Data gathering system for logging operations
by Donald Kane Londgren

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Industrial Engineering
Montana State University

Abstract:
At the outset of work related to this thesis, a "grand system" for acquisition of logging operational data, was visualized. The major hypothesis submitted that a data gathering system for gathering facts about logging operations could be developed to describe these same logging operations to any desired degree of accuracy and detail. This hypothesis was neither proved nor disproved, but considerable support of a positive nature was presented.

In pursuing the major hypothesis four methods of data gathering--!) time lapse photography, 2) standard speed and slow motion movies, 3) stop watch time study, and 4) work sampling--were analyzed relative to the real world of logging.

Before an attempt could be made to create a system from these four data gathering methods, it was first necessary to examine each method relative to the logging environment. Of the four methods, time lapse photography was analyzed the most thoroughly because of advantages of this method found in other industries and due to the problems encountered in applying the method to logging.

Several pitfalls were encountered in the application of the four methods, including the following: 1. Logging has many more variables that must be considered than is typical of other industries.

2. Most logging operations" move frequently.

3. Data gatherers are faced with view obstructions, impediments to movement, and serious hazards.

Attempts to deal with these pitfalls are discussed in the thesis.

Following studies made to establish the feasibility of applying the four data gathering methods to logging, the costs of data gathering were examined and found to be considerably higher than similar data costs in other industries. This is due in part to the distance typically traveled and time consumed in reaching a logging site.

Finally, guides to planning a data gathering system using the four data gathering methods studied were presented. Although much data can be gathered using the four methods, and capabilities of the methods tend to overlap, certain types of data remain which cannot normally be acquired without application of additional data gathering tools and techniques.

DATA GATHERING SYSTEM FOR LOGGING OPERATIONS

by

DONALD KANE LONDGREN

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Industrial Engineering

Approved:

Head, Major Department

Chairman, Examining Committee

Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

August, 1966

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the United States Forest Service for providing facilities and financial support in the development of this thesis.

To Dr. Sidney A. Whitt, chairman of my graduate committee, and to the other members of my committee, I extend my thanks for the helpful suggestions and criticisms they have provided during preparation of this thesis.

Thanks also to my colleagues, including Mr. James T. Kochaver, Mr. Frank J. Cesario, Jr., and Mr. LeRoy C. Stevens, for acting as sounding boards as my ideas developed.

Finally, to my wife Claudia for facing the brunt of my wrath when progress faltered, for typing this entire work, and for performing other errands and tasks leading to its completion, my sincerest thanks.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

At the outset of work related to this thesis, a "grand system" for acquisition of logging operational data was visualized. The major hypothesis submitted that a data gathering system for gathering facts about logging operations could be developed to describe these same logging operations to any desired degree of accuracy and detail. This hypothesis was neither proved nor disproved, but considerable support of a positive nature was presented.

In pursuing the major hypothesis four methods of data gathering--1) time lapse photography, 2) standard speed and slow motion movies, 3) stop watch time study, and 4) work sampling--were analyzed relative to the real world of logging.

Before an attempt could be made to create a system from these four data gathering methods, it was first necessary to examine each method relative to the logging environment. Of the four methods, time lapse photography was analyzed the most thoroughly because of advantages of this method found in other industries and due to the problems encountered in applying the method to logging.

Several pitfalls were encountered in the application of the four methods, including the following:

1. Logging has many more variables that must be considered than is typical of other industries.
2. Most logging operations move frequently.
3. Data gatherers are faced with view obstructions, impediments to movement, and serious hazards.

Attempts to deal with these pitfalls are discussed in the thesis.

Following studies made to establish the feasibility of applying the four data gathering methods to logging, the costs of data gathering were examined and found to be considerably higher than similar data costs in other industries. This is due in part to the distance typically traveled and time consumed in reaching a logging site.

Finally, guides to planning a data gathering system using the four data gathering methods studied were presented. Although much data can be gathered using the four methods, and capabilities of the methods tend to overlap, certain types of data remain which cannot normally be acquired without application of additional data gathering tools and techniques.

CHAPTER I
CONCEPT OF A DATA GATHERING SYSTEM FOR LOGGING

THE HYPOTHESES

The major hypothesis underlying this study is that a data gathering system for collecting facts about logging operations can be developed to describe these same logging operations to whatever degree of accuracy and to whatever degree of detail an analyst may desire. The secondary and implicit hypothesis is that the accuracy and detail required will be accompanied by some "exponentially" increased costs that will resemble the curve in figure 1.

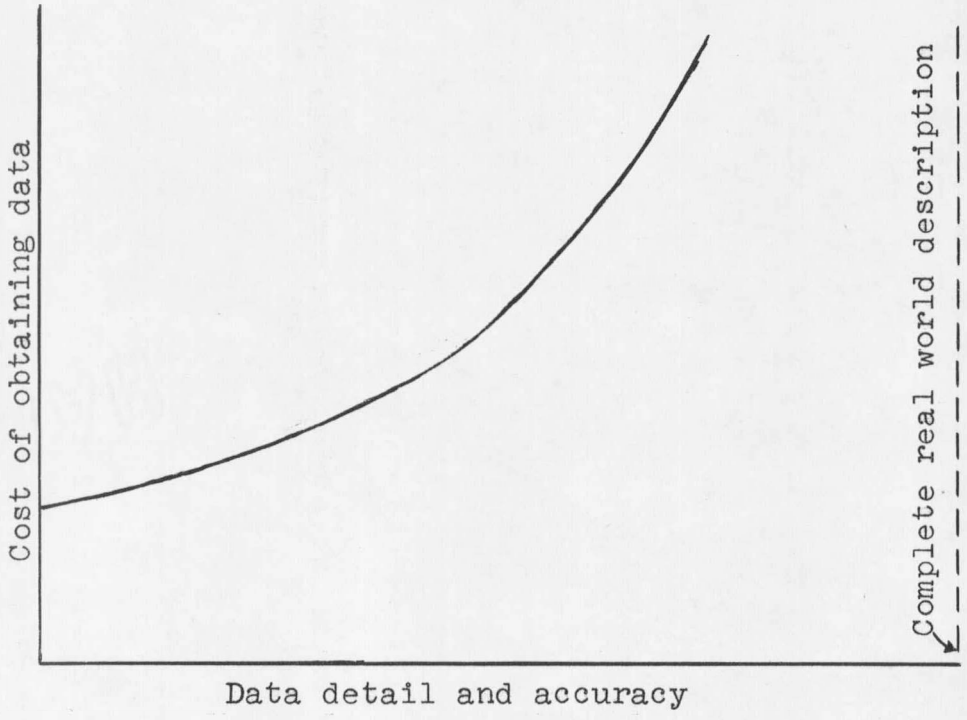


Figure 1: Hypothesized relationship of data cost to detail and accuracy.

To be economically useful, the "data gathering system" should be so developed that either periodically or continuously an estimate can be made of the accuracy and detail of accumulated data, giving consideration to the value of this data and the cost of gathering it.

LOGGING OPERATIONS

The five work operations to be considered here (felling, limbing, bucking, skidding, and loading) are each usually quite readily described from the standpoint of tasks accomplished and the sequence of events. In support of this statement, generalized descriptions are given in the following paragraphs for each of these operations. Most contemporary variations of these operations will fit these generalized descriptions.

A LOGGING OPERATION: FELLING

Felling, which is an operation to cut down a tree, is the first of several steps of logging. The tasks to be accomplished in felling are transportation of a cutting tool or machine to a selected tree and using this tool or machine to sever the tree close to the ground in a manner such that the tree will topple to the ground. It is conceivable that the future could bring forth a means of severing a tree other than sawing. Suitable adjustment to fit such methods should cause no major problems of task description. It is logical to assume that felling also includes control of direction (or at

least partial control) of the tree top's travel to earth when the operation is performed by a skilled worker using currently predominant methods.

SEQUENCE OF WORK EVENTS: FELLING

A common sequence of events of felling a tree is described by the following list:

1. Select the tree to be felled,
2. Transport cutting tool or machine to tree,
3. Determine direction for tree's fall,
4. Use cutting tool or machine to make necessary cuts at base of tree, commonly:
   a. Saw a notch and back cut with power saw,
   b. Shear tree with large mechanical shear,
5. Remove cutting tool and stand clear of falling tree.

These events are repeated with variations in degree for each tree that is felled.

Items not included in this basic list of events, but which are not insignificant to the operation of felling include 1) travel to and from the cutting area, and 2)sharpening and repair of the cutting tool or machine. The lists of events describing other operations will, likewise, omit certain supporting tasks. They may also warrant consideration in a data gathering system, but the major operations will be studied first.

A LOGGING OPERATION: LIMBING

Limbing is the operation of removing limbs from the marketable portion of a tree's stem. The tasks of limbing are 1) transporting a cutting tool or machine to a tree and along the tree's stem, and 2) using the cutting device to sever the limbs.

SEQUENCE OF WORK EVENTS: LIMBING

The sequence of separate events which describe in general the operation of limbing follows:

1. Select the tree to be limbed,
2. Transport cutting tool or machine to tree,
3. Transport cutting tool or machine along stem of tree,
4. Use the cutting tool or machine to sever limbs as they are encountered.

These events are repeated for each tree that is limbed.

A LOGGING OPERATION: BUCKING

Bucking is the operation of cutting trees to log lengths. A special case of "bucking," in which that portion of a tree's top which has a diameter too small for commercial use is removed, is commonly called "topping." The tasks of bucking are transporting a cutting tool or machine to a tree and along the tree's stem, measuring "required" log lengths, and using the cutting device to cut the tree to log lengths.

SEQUENCE OF WORK EVENTS: BUCKING

A common sequence of events involved in bucking a tree follows:

1. Select the tree to be bucked,
2. Transport a "measuring device" and a cutting tool or machine to tree,
3. Measure log length while transporting cutting tool or machine along stem of tree,
4. Cut through tree at the appropriate point(s),
5. Repeat steps 3 and 4 until entire tree is cut into required log lengths.

These events are repeated for each tree that is bucked.

A LOGGING OPERATION: SKIDDING

Skidding, the operation in which logs are moved from the felling point to a loading area commonly termed a "deck," involves the tasks of operating some device or a machine so that it will pick up or "get" the logs, singly or in groups, and transport them to the desired location for loading. In this study, skidding is intended to include all methods of moving logs from the cutting area to the loading area. Those methods which lift one end of the log when it is moved, and methods with other variations, will not be placed in a separate category as is sometimes done in logging terminology.

SEQUENCE OF WORK EVENTS: SKIDDING

A sequence of events for a typical mechanized skidding

operation can be generally described as follows:

1. Guide skidding machine, or a part of it, to area of log or logs to be skidded,
2. Select log to be skidded,
3. Attach cable or hook from skidding machine to the selected log,
4. Repeat steps 2 and 3 until the desired number of logs for one "drag" have been attached,
5. Transport a "drag" of logs to loading area,
6. Release the logs.

These events are repeated for each log or "drag" of logs.

A LOGGING OPERATION: LOADING

Loading is the operation of placing logs on a hauling device, commonly a truck, for transportation to the mill. The tasks involved are the operation and control of a loading machine such that it will pick up logs and place them in desired positions on the hauling unit.

SEQUENCE OF WORK EVENTS: LOADING

The sequence of events to describe generally the loading operation follows:

1. Select logs to be loaded,
2. Operate machine so it will reach for or travel to selected logs,
3. Cause machine to grasp logs,
4. Operate machine so it will pick up logs,

5. Operate machine so it will move logs and position them on the hauling unit,

6. Cause machine to release logs.

It is to be recognized that in some operations only one log is handled each cycle. The sequence of events in the list is repeated as many times as necessary for each "hauling unit" that is loaded.

LOGGING OPERATION DESCRIPTIONS CLARIFIED

Descriptions of operations as presented here do not provide for a breakdown into standard time study elements. The variations that occur increase almost geometrically as an operation description is presented in greater detail. Even these generalized descriptions may not be broad enough to encompass all methods, current or future, of performing the basic logging operations.

As an example, consider event number 3 of the felling operation, "determine direction for tree's fall." A power chain saw is in common current use for making the necessary cuts at the base of the tree. These cuts represent the feller's most useful means for controlling the direction of the tree's fall. To determine the direction in which the tree will fall, the feller must consider such things as the "lean" of the tree (angle with the vertical), amount and position of branches, direction and intensity of the wind, and the slope of the ground. These factors are frequently not constant as

the feller goes from one tree to the next. Occasionally the wind is not even constant during felling of a single tree; cases have been observed where a saw has become wedged in the tree while making a back cut because the wind direction changed.

