construct an accurate crew activity chart.

2. Construction cycles are more likely to be irregular than regular making time studies difficult for even experienced industrial engineers. Contractors generally must use personnel that are not highly trained in time-study techniques. Because a film may be observed as many times as desired, away from the job, it is simple for even the amateur to draw useful data from irregular cycles.

3. Construction operations are influenced by changing work conditions, weather, and surroundings to a considerable extent. Complete documentation of the important conditions, or even a recognition of which conditions are important, is difficult. Where data will be used by others who have never seen the job, the conditions cannot be fully appreciated. A movie record gives a complete and easily understood documentation of work conditions.

4. Proposed improvements, supported by arrays of stop-watch data, are difficult to "sell" to the foreman in the field. A graphic presentation, such as that which is possible by looking at a film strip, is easy to appreciate, encourages participation in further method improvement suggestions by the foreman, and allows him to evaluate more intelligently the changes from a practical standpoint in advance of their trial.

5. The movie studies are an economical means of data procurement. At 3-sec intervals a 100-ft roll of film permits a single operator to record completely a total of 3⅓ hr of continuous operation. Data for a number of cycles of several steps of one operation can usually be obtained on a single film.

TUBULAR FALSEWORK ERECTION

As an illustration, a movie analysis study of a highway structures operation will be described—the erection of tubular metal scaffolding as falsework for an elevated freeway structure. A contractor's cost accounting system would generally include a single account such as "erect and dismantle falsework" to cover this work. This unit cost is of little value from a methods improvement standpoint in determining why this operation is better or poorer than a similar operation on another job. This fact is more understandable when the number of individual steps that are part of this single operation are considered. Table 1 shows 33 separate sub-operations involved in just the erection of falsework towers that were only two frames high.

The movie camera was used to record a number of cycles of each of these operation steps as the opportunity arose. Later the film was edited and the operations arranged in proper sequence. The entire erection operation was covered by four 100-ft rolls of film. The next step was to take the quantitative data collected in the field and to convert it into comparable dollars and cents figures. This was accomplished by viewing the film slowly, picking out cycle end points, and recording frame counter readings. The frame counter readings were converted to elapsed

TABLE 1

ERECTION OF TUBULAR METAL FALSEWORK

Sub-Operation No.	Description
1	Establish stockpiles of materials
2	Stake sill locations
3	Distribute sand for sills
4	Spread and level sand bedding
5	Place sills in approximate position
6	Set sills to string line
7	Mark sills for jack locations
8	Distribute and set bottom jacks
9	Distribute 1st-level frames
10	Distribute 1st-level X-braces
11	Erect 1st-level towers
12	Set grade stakes, ground level
13	Align and plumb 1st-level towers
14	Distribute scaffold planks
15	Distribute 2nd-level frames
16	Distribute 2nd-level X-braces
17	Distribute connecting pins
18	Erect 2nd-level frames
19	Install 2nd-level X-braces
20	Distribute caps with jacks
21	Raise scaffold planks
22	Install caps
23	Set grade line, top of tower
24	Level caps at grade line
25	Level alternate caps, straight edge
26	Hoist stringers
27	Position and toenail stringers
28	Check levels, all jack points
29	Adjust top jacks
30	Final check and adjust
31	Distribute pipe bracing
32	Distribute brace clamps
33	Install pipe bracing

TABLE 2

RELATIVE COST IMPORTANCE OF SUB-OPERATIONS, TUBULAR METAL FALSEWORK OPERATION

Sub-Op. No.	Description	Cost ($)	
		Sub-Op.	Group
26	Hoist stringers (6/load)	19.32	
27	Position and toenail stringers	1.46	20.78
26A	Hoist stringers (4/load)	25.50	
5	Place sills (crane)	11.83	
6	Set sills to string line	2.47	14.30
5A	Place sills (buggy)	12.55	
8	Distribute bottom jacks	3.06	
9	Distribute 1st-level frames	1.36	
10	Distribute 1st-level X-braces	1.54	
14	Distribute scaffold planks	0.62	
15	Distribute 2nd-level frames	(1.36)	
16	Distribute 2nd-level X-braces	(1.54)	
17	Distribute connecting pins	No cov.	
20	Distribute caps with jacks	4.10	
31	Distribute pipe bracing	No cov.	
32	Distribute brace clamps	No cov.	13.58+
13	Align and plumb 1st-level tower	7.60	7.60
3	Distribute sand for sills	4.84	
4	Spread and level sand bedding	2.44	7.28
22	Install caps	5.05	5.05
18	Erect 2nd-level frames	2.84	
19	Install 2nd-level X-braces	1.73	4.57
24	Level caps at grade lines	1.25	
25	Level alternate caps by street edge	3.31	4.56