Considering the various directions in which he can make the tree fall on the basis of factors beyond his control, the feller determines the direction in which he will try to make the tree fall. He then decides how he will cut the tree so that it will fall in the chosen direction. This decision must be made for each tree.

If instead of a chain saw a large machine with a shear and the means for positive control of the tree's direction of fall is used, only one decision may be necessary for the direction of felling an entire block of trees, making the decision process negligible for individual trees.

It is possible to show that many of the other events for each operation will be subject to increasing numbers of variations as elements become more detailed. (5, chap. 1 & 2) Because of this it is not feasible in this paper to discuss in detail all of the possible method variations that could be analyzed for the five logging operations being considered.

EXTENT TO WHICH REAL WORLD IS TO BE DESCRIBED

It is anticipated that data sufficient to describe logging operations in complete detail and with precise accuracy

would, if it is possible to gather that much data, cost an astronomical amount of money. There are, however, many practical situations that do not require such completeness of detail and preciseness for every part of an operation.

If the data gathering system is not to provide a complete real world description of all details of every operation to which it is applied, then precisely what and how much information should be gathered? At least two factors must be considered to intelligently answer this question. First, what is the intended use of the data; and second, what means, if any, are available for gathering the desired data.

WHAT DATA IS DESIRABLE

There are many possibilities as to what information could be required. In this sytem, only data that can be used to determine or reduce production costs of an operation or group of operations will be considered. We must, of course, be concerned with the cost per unit of production at some production level.

Since the data gathering system is to provide data that will aid in the determination of costs or that can be analyzed in an effort to reduce costs, and since we are concerned with these costs as they relate to production, the data gathering system should provide:

1. A means of measuring factors affecting costs,
2. A means of measuring productivity rate,

3. A means for measurement and description of factors that have a significant controlling influence on productivity rates.

OBSERVATION, MEASUREMENT, AND RECORDING OF THE FACTORS THAT AFFECT LOGGING COSTS

The factors that commonly affect costs of any production operation include men and machines required to perform the operation and the time elapsed during each cycle of the operation. Idle time also affects the cost.

The number of men and brief machine descriptions are readily obtained by observation. Reasonably complete machine descriptions are often available from the manufacturer's advertising literature. More complete descriptions of both men (such as skill requirements and skill levels) and machines can usually be prepared if increased benefits warrant the increased expense.

Measurement of cycle times can be readily accomplished by one of the time study techniques. Cycle times in many logging operations, unlike the operations in many industries, appear to be subject to large variations. To quantitatively relate cycle time variations to the causes of the variations demands special attention to pertinent data in a data gathering system. A single fixed "cycle time" standard, for most logging operations, is expected to have little practical value.

Compensation rates for logging in the lodgepole pine areas are usually available on inquiry, but are commonly based on board feet of merchantable timber delivered to the mill. This measure is subject to natural and human factors that make its use as a measure of productive effectiveness inconsistent. Consequently, in actual practice costs per board foot for logging operations tend to be inconsistent even for a particular combination of methods, men, and machines.

MEASUREMENT OF PRODUCTIVITY RATE

Sawlogs are normally bought and sold on a board foot basis, and it is common for production workers to be paid on the same basis. This would therefore appear to be a logical unit of production measurement for data gathered for analysis.

The board foot as a unit of production measurement does, however, present problems. For most logging operations it appears difficult, if not impossible, for one observer to make the necessary measurements in the time available during a cycle if interference with production is to be avoided.

For many operations, production effort and effectiveness are not readily related to board foot production rates. This leads to the conclusion that comparisons of operation alternatives on the basis of board foot production rates will have questionable value. Establishing costs on a board foot basis, though valid for a particular situation, may be next to

useless as a tool for prediction of future costs in a slightly different situation.

Productivity rates, should, perhaps, be established on a work element basis. For example, times required to make the necessary cuts to fell trees of various sizes could be determined; rates of travel between trees could be determined for fellers carrying various sizes of saws over various slopes, and so on with each element having a productivity rate established on the basis of influencing factors having the greatest effect in each case.

MEASUREMENT AND DESCRIPTION OF FACTORS THAT HAVE A SIGNIFICANT CONTROLLING INFLUENCE ON PRODUCTIVITY RATES

Determination of such things as time to make the necessary cuts to fell trees of various sizes will require certain measurements in addition to elapsed time values. For example, in this case it is necessary to measure the tree size (particularly its diameter). In other words, it is necessary to measure the controlling influences if they are to be related to productivity rates.

METHODS OF DATA GATHERING

Four data gathering methods are to be considered in this thesis. They are 1) time lapse photography, 2) standard and slow motion movies, 3) time study, and 4) work sampling. The greatest amount of attention will be devoted to time lapse photography which already appears to be a promising tool.

CHAPTER II
TIME LAPSE PHOTOGRAPHY
A PERTINENT TIME AND MOTION STUDY TECHNIQUE FOR DATA GATHERING IN THE FIELD

Time lapse photography is a modified motion picture technique, involving the use of a special movie camera. The camera is modified so that, in the original photography, a greater than normal time interval elapses between successive frames. It is commonly used for visualizing and recording the normally invisibly slow processes. (A well-known example of the use of time lapse photography is the visualizing of the opening of a flower bud.) (10,p.13)

In the later 1940's (9,p.13) time lapse photography began to find industrial application in a newly developed work analysis tool called memomotion study.

Memomotion study is a motion and time study technique invented by Marvin E. Mundel. (8,p.1786) In the words of Mundel:

> "Memomotion study is the name given to the special form of micromotion study in which motion pictures are taken at unusually slow speeds. Sixty frames per minute (one per second) and one hundred frames per minute are the speeds most commonly used. Like all micromotion study, it is primarily another means of performing the second step of the logical method, 'analysis,' with man activity, and requires three phases: filming, film analysis, and graphic presentation. Memomotion may also be used to study the flow of material or the use of materials-handling equipment in an area, or to study simultaneously the man work, equipment usage, and flow of material. The information contained on the film may be analyzed

> in numerous ways and alternative presentations of the data in graphic form are possible, depending on the objectives of the study."
> (18,p.301)

The logical method of which Mundel speaks involves the application of the following steps:

1. Aim (determination of objective),
2. Analysis,
3. Criticism,
4. Innovation,
5. Test,
6. Trial,
7. Application.

Discussion of the method can be found in Mundel's book, Motion and Time Study, Principles and Practice. (18,p.27-28)

"Time lapse photography" is the first of the three phases (namely, filming) that Mundel points out as being required for memomotion study. It is the device by which data are gathered when memomotion study is used for operation analysis.

Time lapse photography, when used as the first phase of memomotion study, is simply a means of briefly recording on film the essential "elements" (standard industrial engineering definition) of an operation cycle. This technique is subject to several limitations, but it also has numerous advantages (where favorable circumstances exist) over other motion and time study techniques. The advantages and

limitations of time lapse photography will be discussed in later sections of this chapter.

Known applications of this technique in other industries are discussed below.

USE OF TIME LAPSE PHOTOGRAPHY IN MANUFACTURING AND OTHER INDUSTRIES

Time lapse photography, in its relatively new memomotion study application, is primarily useful in studying any of, or any combination of, the following: (18,p.301-302)

1. Long cycles,
2. Irregular cycles,
3. Crew activities,
4. Long period studies.

It has been successfully used in a wide variety of other industries prior to its trial at Montana State University as a tool for data gathering in the study of logging operations. (The author has found no evidence of previous application of time lapse photography to the study of logging operations.)

The following list will serve to illustrate the wide range of activities where time lapse photography has been used as a means of gathering data for analysis of the operations: (18,p.302)

1. Gas company street work,
2. Twenty-four-man steel casting mold line
3. Prefabricated house section manufacture,

4. Railroad car humping in a classification yard,
5. Aircraft service on the ramp at a commercial airport,
6. Dry-salt meat packing line,
7. Stripping at delivery end of a cutting press,
8. Package handling at a packing-house sorting center,
9. Two-man welding crew on water heater assembly line,
10. Municipal garbage handling,
11. Dental activity,
12. Household activities,
13. Department store clerks,
14. Fifty-man paper making-machine repair crew,
15. Ice house crew,
16. Railroad car loading crew.

To multiply the significance of the wide range of activities where time lapse photography has been used, the ways in which it has been used also cover a broad area of approaches as illustrated by the following list of "fields of application": (21,p.208)

1. Production allowances,
2. Irregular work cycles for the indirect and related production groups,
3. Crew operations and long cycles,

4. Traffic flow,
5. Time study,
6. Determining waiting times in queues,
7. Establishing identity of people,
8. Psychological suggestion,
9. Silent watchman.

Even though the time lapse photography application in memomotion study is relatively new, the foregoing illustrates that it is already finding considerable use. As Phillip F. Ostwald stated, "Memomotion study is developing into a respected Industrial Engineering measurement technique with interesting and new variations to the spectrum of human measurement." (21,p.211)

ADVANTAGES OF TIME LAPSE PHOTOGRAPHY

The growth of the memomotion application of time lapse photography in the many and varied industries must certainly be related to the advantages associated with memomotion studies. These advantages, as discovered by the users of this method, lie chiefly in its utility as an industrial data gathering technique. The following is a composite list of advantages cited by authors who have described the use of time lapse photography and memomotion study of industrial operations:

ADVANTAGES CITED BY MUNDEL AS COMMON TO ALL METHODS OF MOTION PICTURE ANALYSIS... (17,p.85)

1. Permits greater accuracy than stop-watch studies, when used for time study purposes.
2. Permits observation in greater detail than floor studies (for example, interrelated events can be recorded more accurately). (18,p.302)
3. Provides greater flexibility (than other operation analysis methods). The record may be reviewed and analyzed when most convenient.
4. The record is positive. Questions concerning details of the method, work pattern, crew distribution, or time values may be settled directly without having to depend on secondary sources.

ADVANTAGES CITED BY MUNDEL AS ATTRIBUTABLE TO THE USE OF TIME LAPSE PHOTOGRAPHY... (17,p.85)

5. Film cost is reduced (as compared to micromotion study).
6. Cost of analysis is drastically reduced, in time and effort (as compared to micromotion study).
7. Complexity of analysis is likewise reduced.
8. Special lighting requirements are minimized (or eliminated) due to increased duration of film exposure (as compared to micromotion study).

ADDITIONAL ADVANTAGES ATTRIBUTED TO TIME LAPSE PHOTOGRAPHY (OR PHOTOGRAPHIC DATA GATHERING IN GENERAL) CITED BY OTHER AUTHORS...

9. Workers become indifferent to presence of camera, thereby reducing bias resulting from the presence of an observer. (21,p.210)
10. The "permanent record" feature of films permits refined analysis by a team of varied experts. (21,p.210)
11. Memomotion dramatizes bad conditions, particularly when a high-speed time study projector compresses extended periods of continuous filming into a short viewing time. (21,p.210)
12. "The memomotion camera does not need an attending Industrial Engineer during the filming." (21,p.210) To qualify this statement, it is to be recognized that in certain cases, such as where the operation is continuously moving, someone must attend to the camera. He need not, however, be an industrial engineer.
13. Effects of method changes on time requirements and operator workloads can be easily calculated. (7,p.31)
14. The film aids in selling supervision on the desirability of method changes. (7,p.31)
15. Memomotion can be adapted to "work sampling" of repetitive operations through the use of a random

timer. (2,p.53)

16. Time lapse photography requires less familiarity with the operation than other methods of time study. (22,p.68)

17. Time lapse photography is less tedious than other work measurement methods. (22,p.68)

18. The time lapse method requires no more analysis than other methods yielding a comparable degree of accuracy. (22,p.68)

The foregoing list essentially summarizes the advantages cited by experienced practitioners who have written on the use of time lapse photography (as applied in memomotion study) for data gathering in other industries. Many of the ideas were presented by several authors even though only one author is referenced for each advantage in this list. The primary intent here is to provide the reader with a single, reasonably inclusive, listing of favorable characteristics related to time lapse photography as used in memomotion study.

DISADVANTAGES, DIFFICULTIES, AND LIMITATIONS OF TIME LAPSE PHOTOGRAPHY

Along with the rather extensive array of advantages attributed to it, time lapse photography also has its shortcomings. In particular, the disadvantages cited by other authors include:

1. Immobility of the typical camera and tripod. (21,p.210)

2. Limited field of vision. (21,p.210)
3. Not well adapted to scattered crew operations. (22,p.69)
4. Not always most efficient means of measuring one-man production operation. (22,p.68-69)

According the available literature, time lapse photography is not accompanied by serious shortcomings when it is used in manufacturing and other industries. Many authors made no mention of any shortcomings. Others touch only very briefly on problem areas. Even the composite list of the previous paragraph can be shortened as will be described here.

The first problem area has been largely eliminated (for certain applications) by portable micromotion equipment illustrated in Motion and Time Study, Principles and Practice by Mundel. (18,p.311)

The second and third problem areas are essentially the same. A major reason that time lapse photography is not well adapted to scattered crew operations is the fact that the camera does have a limited field of vision.

Problem areas in the application of time lapse photography to gathering logging operation data will be treated in various parts of this dissertation. These problem areas are essentially:

1. Special equipment requirements (chapter IV),
2. Film requirements (chapter V),
3. Film and operation identification (chapter VIII),

4. View obstructions (chapter IX),

5. Environment and operation factors (chapter X),

6. Hazards of data gathering (chapter XV).

Discussion of these problem areas will be reserved for the chapters indicated.

PRELIMINARY CONCLUSIONS

Uses of time lapse photography in other industries, and the success thereof, have suggested the possibility of applying this novel technique to logging. The next chapter will discuss some early basic considerations regarding time lapse photography of logging operations.

CHAPTER III
USEFULNESS OF TIME LAPSE PHOTOGRAPHY FOR STUDY OF LOGGING OPERATIONS

Chapter II provided an indication of the usefulness of time lapse photography in established industries other than logging. From several examples, it is reasonable to conjecture that this data gathering tool may be similarly useful in the study of logging operations. Based on the literature description of applications in other pertinent industries, this chapter will present a preliminary evaluation of the likely usefulness of time lapse photography in the engineering analysis of logging operations.

Clues to this possible potential value will be sought through relating present knowledge of logging operations to known areas of usefulness and advantages of time lapse photography as applied in other industries. As mentioned in Chapter I, the fundamental logging operations being considered here are the following:

1. Felling,
2. Limbing,
3. Bucking,
4. Skidding,
5. Loading.

"AREAS OF USEFULNESS" IN TIME LAPSE PHOTOGRAPHY

Areas of usefulness listed for time lapse photography in Chapter II are any of, or any combination of, the following

types of man-machine activities:

1. Consisting of long cycles,
2. Containing irregular cycles,
3. Involving crew activities,
4. Requiring long period studies.

Each area of usefulness will be discussed separately in relating it to logging operations.

LONG CYCLES

Discussion of long-cycle studies in the Industrial Engineering Handbook (16,p.3,119-120) indicates that a long cycle is one that could last for several shifts. This area of usefulness of time lapse photography does not, therefore, appear applicable to any one of the logging operations being considered here, as the order of magnitude of time required per cycle is far less, even, than a single shift in each case.

IRREGULAR CYCLES

"The irregular cycle is always a time-study problem because it takes an extremely good recorder to catch all the elements and keep them clearly segregated for summarizing." (16,p.3,120) Time lapse photography will record irregular cycles with almost perfect accuracy. It has the added advantage of recording the actual sequence of events for the cycles which are studied.

Observation of current logging operations indicates that irregular cycles are common in all of the five operations

being considered here. To illustrate, in the felling operation, the feller may cut a tree that is tangled with another tree, leave that tree (even though it is still standing) and cut the other tree, causing both to fall at once. It is difficult to make an accurate, instantaneous, on the spot decision as to when the work on one tree is finished and work on the next has begun. Accurate separation of cycles into elements may be even more perplexing than determining the beginning and end of each cycle.

Felling, limbing, and bucking are sometimes each performed individually, and at other times are performed in various sequence combinations. The sequence is frequently not consistent even for a single cutter performing a small number of consecutive operation cycles. Observation of the sequence for one cycle may not give the observer a reliable indication of the sequence that will occur the next cycle.

The sequence that a cutter follows in felling, limbing, and bucking is sometimes too irregular for accurate prediction of what his next move will be until he has actually made the move, thus rendering ordinary stop watch time study of complete cycles nearly impossible.

Time lapse film can be analyzed to determine the sequence of moves, then re-analyzed to establish time values.

The skidding operation may be interrupted to push over dead trees (using the skid tractor as a dozer) that the feller

left standing, thus disrupting the skidding cycle and making segregation of elements extremely difficult when using ordinary stop watch time study.

A typical interruption that occurs in the loading operation results when an occasional log has not been bucked to the required length. It is common to temporarily stop the loading operation so the log may be bucked to proper length.

The preceding examples are only samples of the situations that occur to make the logging operations irregular. Numerous other factors, including the logging environment, also impinge to make the basic logging operations irregular. Perhaps this irregularity can be reduced eventually by standardization of methods (including sequence of events); however, since the operations are performed in an "irregular" environment, varied approaches for various situations may continue indefinitely. At any rate, the immediate need is a means to record current operations.

Considering logging's characteristic irregularity, time lapse photography appears extremely well suited to the study of the fundamental logging operation being considered here on the basis of the second "area of usefulness" (of time lapse photography), irregular cycles.

CREW ACTIVITIES

"Studies of group operations probably provide the best application of memo-motion [which implies the use of time

lapse photography*] study." (16,p.3,120) Felling, limbing, and bucking are normally one man operations; however, skidding and loading are frequently crew operations. Therefore, the third area of usefulness, crew activities, is frequently present in the skidding and loading operations.

LONG PERIOD STUDIES

It is the opinion of the author that when Mundel included "long period studies" in his list of areas of usefulness, he was referring to such things as "recording picture histories of methods and working conditions." (18,p.302) The progress of the improvement of methods of performing an operation could be the object of a long period study. This progress can be recorded by means of a series of films even if the films are not all completely analyzed at the outset. (16,p.3,119)

For purposes of observing and appraising the progress of the logging industry, and perhaps the eventual contribution of research to this progress, films, including time lapse, are suggested as a valuable recording tool. Thus, though this is recognized as an opinion, long period studies will be included herein as an area of usefulness appropriate to all logging operations.

In summary of the preceding discussion, Table I is presented to show the logging operations being considered in this

*Author's note within the brackets.

dissertation as they relate to the "areas of usefulness" of time lapse photography.

TABLE I
TIME LAPSE PHOTOGRAPHY "AREAS OF USEFULNESS"
FOR SELECTED LOGGING OPERATIONS

Logging Operation / Type of Cycle	Felling	Limbing	Bucking	Skidding	Loading
1. Long cycles	No	No	No	No	No
2. Irregular cycles	Yes	Yes	Yes	Yes	Yes
3. Crew activities	No	No	No	Yes	Yes
4. Long period studies	Yes	Yes	Yes	Yes	Yes
Potential Time Lapse Application*	Yes	Yes	Yes	Yes	Yes

*Referring to page 23 of this dissertation, the areas of usefulness are any of, or any combination of, long cycles, irregular cycles, crew activities, and long period studies.

ADVANTAGES OF TIME LAPSE PHOTOGRAPHY FOR LOGGING

The advantages attributed to time lapse photography in Chapter II will appear general enough to include the logging operations. The reader may wish to review that portion of Chapter II which discusses the advantages to observe for himself that they are applicable in the case of logging. Further discussion of the advantages does not appear justified at this point.

DISADVANTAGES OF TIME LAPSE PHOTOGRAPHY FOR LOGGING

The disadvantages of time lapse photography cited in industries other than logging (see Chapter II, pages 20-21) are each of some concern in at least one part of the logging system. The list is therefore repeated here and then discussed relative to the logging operations. Disadvantages cited by other authors include:

1. Immobility of the typical camera and tripod. (21,p.210)
2. Limited field of vision. (21,p.210)
3. Not well adapted to scattered crew operations. (22,p.69)
4. Not always most efficient means of measuring one-man production operation. (22,p.68-69)

IMMOBILITY OF CAMERA AND TRIPOD

The first disadvantage, immobility of the typical camera and tripod, is of concern in virtually all logging operations as a logging operation in a "fixed" location is, for all practical purposes, non-existent. Even the relatively stationary loading operation will sometimes move one or more times during the loading of a single truck-load. The problem is intensified, for example, in felling where the operation location moves for every tree that is cut.

This disadvantage of immobility and its particular significance in logging has not been accepted as sufficient reason to discard the idea of time lapse photography as a data gathering tool. Instead, efforts are being made to improve

mobility of the camera and accessories. These efforts will be discussed in Chapter IV.

LIMITED FIELD OF VISION

The limited field of vision of the time lapse camera becomes a problem when the available field does not permit the entire operation to be photographed with every exposure. The analyst is subsequently left with no information about operational factors not included in the picture. This is sometimes a problem in photographing logging operations because site characteristics do not always allow placement of the camera to include an entire operation in the field of vision. This problem is expected to be most frequently relevant in the cases of skidding and loading.

The relative frequency of occurrence of situations where the camera's field of vision is inadequate for logging operations has not been established. The limited field of vision is not presently regarded as a serious enough drawback to curtail further investigation of the time lapse camera as a data gathering tool in the study of logging operations. There is also a possibility that lenses with a wider view may be available.

SCATTERED CREW OPERATIONS

Time lapse photography is not well adapted to scattered crew operations. (22,p.69) Considering the operations of felling, limbing, bucking, skidding, and loading, the author has

observed that only skidding is frequently a scattered crew operation. Loading, when performed as a crew operation, does not ordinarily have a "scattered" crew. The remaining three are commonly one-man operations. Thus, time lapse photography with a single camera may not be well adapted to skidding operations.

ONE-MAN OPERATIONS

Time lapse photography is not always the most efficient means for simple measurement of one-man production operations. (22,p.68-69) As mentioned previously, felling, limbing, and bucking are all normally one-man operations. This limitation does not flatly say that time lapse photography will therefore be inappropriate for these three operations. It does, however, imply that examination should be made to see if some other data gathering tool is more appropriate.

It appears at this point that the drawback of time lapse photography not always being the most efficient means of measuring one-man operations may be nullified by:

1. Desirability of a picture history for work simplification studies.
2. Irregularity of the operations.
3. Small cost of film relative to other costs of gathering logging data.
4. Advantages of time lapse photography cited in Chapter II.

Therefore, it will not be regarded at this point as sufficient reason to curtail further investigation of this data gathering tool for use in the study of one-man logging operations.

CHAPTER SUMMARY

It has been shown that felling, limbing, bucking, skidding, and loading all come within the boundaries of the "area of usefulness" of time lapse photography. Further, the advantages of time lapse photography found in other industries also appear applicable to the logging operations.

Disadvantages of time lapse photography found in other industries have been discussed relative to logging. Others peculiar to logging are anticipated. The magnitude of detrimental effects cannot be evaluated without field trial.

Field application of time lapse photography to the five operations under consideration in this study will be discussed in the following chapters. This field application is intended to provide factual conclusions, regarding the usefulness of time lapse photography for logging, not possible on the basis of information presented in this chapter alone.

CHAPTER IV
EQUIPMENT USED IN THIS STUDY FOR TIME LAPSE PHOTOGRAPHY

The original time lapse photography equipment used in this study is an adaptation of the Kodak model K-100 single lens 16mm movie camera. The adaptation was developed by Meterological Research, Inc. of Altadena, California. The total cost of this prototype equipment was approximately 1000 dollars.

The most significant single feature of this time lapse adaptation is that the power for the frame interval control is supplied by a 45 volt "B" battery, thus making the time lapse equipment a self-contained unit. Equipment commonly used for time lapse photography in other industries, as described by literature on memomotion, requires a 120 volt, 60 cycle electric current source.

Logging, unlike many other industrial operations, is usually not carried on near a source of 120 volt, 60 cycle power. The importance of a self-contained power supply for time lapse equipment used in the study of logging operations is thus readily apparent.

The original equipment is shown in figure 2.