time. The pictures showed the men and equipment involved. Knowing labor classifications and rates and knowing equipment use rates, costs were developed. To appreciate the relative importance of the costs of the various sub-operations, these costs were developed for a block of work common to all operations. In the example cited, a given number of square feet of supported roadway soffit was the common denominator. Table 2 shows sub-operations grouped in descending order of importance. Knowing the relative importance of the sub-operations, the appropriate amount of attention may be directed towards each.

Having used the films to analyze the operations, improvements are sought. The common-sense questions of Why?, Where?, What?, How?, and When? asked about the details shown may suggest changes in even the simplest tasks. For example, the sub-operation "distribute sand for sills" is about as basic a job as can be encountered. It is accomplished by common laborers and wheelbarrows moving sand from a pile at the edge of the roadway site to sill locations marked by string lines. Foreman directions such as "a couple of you men take a wheelbarrow over and move some of that sand" gave a work cycle in which one man stood idle at the sand pile while the other wheeled and dumped the sand and then returned to help fill the wheelbarrow again. The formal approach of a crew balance study is not required to suggest that costs might be reduced by sending one man to do the same job instead of two. Not only are costs cut in half because the crew is cut in half but costs are further reduced, as shown by other filmed cycles, because one man working alone fills the wheelbarrow faster than two men chatting with each other as they work together. But this is only one possible improvement. Another detail noticed was that the wheelbarrows being used were of the 1½-cu ft garden variety. A laborer could just as easily wheel 5 or 6 cu ft per trip if given a properly sized piece of equipment. When this film was shown at a meeting of job superintendents and foremen, one of the men observed that an entirely different approach had been used on his last job. A special chute had been provided for the tailgate of the truck, and the sand had been dumped directly along the sill lines upon delivery to the site. Another point that came up for discussion at this meeting was "Why do it at all?" Under some conditions a careful grading job might permit the omission of sand bedding. Another alternative is the use of small, individual pads under each tower leg instead of continuous sills. This affects both the distribution of sand bedding and the more costly crane operation of handling the heavy timbers used as sills. There are good reasons for adopting one alternative over another, but these can be profitably documented for future reference to insure that an alternative is not blindly used when the reasons for it are absent.

This simple example would hardly justify much formal attention. But, as is the case with practically all operations filmed, it is effective in making job management conscious of several points. First, there are numerous possibilities for cost reduction through measures that are properly management functions, including giving specific directions as to the manner in which a task is to be performed, sizing the crew properly, and selecting the best tools to furnish the workmen. Second, there is more than one way to accomplish even a simple task. It is only by the continual attempt to seek out the best, retain it, and see that it is used until a better procedure is developed, that real cost reduction can be achieved. Third, there are possibilities on many small, routine tasks of cutting costs not by 5 or 10 percent but in half, or to a fourth or even to a tenth of their present level. Or stated conversely, where management does not assume its proper responsibilities, costs of many sub-operations can increase in the order of magnitude of 100 to 1,000 percent without the reasons being readily apparent even to those in charge of the work.

The same contractor that erected the falsework in the foregoing example was concurrently performing a similar freeway job in another city. Many of the corresponding operations were handled quite differently. Even on the same job, the same operation is performed by different methods from time to time. This is the natural result of the fact that management has turned over the selection of detailed methods to temporary employees with different backgrounds of experience. The sub-operations themselves are often quite similar in scope from job to job. In the case of erecting tubular metal falsework, the procedure for aligning and plumbing a tower, for installing caps on top of it, or for doing practically any of the 33 sub-operations of Table 1 is little affected by whether the job is in San Diego or Philadelphia. Moreover, these are operations that will be repeated by the same contractor and by different contractors many millions of times. More attention to detailed performance seems justified.

Incidentally, comments on the example used for illustration are not a reflection on the abilities of the contractor doing this work; rather, the reverse is true. This company is one of the biggest and best in the United States. Its work receives more detailed planning and is in the hands of more competent supervision than the vast majority of similar jobs. In general, its procedures could serve as models to guide others. So if there are opportunities for method improvements in its work, as it would be the first to agree, then there are even greater opportunities for most other organizations. More important examples than falsework operations can receive similar analysis. For example, building form panels in the yard, erecting and stripping box girder forms, erecting and stripping column forms, handling and driving piles, and placing concrete are all operations that involve greater costs and also have repetitive sub-operations.