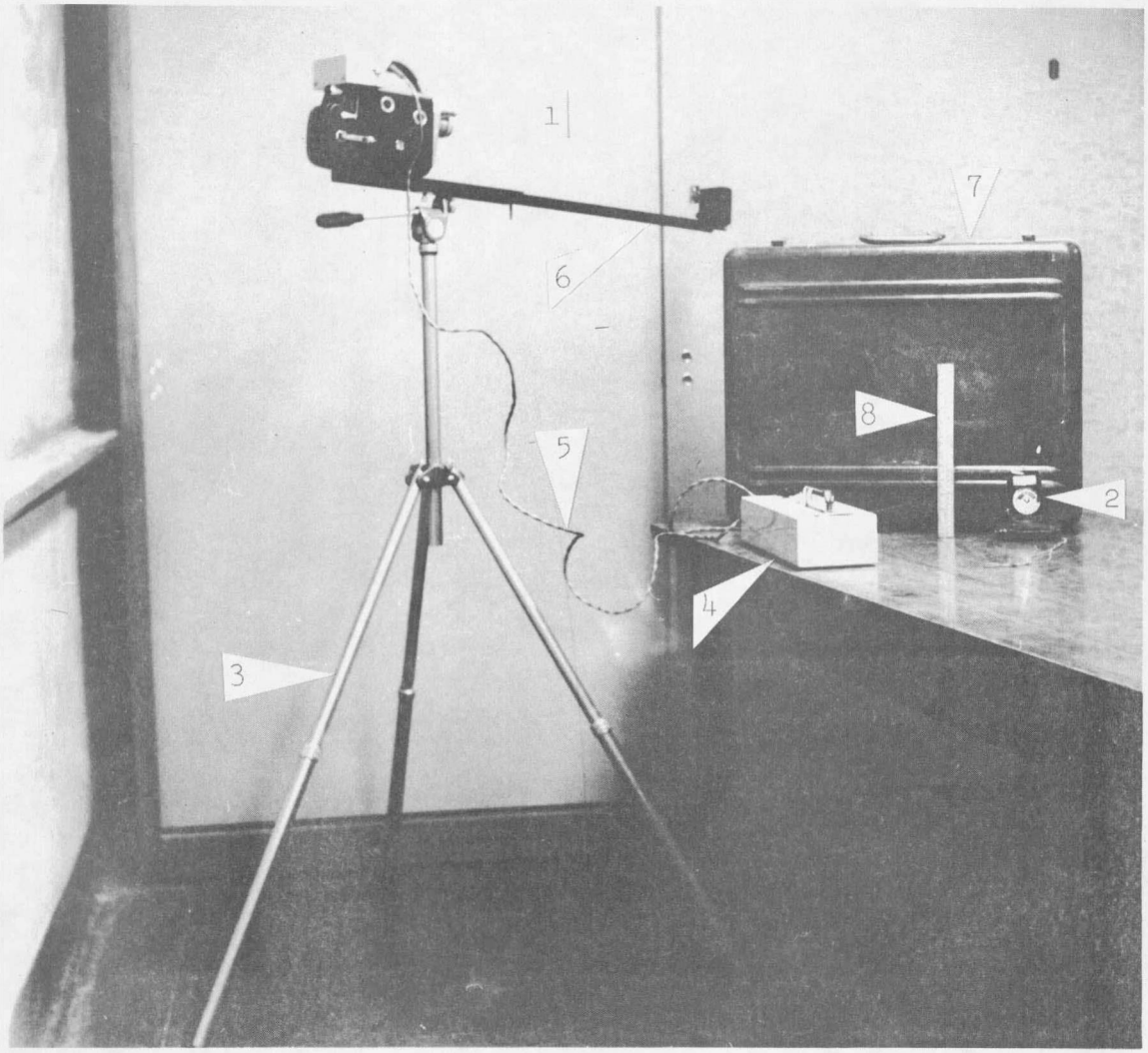


Figure 2: Original time lapse equipment, set up and ready for use, along with the original carrying case. One foot scale in the photograph is to provide size perspective.

Key to numbered items:

1. Camera with attached actuator-counter
2. Light meter
3. Tripod assembly
4. Intervalometer
5. Electrical cable
6. Clock arm assembly and clock
7. Carrying case
8. One foot scale

The intervalometer, item 4, and the actuator-counter, item 1, connected by a ten foot electrical cable, provide the frame interval control for time lapse photography. The power supply for this control, a 45 volt "B" battery, is housed in the metal box, item 4, containing the intervalometer.

The intervalometer is a timing device that periodically sends an electric impulse to the actuator-counter. The time value of the period from one impulse to the next is controlled by a manually set control knob. The available intervals are over a continuous range from less than one second to slightly over two minutes. Markings on the intervalometer indicate the approximate settings for the 1 second, 2 second, 5 second, 10 second, 30 second, 60 second, and 120 second intervals.

The actuator-counter is attached directly to the movie camera. It receives the periodic electrical impulses from the intervalometer and instantaneously triggers the camera to expose a single frame each time an impulse is received.

The movie camera exposes one frame each time it is triggered by the actuator-counter. Thus, by selecting a time interval within the available range from less than one second to slightly over two minutes and setting the manual control knob of the intervalometer accordingly, the time between successive pictures can be set as desired. A change in the interval requires readjustment of the manual control knob.

LATER ADDITIONS TO TIME LAPSE EQUIPMENT

Additional equipment acquired for photographic research of logging operations included another complete time lapse camera and accessories. All items were similar to the original equipment except that the newer camera is equipped with turret lens. As a result, it has three lenses--15mm, 25mm, and 63mm. The desired lens can be positioned for use almost instantaneously.

Various other lesser items have been used from time to time in an attempt to improve the data obtainable on film. Included are the following:

1. Titling devices (see Chapter VIII),
   a. Slate and chalk,
   b. Cards and marking devices,
2. Clock illuminator,
3. Pack frames.

Items 2 and 3 will be discussed further in later parts of this chapter.

PHYSICAL CHARACTERISTICS

Selected physical characteristics of the cameras and accessory equipment are described here. The last section in this chapter, "recommended modification areas," will illustrate the significance of these characteristics.

PHYSICAL CHARACTERISTICS AFFECTING MOBILITY

Weight is the first physical characteristic included

because it is easily measured and because it is an important consideration in the selection or development of man-carried mobile equipment. Table II lists itemized weights of cameras and accessories for the single lens outfit and for the turret lens outfit, respectively.

TABLE II
CAMERA AND ACCESSORY WEIGHTS

ITEM	Single lens outfit WEIGHT	Turret lens outfit WEIGHT
Camera with attached actuator-counter	6.53 lbs.	7.30 lbs.
Light meter	0.45 lbs.	0.45 lbs.
Tripod assembly	4.45 lbs.	4.19 lbs.
Intervalometer	5.50 lbs.	5.44 lbs.
Cable, 10 feet	0.37 lbs.	0.35 lbs.
Clock arm assembly and clock	1.75 lbs.	1.74 lbs.
Titling pencil and (20) cards	0.08 lbs.	0.08 lbs.
Film, per 100 foot roll	0.43 lbs.	0.43 lbs.
Carrying case	14.35 lbs.	14.54 lbs.
Total	33.91 lbs.	34.52 lbs.

Bulk is another important consideration in man-carried mobile equipment. As an illustration, the author submits that a fifty pound sack of flour is more easily carried than a

fifty pound sack of loosely packed feathers. Rather than including herein dimensional drawings of the equipment, the reader is directed to the photograph on page 34 for visual illustration of the bulk of the various items.

A third factor affecting mobility is the awkwardness of the equipment. Awkwardness results from such things as too many items (individual pieces) to be handled, poor balance or shape, excessive size or weight, and details of component adjustments. Although it is difficult to place a numerical value on awkwardness, one of several possible alternatives can usually be selected to minimize awkwardness. Experience in handling a particular type of equipment is an aid in this selection.

The time lapse equipment used in this study is believed to have factors of awkwardness which can be reduced in magnitude. Specific illustrations are included, beginning on page 51.

PHYSICAL CHARACTERISTICS - OPERATIONAL LIMITS

Certain operational limits of the cameras and accessories are included here since they affect the application of cameras to data gathering. Included are the following:

1. Frame intervals available and corresponding exposure times,
2. f/stop settings, as marked on lenses,
3. Selected depths of field,

4. Field of view, each lens,

5. Parallax,

6. Time limits of operation recording.

1. Frame intervals:

The frame intervals available fit into two classifications: those available with the camera alone (time lapse equipment disconnected), and those additional intervals available as a result of the time lapse adaptation. (It should be mentioned that other intervals are possible by means of hand triggering single frames but that this method seldom has practical application for presently accepted work measurement methods.)

Exposure times depend upon the frame interval selected. The five intervals marked on the camera (time lapse equipment disconnected) and the corresponding exposure times are as follows:

Frame interval (seconds)	Exposure time (seconds)
1/64	1/140
1/48	1/100
1/32	1/70
1/24	1/50
1/16	1/35

The exposure time is 1/20 of a second for all of the frame intervals added as a result of the time lapse adaptation. Available frame intervals resulting from the time lapse

adaptation are in a continuous range from less than one second to slightly over two minutes.

2. f/stop:

Each lens on the camera used in this study has an adjustable lens opening. Available lens openings, along with exposure times and light conditions, are important criteria in film selection.

The amount of lens opening is calibrated over a range of f/stop values. Particular f/stop values are marked on each lens. Marked f/stop values for each lens are listed in Table III. (The 15mm lens of the single lens camera is identical to the 15mm lens mounted on the turret camera.)

TABLE III
LENS OPENINGS AS MARKED ON EACH LENS*

LENS OPENING	LENS 15mm	25mm	63mm
1.9		X	
2			X
2.5	X		
2.8	X	X	X
4	X	X	X
5.6	X	X	X
8	X	X	X
11	X	X	X
16	X	X	X
22	X	X	X

*This table is a check list of the f/stop settings marked on each lens of the two cameras used in this study. Only the 15mm lens is mounted on the single lens camera; all three are mounted on the turret camera.

3. Selected depths of field:

For any given lens opening there is a range of subject-to-film distances over which the camera is properly in focus. The 15mm lenses on both cameras and the 63mm lens on the turret camera have markings to indicate the range over which the camera is in focus for various lens openings and focus settings. The 25mm lens on the turret camera does not have such markings.

The available depth of field becomes significant when close objects and distant objects are to be photographed at the same time. (An important example is when the clock is to be photographed concurrently with a logging operation in order to record time values along with other details of the operation.)

In addition, if the available depth of field is great enough, the lens may be used as a "fixed focus" lens. To illustrate, in a particular case of the 15mm lenses used in this study, "the camera can be used as a 'fixed focus camera' if the focusing ring is set at six feet and a lens opening of f/5.6 or smaller[1] is used. When the lens is adjusted in this way, subjects from approximately three feet and beyond will be sharp." (14,p.6)

---

[1] As lens openings become smaller, corresponding f numbers become larger.

The value of a fixed focus camera for filming of logging operations lies in the simplification of camera operation that results when the focus can be set in one position and does not need to be readjusted.

Available depths of field are referred to later in this chapter on page 50 and again on page 56.

4. Field of view, each lens:

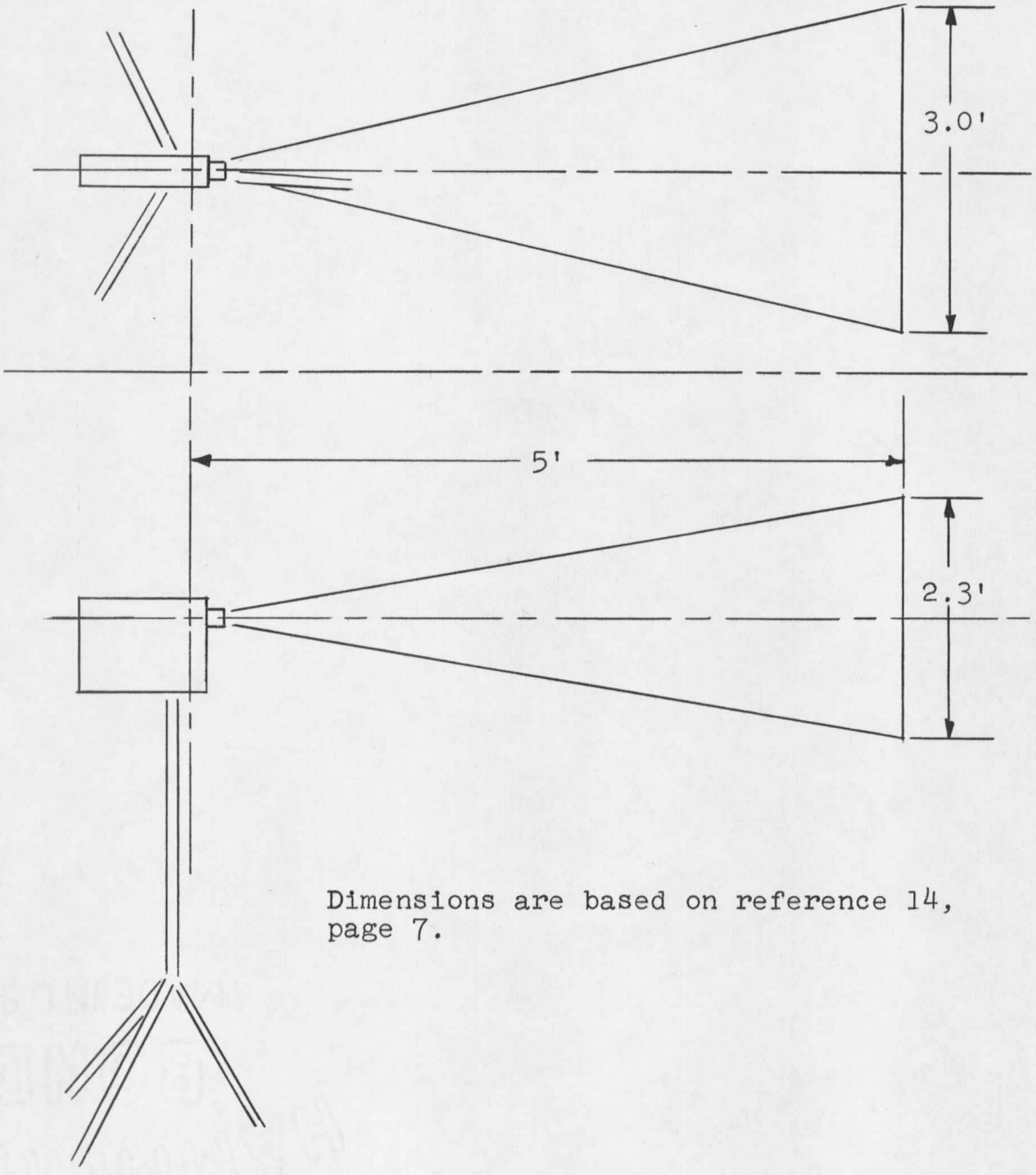
The field of view encompassed by the camera depends upon the lens selected and upon the film-to-subject distance. These relationships are illustrated for a given lens and film-to-subject distance in figure 3.

Figure 4 graphically illustrates the relationship of camera-to-subject distance, lens used, and field of view size available with each of the three lenses used in this study.

5. Parallax:

The viewfinder and the picture taking lens are separated on the two cameras used in this study. They do not, therefore, cover precisely the same area. This condition is known as parallax.

The apparent effect of parallax is the greatest for short film-to-subject distances. Assuming the viewfinder and the picture taking lens are exactly parallel, the area covered by the viewfinder is offset from the area covered by the picture-taking lens by the same amount regardless of the film-to-subject distance. But the apparent effect of, say, one inch



Dimensions are based on reference 14, page 7.

Figure 3: This shows the relationship of field size to lens selected and film-to-subject distance using a 15mm lens at a distance of 5 feet.

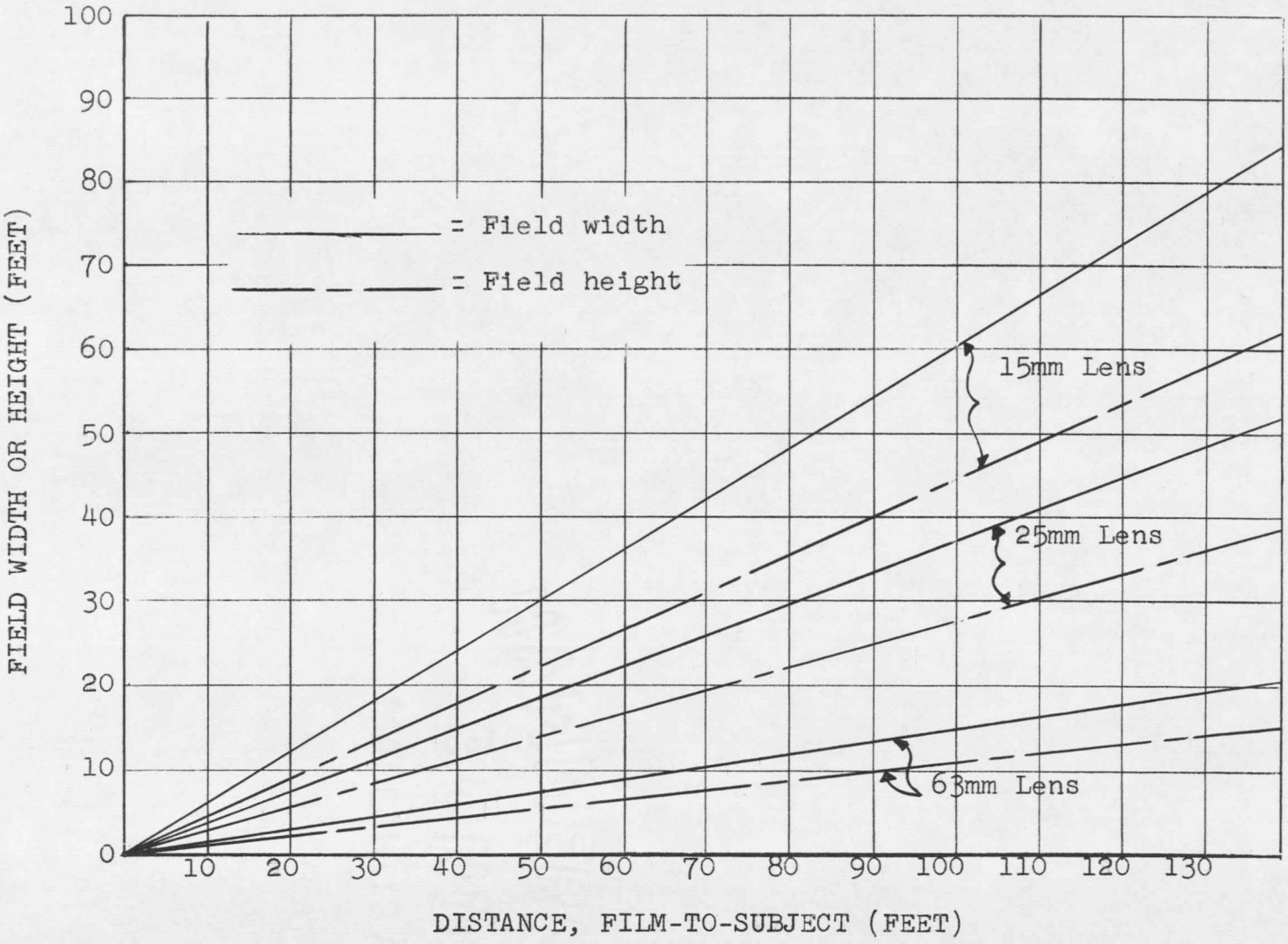


Figure 4: Fields of view for three lenses used in this study.

horizontal offset is much greater for a field of view one foot wide than it is for a field of view twenty feet wide.

For the cameras used in this study the actual area photographed is offset approximately 1.2 inches to the left and 0.8 inches down from the area indicated by the viewfinder. The effect of parallax using the 15mm lens and at a film-to-subject distance of 2.25 feet is illustrated by figure 5.

6. Time limits of operation recording:

Continuous recording of an operation for an unlimited period of time is not possible with a single camera of the type used in this study. There is an interruption each time a new roll of film is installed in the camera. Also, for short[2] frame intervals, winding of the camera is a source of interruption.

The film capacity of the cameras used in this study is limited to one hundred feet. The spring motor has capacity to drive the camera to expose forty feet of film before it requires rewinding.

---

[2] A "short" frame interval, in the sense used here, is one which will not permit the camera to be rewound between successive exposures. Intervals of less than 2 seconds will generally fall into this classification.

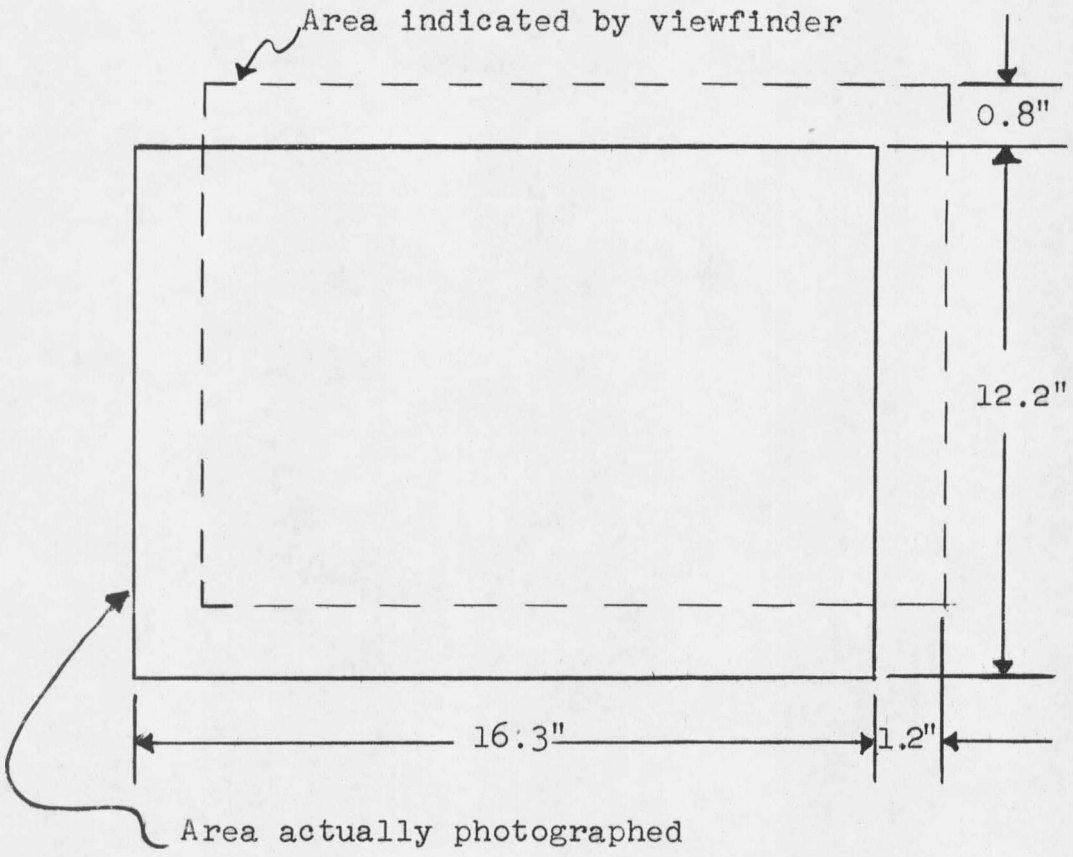


Figure 5: This shows the effect of parallax at a film-to-subject distance of 2.25 feet using the 15mm lens.

16mm film has forty frames per foot. Therefore, there are about 4000 frames available for operation recording in a one hundred foot roll of film. Winding of the camera to full spring capacity permits approximately 1600 frames to be exposed before rewinding is required. This information of the frames available between interruptions, together with knowledge of the frame interval to be used, determines the length of time that an operation can be recorded without interruption for film replacement or winding of the spring. Available recording times for forty feet and one hundred feet of 16mm film are presented in table IV for selected frame intervals.

Some of the information included in this chapter on physical characteristics of equipment may at this time appear to be mere details. Little attempt has been made, up to this point, to justify its inclusion. These details of the physical characteristics will be referred to in various arguments presented later in the thesis. It is for the benefit of these arguments and for quick reference by future users of photographic study of logging that this material is compiled.

The equipment in its original form has shortcomings when applied to the specific task of recording operational data of logging. Certain modifications, as described in the next section, are recommended to permit more effective use of the camera.

TABLE IV
AVAILABLE RECORDING TIMES, 16mm FILM

Frame Interval (seconds)	Recording Period	
	40 feet of film	100 feet of film
1/64	25 sec	1 min 2 sec
1/48	33 sec	1 min 23 sec
1/32	50 sec	2 min 5 sec
1/24	1 min 7 sec	2 min 47 sec
1/16	1 min 40 sec	4 min 10 sec
1	26 min 40 sec	1 hr 6 min 40 sec
2	53 min 20 sec	2 hr 13 min 20 sec
5	2 hr 13 min 20 sec	5 hr 33 min 20 sec
10	4 hr 26 min 40 sec	11 hr 6 min 40 sec
30	13 hr 20 min	33 hr 20 min
60	26 hr 40 min	66 hr 40 min
120	53 hr 20 min	133 hr 20 min

RECOMMENDED EQUIPMENT MODIFICATIONS[3]

Improvements recommended for time lapse cameras and equipment, more or less in order of priority based on the author's experience, can be generalized as they appear on the following page:

---

[3] Some of the modifications recommended here are being made concurrently with the preparation of this thesis. Appendix I describes modifications that have been made prior to December 30, 1965.