SUGGESTED PROGRAM

A systematic procedure for management control of job-level operations might include the following steps:

1. Analyze operations and attempt to develop the best methods for their performance. Draw on job personnel assistance at all levels in evaluating procedures. Just as safety meetings can create safety consciousness, method study sessions can create consciousness of method improvement opportunities. Films can often be used for both of these purposes simultaneously, inasmuch as a revised method cannot be a better one unless it is also a safe one.
2. Maintain a record of the best methods to be used with appropriate documentation of the reasons why it is considered best. (Table 3 gives a sample for the sub-operation discussed.)
3. Go over these methods with supervisory personnel, and workers also when practical, at the beginning of a job to obtain their cooperation in the use of methods.
4. Prepare pre-plans of work in order to assure that the proper tools and materials are available, the personnel is instructed as to how to accomplish the work, the crews are sized correctly, and units of work are performed at the proper times.
5. Encourage job personnel to challenge the "best" ways that have been

TABLE 3
TUBULAR METAL FALSEWORK OPERATION, SUB-OPERATION 3: DISTRIBUTE SAND FOR SILLS

Reference:
Film TTI; Frames 862 to 1190.

Conditions:
Sill locations indicated by string lines. Truck load of sand dumped at side of roadway location. Laborers shovel sand into $1\frac{1}{2}$-cu ft wheelbarrow and dump in piles along string line.

Typical Cycle:

Activity	*Time (min)*
1. Load wheelbarrow	0.90
2. Transport load (avg. 90 ft)	0.62
3. Dump sand	0.15
4. Return empty	0.60
	2.27

Crew and Equipment:

1 Laborer	\$3.045
Wheelbarrow and shovel	(No use rate)
Total direct cost	\$3.045 per hr

Cost Computation, 3,000 sq ft:

Avg. loads per row of sills	= 10.5
Cycles per 4 rows = (4) (10.5)	= 42
Cost = (42) (2.27) (3.045/60)	= \$4.84

Remarks:
This cost based on performance by individual laborer. Cost much higher for two-man crew.
On future operations, try larger wheelbarrow (5 or 6 cu ft).
On future operation, consider tailgate chute to dump sand directly from delivery truck.

determined to date. If a foreman, for example, thinks he has a better approach and can give reasonably convincing arguments, permit him to try his method.

6. Analyze the new methods, including those of competitors, on a quantitative basis and replace existing methods as better ones are discovered.

The use of time-lapse movie methods is a technique that facilitates most of these steps. A basic premise of this paper is that foremen and workers do not necessarily know the best ways to perform their tasks. However,it is not intended to suggest that job management knows better ways and should arbitrarily enforce its ideas on the foremen. Construction management should assume greater responsibility and leadership in working with foremen and labor to develop better methods and to retain and use them. Group viewing of films of familiar operations by job personnel can produce very rewarding results. Foremen and workers are interested in presentations of this sort. Many of them have constructive ideas which they often are not given the opportunity to express. This attention to their work gives it an importance that they appreciate; moreover, it causes them to take a new look at their daily activities.

CONCLUSION

Over the past several years the author has conducted several movie analysis studies on heavy construction work. A by-product of these methods improvement studies has been material of considerable value for educational purposes. Detailed analysis of firms covering construction operations, such as box girder forming and placing, pile driving, or pipe laying, offers an excellent basis for understanding problems and procedures. More recently the National Association of Home Builders has been using 3-sec interval time-lapse movies for very complete studies of home building methods. The goal of its studies is not only methods improvement but also the development of new materials and new tools.

It should be emphasized that the described methods improvement studies are not directed towards making the individual worker work harder. Rather they are directed towards increasing the workers' effectiveness through measures that should be entirely within the realm of management's responsibility and authority. As construction wages continue to rise, it becomes more essential for management to assume this responsibility and for labor to adopt a cooperative attitude.

ACKNOWLEDGMENT

This work was made possible by a research contract awarded to the Civil Engineering Department at Stanford University by the Bureau of Yards and Docks, U. S. Navy. The purpose was to investigate and develop possible cost reduction techniques for construction operations. The use of time-lapse movies for methods analysis is only one of several areas of study undertaken under this contract. For assistance on the tubular scaffolding example, the author is indebted to Henning Jakobsen, a former graduate student in the construction engineering program at Stanford.