1. Any improvements to maximize probability of actually recording required data,
2. Simplify camera and equipment operation,
3. Reduce awkwardness,
4. Reduce bulk,
5. Reduce weight,
6. Improve flexibility,
7. Extend operational limits,
8. Improve resistance to weather conditions,
9. Improve durability and ruggedness.

1. Any improvements...:

Item number one, "any improvements to maximize probability of actually recording required data," in a sense includes the other eight items. It may also include areas for improvement that have not occurred to the author. It is the author's intent that the list should serve as a guide for future improvements and that item one encourage the reader to think in terms of the eight remaining listed items plus others that he may conceive.

2. Simplify camera and equipment operation:

There are many steps that are necessary in order to take satisfactory pictures with the movie camera. These steps are not particularly difficult if 1) the photographer has ample time, 2) light conditions and subject-to-camera distances are essentially constant, and 3) there are no hazards to life and

limb that require watching.

Data gathering in logging operations frequently must operate outside of these three restrictions. Felling is a prime example in which the photographer is kept on the move much of the time; light conditions and subject-to-camera distances change frequently; and serious hazards do exist.

Suggested improvements to simplify camera and equipment operation include an automatic exposure control and a "fixed focus" lens.[4]

3. Reduce awkwardness:

Awkwardness was discussed earlier in this chapter in the section titled "Physical Characteristics Affecting Mobility." From that discussion it follows that awkwardness can be reduced by the following approaches taken singly or in various combinations:

a. Minimize number of individual pieces,

b. Improve balance,

c. Improve shape,

d. Optimize size,

---

[4] A "fixed focus" lens is one which permits a single focus setting for all anticipated conditions of lens opening and subject-to-camera distance. This condition is sometimes possible due to the available depth of field. A lens that may be locked in any selected fixed focus position would be highly desirable.

e. Minimize weight,

f. Eliminate, automate, or simplify adjustments.

Some specific examples of awkwardness of the original time lapse equipment used in this study are the following:

a. Thirty-four pound suitcase (loaded weight) for carrying equipment to logging site is a heavy load poorly distributed on the carrier for woods travel. (See figure 6, page 52.)

b. Essential time lapse picture taking equipment is heavy, has long projecting clock arm, many joints and adjustments, and large separate interval control box.

c. Interval control is easily jostled to position other than the selected one.

d. Focus is easily thrown out of adjustment when setting lens opening.

e. Determination of proper lens opening is too involved to properly follow frequently light changes.

f. Best setting of clock arm is not readily obvious (due to parallax).

The reader may refer to Appendix I for improvements to reduce awkwardness that have been made prior to December 30, 1965.

Figure 6: Photograph of man carrying 34 pound suitcase loaded weight for transportation of equipment to logging site.

4. Reduce bulk:

Bulk, of course, refers to the physical size of equipment. The meaning of bulk reduction is obvious. The means of accomplishment frequently are not.

5. Reduce weight:

Time lapse equipment almost invariably must be carried if it is to be used in recording logging operations data.

The distance it must be carried will vary with each operation studied. It may be only several feet, or it may be a mile or more. It may only be moved to a single vantage point and set up to follow a relatively stationary operation, or it may require almost continuous moving to follow operations that change location frequently.

Carrying begins wherever it becomes unreasonable to travel further with the vehicle used on a data gathering trip and continues to the site of the operation. Depending on the operation, further carrying may be necessary while the operation is being recorded. After the operation is recorded, the equipment must be carried back to the vehicle.

As implied, carrying begins when the road becomes impassable or non-existent. Climbing up and down steep mountainsides, crossing down timber, and passing through or around various forms of undergrowth are commonly necessary if useful pictures are to be taken. Ground surface and log surfaces are often slippery and uneven. To say the least, walking conditions encountered are seldom ideal.

Anyone experienced in hiking with a load under adverse conditions will quickly recognize the need to minimize the load. It is to this end that the recommended improvement "reduce weight" is directed. Equipment weights listed on page 37 may be used as a reference (it should be revised as weight reductions are contrived) for determining if new

concepts do result in reduced weight.

6. Improve flexibility:

The ideal in flexibility would be a single camera set-up that was best for recording all types of film data under all conditions encountered for all logging operations. It is not known now how closely this ideal can be approached, even if cost were no consideration.

7. Extend operational limits:

The camera and equipment impose operational limits such as footage available on a roll of film, camera spring capacity, battery life (intervalometer power supply), fields of view, and others. Such factors place limits on data gathering capabilities of the camera. When these limits are too restrictive, either the data requirements must be revised, or camera and equipment modifications become necessary.

8. Improve resistance to weather conditions:

If data is to be gathered under all weather conditions that permit logging operations to continue, it may be necessary to provide moisture protection and improve the cold weather operation of the equipment. (The major cold weather problem noted to date is a significant reduction in dry-cell battery life.)

9. Improve durability and ruggedness:

The camera and equipment are in constant danger of being dropped or bumped against the various objects to be found in

a logging environment (logs, trees, rocks, ground, etc.), and less frequently are in danger of being struck by falling and flying objects. The camera and equipment must be rugged enough to take the abuse to which it will be subjected, or else allowances must be made for extensive damages that are likely to occur in time.

A CLOSING NOTE ON EQUIPMENT MODIFICATIONS:

Changes that result in improvements to time lapse cameras and equipment considering certain measures of utility are sometimes accompanied by unfavorable effects when other measures are considered. For example, using a smaller battery in the intervalometer can result in reduced weight and reduced bulk, but it will also tighten operational limits due to its shorter life. When changes are contemplated, all of the resultant effects should be considered and balanced against each other.

CASE STUDY: A MODIFICATION RECOMMENDATION

Proposed modification: eliminate the clock

The clock arm assembly and clock contribute to time lapse equipment awkwardness, bulk, weight, and limitation of flexibility. Although the clock's intended purpose is to present time values to be recorded on film, the pictures of the clock are not dependable.

The success of recording time values on film depends upon clock illumination, focus setting of the camera lens, and

positions of the clock. It should also be noted that when the clock is photographed, regardless of success, the field of view available for operation recording is reduced.

CLOCK ILLUMINATION:

If the clock is shaded and the operation to be recorded is not shaded, a photograph of the clock face may not be clear enough to be read (assuming, of course, that exposure is set to properly photograph the operation). This has occurred several times in the author's experience.

FOCUS SETTING OF CAMERA LENS:

Proper focusing of both clock and operation requires an adequate depth of field. An adequate depth of field is not always available. In the case of the time lapse equipment being studied, the clock face is 2.25 feet from the film plane of the camera. Table V is a chart of the maximum distances in focus when the minimum distance in focus is 2.25 feet. These values are given for the three lenses available to this study for several lens openings.

The lens and the camera-to-subject distance establish the field size. Using the maximum distance in focus when the minimum distance in focus is 2.25 feet, the corresponding maximum field size in focus can be determined. Table VI shows the maximum field sizes in focus when the minimum distance in focus is 2.25 feet for several possible lens openings of each of the three lenses used in this study.

TABLE V
MAXIMUM DISTANCE IN FOCUS (FEET)
WHEN THE MINIMUM DISTANCE IN FOCUS IS 2.25 FEET*

Lens Opening	15mm Lens	25mm Lens	63mm Lens
1.9		< 4	
2			< 3
2.5	< 4		
2.8	< 4	< 4	< 3
4	< 8	< 4	< 3
5.6	< 13	< 4	< 3
8	> 104	< 5	< 3
11	∞	< 8	< 3
16	∞	< 15	< 3
22	∞	∞	< 3

*Maximum distance in focus when the clock, at a distance of 2.25 feet, is the minimum distance in focus. Values in the table are based on references 14,p.8-10 (15mm); 15,p.22-26 (25mm); and 12,p.10-13 (63mm).

TABLE VI
MAXIMUM FIELD SIZE IN FOCUS
WHEN THE MINIMUM DISTANCE IN FOCUS IS 2.25 FEET*

Lens Opening	15mm Lens width'x height'	25mm Lens width'x height'	63mm Lens width'x height'
1.9		< 2 x 2	
2			< 1 x 1
2.5	< 3 x 2		
2.8	< 3 x 2	< 2 x 2	< 1 x 1
4	< 6 x 4	< 2 x 2	< 1 x 1
5.6	< 9 x 7	< 2 x 2	< 1 x 1
8	> 70 x 50	< 2 x 2	< 1 x 1
11	∞	< 4 x 3	< 1 x 1
16	∞	< 7 x 5	< 1 x 1
22	∞	∞	< 1 x 1

*Maximum field size in focus when the clock, at a distance of 2.25 feet, is the minimum distance in focus.

The information in Table VI suggests the "in focus" field size available when the clock is in focus will be inadequate for logging study at most lens openings of the 25mm and 63mm lenses. The field size available with the 15mm lens will seldom be adequate at lens openings of f/2.5, 2.8, and 4; occassionally adequate at f/5.6; and generally adequate at f/8, 11, 16, and 22.

Proper focusing is thus found to be impossible for practical application of the 25mm and 63mm lenses and possible for only part of the lens opening range of the 15mm lens.

POSITION OF THE CLOCK:

To be photographed, the clock must be within the field of view of the camera's picture taking lens. It should not, however, be positioned any closer to the center of the picture than is necessary. This is because the clock eliminates part of the field of view available for recording details of the operation, and it is desirable to minimize the area blocked by the clock. This reasoning is illustrated in figure 7 for a 15mm lens.

The clock, when properly positioned (i.e. in the lowest position which will permit the entire clock to be photographed), blocks the center strip of the field of view from the bottom up to approximately twenty-five percent of the total field of view height. It is possible, by improper adjustment, to block the center strip as much as forty-five

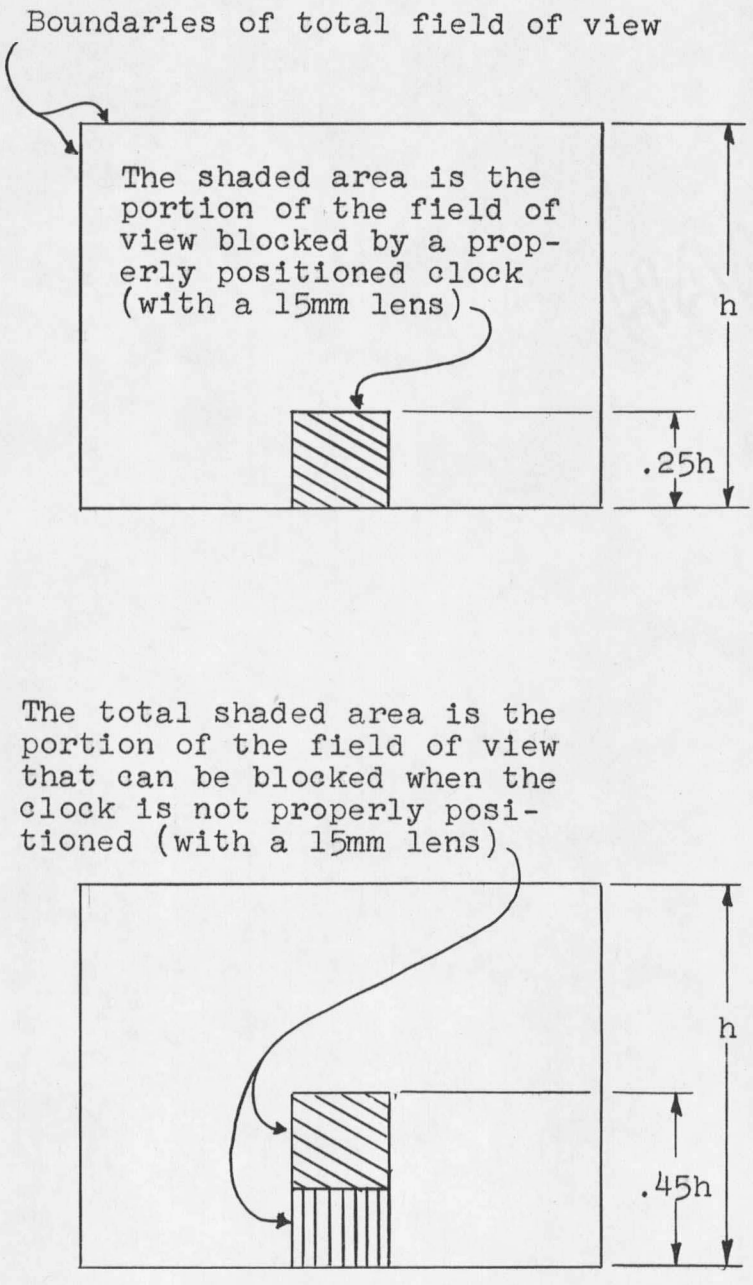


Figure 7: This shows the portion of the field of view that is blocked when the clock is properly and improperly positioned. This field of view is available with a 15mm lens.

percent of the total field of view height. Blocking more than 45% is not possible due to adjustment travel limitations of the clock arm. (The figures in this paragraph assume use of the 15mm lens.)

The portion of the field of view required by a properly positioned clock is larger for the 25mm lens than for the 15mm lens, and in the case of the 63mm lens the clock takes almost the entire field of view. Portions of the field of view required for the clock when properly positioned are illustrated in figure 8.

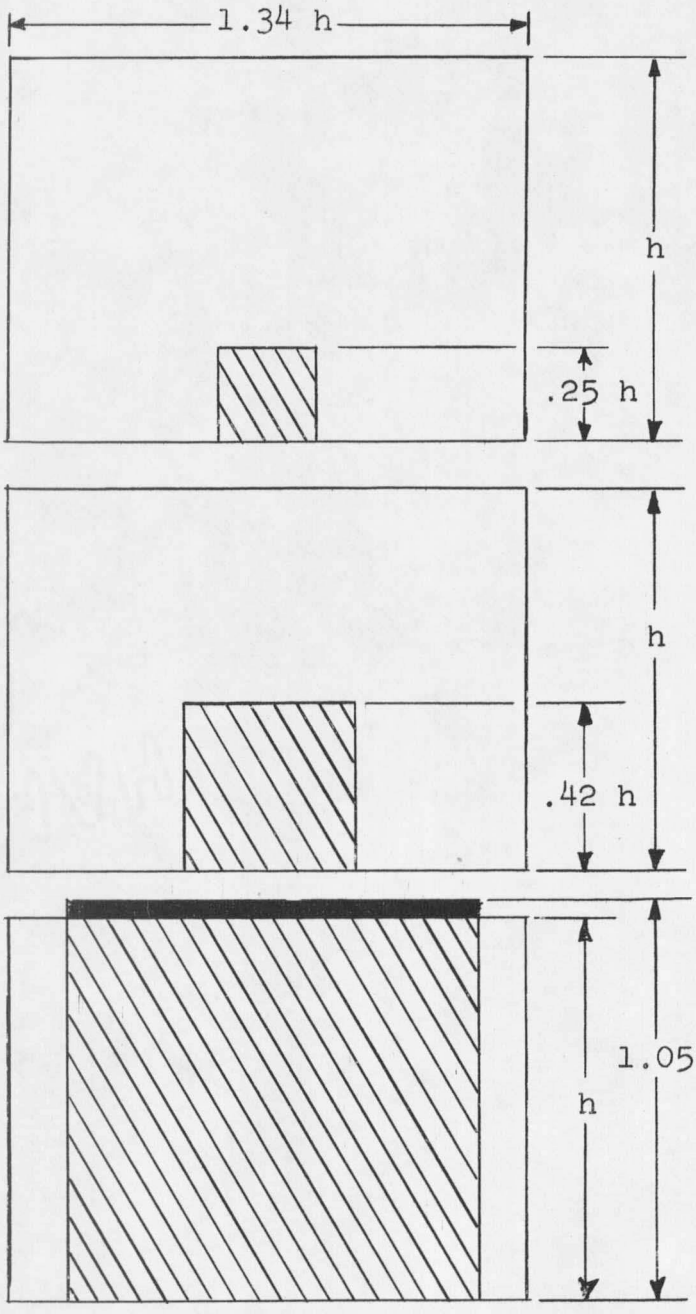
SUMMARY OF FACTORS AFFECTING PICTURES OF CLOCK:

The factors affecting success of recording time values when pictures are concurrently taken of the clock and operation, and conclusions pertinent to these factors are summarized in Table VII. The information is based on the use of the camera and clock available for this study.

AN ALTERNATIVE TO THE CLOCK:

Time lapse pictures for memomotion study commonly do not include a clock image. (18,p.303) Time values related to the operation are instead ascertained through the use of frame intervals of a constant, known time value. Any desired elapsed time is then determined by counting frames and multiplying by the appropriate time per frame.

Since the intervalometer used in this study has a continuous range of time values, and accidental change of the



15mm lens

25mm lens

63mm lens

The blackened area is part of the clock that is actually outside the field of view of the 63mm lens.

Figure 8: Shown above are the portions of the available field of view required by the clock (shaded area) for each lens used in this study.

TABLE VII
SUMMARY OF FACTORS AFFECTING CLOCK SUCCESS

Lens Size / Factors affecting pictures of clock and operation	15mm	25mm	63mm
Illumination of clock	Not dependable	Not dependable	Not dependable
Proper focus for clock and operation	Possible for lens openings of f/8-22	Impossible for most known situations	Impossible for known applications
Clock position	Requires careful attention	Requires careful attention	No acceptable position
Portion* of field of view required by clock	4.67%	13.2%	78%
Clock evaluation (currently known applications in logging study)	Sometimes usable but not dependable	Useless	Useless

*This is the percentage of the area of view required by the clock. The detrimental effect is greater than this figure indicates due to the position of the clock.

interval control is difficult to avoid, modification of the control is recommended to provide assurance that the frame interval will be easily maintained constant at the desired time value. Such a control, for example, could be achieved by using a constant speed motor with a succession of predetermined film drive speeds obtained through a combination of gears.

CONCLUSIONS OF THE CASE STUDY:

1. Clock inadequate for intended purpose.
2. Clock and arm detrimental to mobility.
3. Constant value frame interval of known value will record elapsed times more effectively under typical logging conditions.

RECOMMENDATIONS BASED ON CASE STUDY:

1. Modify intervalometer to provide known, constant frame interval of desired value.
2. Eliminate clock and clock arm.

CHAPTER V
FILM CONSIDERATIONS: THE MOVIE CAMERA

THE LOGGING WORKPLACE

The usual logging operations take place outdoors, during the hours of daylight. Under these conditions natural light is normally sufficient to permit pictures to be taken without use of artificial light.

Intensity of the natural light, though sufficient in itself for the taking of pictures, covers a wide range. Large and frequent variation is most commonly caused by cloud movement and movement of the operation.

Camera-to-subject distances, like light intensities, are subject to variation. This variation is usually the result of movement of the operation; but sometimes it occurs when the operation stays in a particular location, and the camera is moved. Moving away from potential extreme hazard areas or to better vantage points are common reasons for moving the camera when the operation is stationary.

In addition to variation of camera-to-subject distances, circumstances may require a range of camera-to-subject distances to be simultaneously in focus. For example, pictures have been taken where a clock at a distance of 2.25 feet is photographed simultaneously with a loading operation. The camera to loading operation distance depends, of course, on the operation itself, the terrain, and the obstructions. Considering a possible situation requiring a broadside view

of the log-carrying portion of the truck and trailer (assume thirty-five feet, which allows for thirty three-foot logs plus two feet of lengthwise scatter) plus space between the log load and loader (say ten feet) plus the loader itself (assume fifteen feet) we could expect a total field of view requirement of sixty feet. With a 15mm lens, the camera-to-loading operation distance would need to be at least one hundred feet. Thus, in this case, depth of field requirements would call for camera-to-subject distances of 2.25 feet and one hundred feet to be simultaneously in focus.

Focal distance requirements must be considered in film selection because film speed is one of the factors which establishes the available depth of field. That is

depth of field varies with lens opening;

lens opening varies with film speed;

therefore

depth of field varies with film speed.

It is important to note that changes in light intensity and camera-to-subject distances occur quickly and may occur frequently. Experience on the part of the author indicates that these changes create the most serious problems in maintaining continuous proper adjustment of the camera during filming of an operation.

THE NOVICE PHOTOGRAPHER: TYPICAL DATA GATHERER

The people who have gathered data in connection with this study have had, at best, very limited experience with movie and time lapse photography. Some, including the author, had no previous experience. This means that light measurements and camera adjustments are not second nature to the typical data gatherer. Simplest possible measurement techniques and camera adjustments and maximum possible margin for error are desirable.

THE CAMERAS USED IN THIS STUDY

For proper film exposure, the cameras used in this study require two adjustments to match film, light conditions,(6) and camera-to-subject distances. These adjustments are the lens opening and the focus. Both are set manually.

REQUIREMENTS OF THE FINISHED FILM

Films intended only for the recording of specific data will be acceptable if this data is visible on a projection of the finished film. Deviations from correct exposure and focus can be tolerated if these deviations are not large enough to obscure the required data.

Films intended for presentation of ideas and recommendations may require more accurate exposure than films intended only for recording specific data. The intended audience and desired film impact should be considered in establishing finished film quality requirements.

From the engineer's point of view, the information recorded on a film is of far greater importance than the artistic quality. This applies regardless of whether film is intended strictly as a data record or for both a record and presentation of ideas and recommendations.

DESIRED FILM CHARACTERISTICS

1) Films for logging study should provide good detail and contrast. 2) Wide exposure latitude is desired to allow some tolerance in exposure setting. 3) Duplication should be possible with little or no loss of detail or contrast.

THE CONCEPT OF ONE ALL-PURPOSE FILM

One all-purpose film for photography of logging operations is desirable from the standpoint of simplifying data gathering techniques. Disadvantages do not appear too critical on the basis of experience; however, no detailed evaluation of possible disadvantages has been attempted to date.

Some advantages of using one film for all logging studies are the following:

1. Simplifies photographer training,
2. Avoids confusion as to what film is in camera,
3. Photographer can more readily become proficient with proper exposure,
4. Light meter scales could conceivably be marked to show proper lens openings directly for all time lapse photography,

5. Avoids confusion when exposed films are delivered for processing,
6. Minimizes film inventory requirements.

FILM SELECTION

Selection of the best film for all around use or selection of several films to best match each situation encountered in the study of logging operations are each beyond the scope of this study. Instead, films used to date have been somewhat arbitrarily selected based upon available recommendations from the manufacturer.

The decision to avoid a more intense approach to film selection at this time is based on the following:

1. Films presently in use are adequate for current needs,
2. Required magnitude of a study that could yield conclusive results due to a) large number of films available, b) wide variations of filming conditions, and c) factors other than film affecting end results of photography.

The list which follows gives some factors that need to be considered when film is selected:

1. Conditions film is designed for,
2. Anticipated field conditions,
3. Film speed,
4. Grain size,

5. Exposure latitude,
6. Availablity of film,
7. Developing time,
8. Clarity of developed film,
9. Duplicating quality,
10. Filter requirements,
11. Color or black and white,
12. Film and developing cost.

Useful comparisons for reasonably intelligent choice can be made for most of the factors to be considered when film is selected even without intensive research. This is the approach that has been used in this study.

Films that have been used with acceptable results for current needs are the following:

1. Kodachrome II (color),
2. Ectachrome ER (color),
3. Kodak Plus X (black and white),
4. Agfachrome (color),
5. Anscochrome (color).

All are outdoor daylight films. Other films may be acceptable but have not yet been tried in this study.

CHAPTER VI
ESTABLISHING TIME LAPSE INTERVALS

Motion pictures are taken at unsually slow speeds for time lapse photography--but how slow? According to the originator of memomotion study, "Sixty frames per minute (one per second) and one hundred frames per minute are the speeds most commonly used." Literature and experience indicate other speeds can also be successfully used.

Many authors have indicated the lengths of frame intervals they have used for time lapse photography. A. A. Timmins discusses the selection of frame intervals when he says, (23,p.814)

> "...a suitable frame interval must be selected. This depends on the information required and is influenced by:
>
> "Amount of detail required--In general the greater the interval between pictures the less the detail picked up.
>
> "Cycle time of the work being examined--If the different parts of the task occupy short periods of time, short intervals between frames become desirable.
>
> "Accuracy of the time measurement required--This is related to the work cycle time but short intervals of half a second obviously record to greater accuracy than four second intervals.
>
> "Floor are to be covered by the examination--If it is necessary to film at some distance from the work place, very short intervals are generally unprofitable because the detail is naturally poorer than in 'close up' situations. In such studies the broad pattern of movement is usually more important than detail."

Frame intervals used or suggested for use in other industries where time lapse photography has been applied are discussed in the next section. Each of these intervals is

presented separately starting with the shortest interval and proceeding to the longest.

INTERVALS USED IN OTHER INDUSTRIES

Several different frame intervals have been used or suggested for use in other industries. The following intervals have been cited by other authors as being useful for work analysis:

.12 seconds = .002 minutes,
.125 seconds,
.5 seconds,
.6 seconds = .01 minutes,
1.0 second,
1.2 seconds = .02 minutes,
2.0 seconds,
2.4 seconds = .04 minutes,
4.0 seconds,
8.0 seconds.

Discussion of each of these frame intervals follows.

.12 SECONDS:

This frame interval is equivalent to 500 frames per minute. It can be used where slightly more detail than that obtained at one frame per second or 100 frames per minute is needed. (4,Sec.13,p.9)

.125 SECONDS:

This frame interval is equivalent to 8 frames per second or 480 per minute. Like 500 frames per minute (frame interval of .12 seconds) it can be used where slightly more detail than that obtained at one frame per second or 100 frames per minute is needed. It has no particular advantage (4,Sec.18,p.9)

except that it uses 50% as much film as required by usual (16 frame per second) photography.

.5 SECONDS:

This frame interval is equivalent to 2 frames per second. Half-second frame intervals have been used in a technique where the camera is operated intermittently. The camera, by this technique, is operated at half-second intervals to record 2 or 3 cycles. It is then stopped for a random period of time. This operation of the camera at half-second frame intervals and then stopping the camera for a random period of time is then repeated for whatever number of times the film will permit. (23,p.818) This procedure could be "work sampling" at its best.

.6 SECONDS (OR .01 MINUTES):

This frame interval is equivalent to 100 frames per minute. It is one of the two most commonly used speeds. (18,p.301) "The speed of one-hundred frames per minute allows the timing of any element with the same precision as the decimal minute stop watch." (19,p.196) In describing the accuracy of one-hundred frames per minute L. C. Dick says, "This provides great enough accuracy in developing standard data for most of our operations, when you consider that it is difficult for an experienced time study engineer to read a stop watch and accurately record time values smaller than 0.03 to 0.04 minute."(7,p.29)

1.0 SECOND:

A one-second frame interval (or a speed of one frame per second) appeared in more of the references cited in this study than any other memomotion interval. Mundel calls it one of the two most commonly used speeds. (18,p.301) Niebel has standardized on this speed. (19,p.196)

According to Niebel, one frame per second gives measurement of elapsed elements with adequate precision for establishing standards and still gives significant economy over regular camera speeds. (19,p.196)

1.2 SECONDS (OR .02 MINUTES):

This frame interval is equivalent to 50 frames per minute or 20 times the usual micromotion film interval. It has been used in a form of work sampling. (2,p.53) The camera was operated at randomly spaced times, and each time 20 to 25 frames were exposed at a .02 minute interval. Only the tenth frame was used from each burst. The extra frames helped to define the control frame. The camera was controlled by a program timer set up to turn the camera on at random times.

2.0 SECONDS:

This interval has been recommended for use, "When the interest lies chiefly in the incidence of non-periodic occurrences or in the broader aspects such as machine utilization, rather than sequence detail...." (23,p.815)

2.4 SECONDS (OR .04 MINUTES):

This frame interval would be used much the same as a frame interval of two seconds. The major difference is that time value calculations can more readily be made in terms of minutes using this interval.

4.0 SECONDS:

Again, as was the case with the two-second interval, the four-second interval has been recommended for use, "When the interest lies chiefly in the incidence of non-periodic occurrences or in the broader aspects such as machine utilization, rather than sequence detail...." (23,p.815) The advantage of the two-second interval is real, but it is worth noting that, "When projected at 16 frames per second even the four-second interval pictures show sufficient continuity to yield useful information." (23,p.814)

8.0 SECONDS:

An eight-second interval has been used to study delays of industrial trucks in congested areas. The eight-second interval permitted an eight-hour study to be made using only 100 feet of film. (20,p.76)

Ten different frame intervals have been found in literature examined by the author describing use of time lapse photography in industries other than logging. Based on these references figure 9 summarizes the usage and "suggested for use" frequencies for each frame interval.

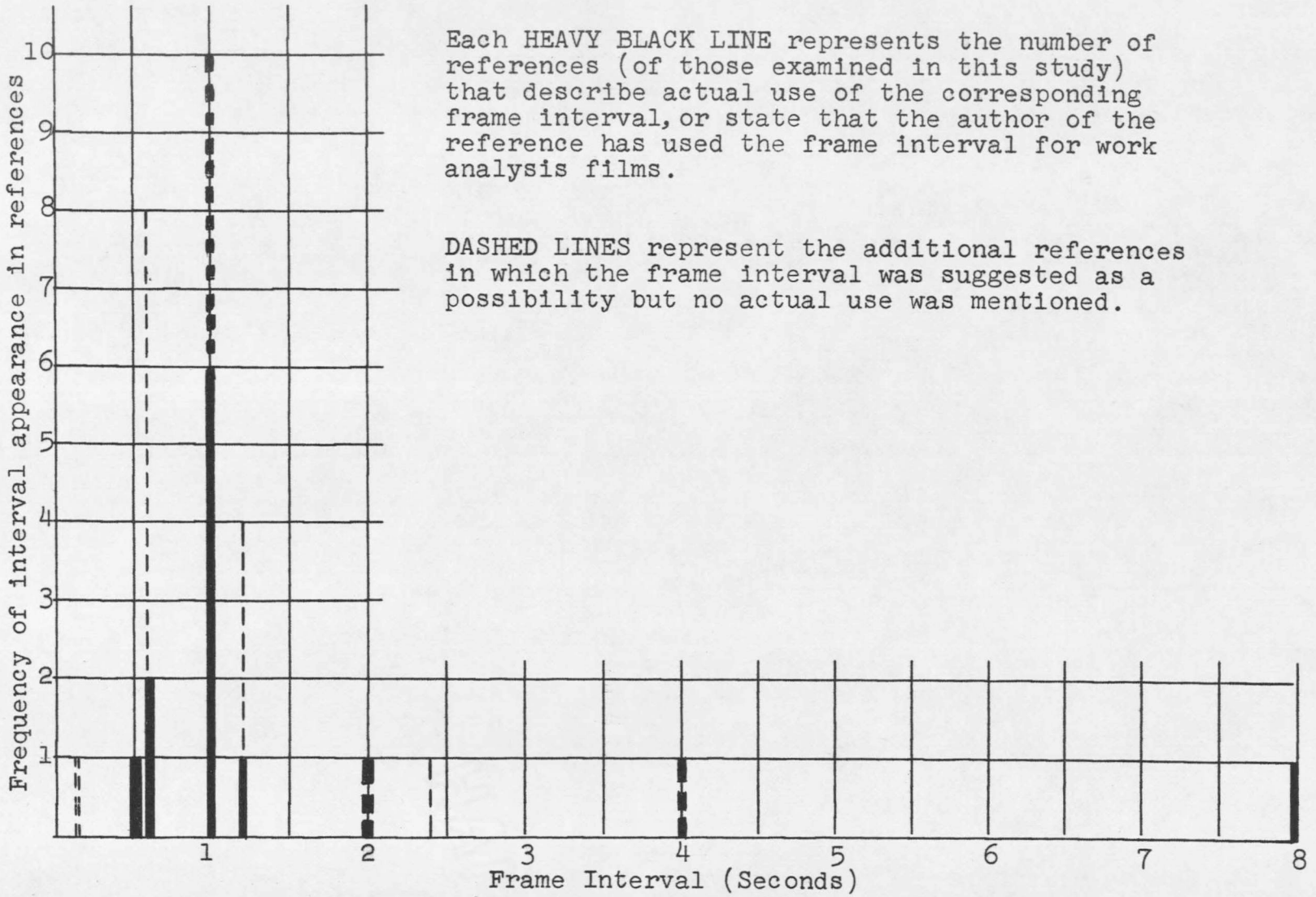


Figure 9: Frequency diagram of frame intervals used in other industries for time lapse photography.

FACTORS INFLUENCING INTERVAL SELECTION

The preceding section indicates there are several different intervals in use for time lapse photography of industrial operations. Several factors influence interval selection. Some favor long intervals while others favor short intervals.

The following factors influence interval selection:

1. Detail required,
2. Accuracy required,
3. Duration of photographic study,
4. Costs,
5. Interruptions,
6. Time units.

1. Detail:

The amount of detail recorded on film is affected by the frame interval. "In general the greater the interval between pictures the less the detail picked up." (23,p.814) This, of course, refers to task details and not picture details.

2. Accuracy:

The accuracy of time values measured on film depends in part on the frame interval selected. Elapsed time for an element is estimated by counting the number of consecutive frames in which the element appears and multiplying this number by the frame interval. The error of estimated elapsed time for an element can approach ± 1 frame interval as a

maximum. This is illustrated in figure 10 for situations in which the estimated elapsed time is two times the frame interval.

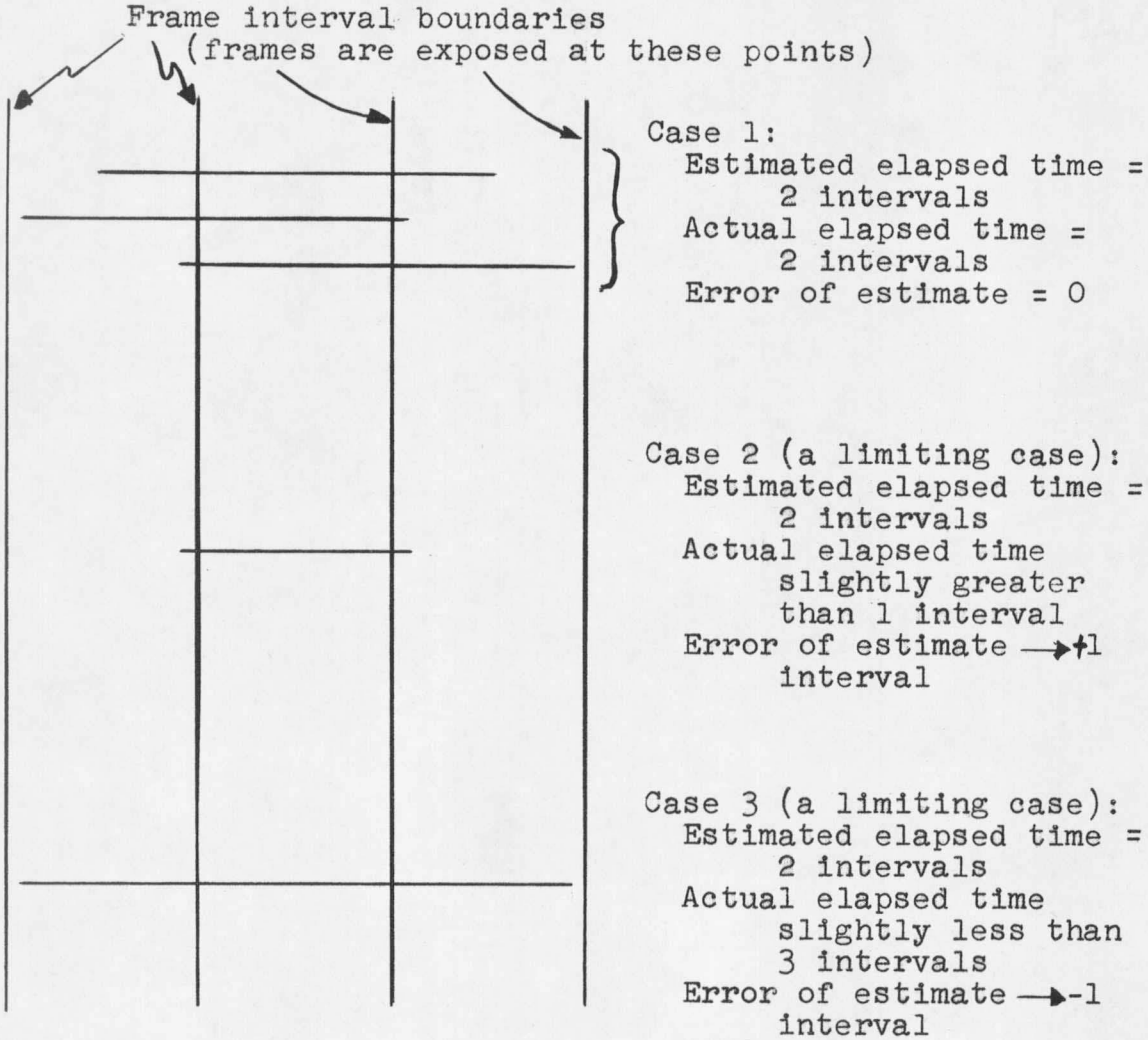


Figure 10: This figure illustrates the statement that the error of estimated elapsed time can approach ±1 frame interval as a maximum. (→ is the symbol for approaches as a limit.)

3. Duration of photographic study:

The importance of this factor to interval selection can be summarized in a single statement, "More operation time can be recorded per foot of film if a longer frame interval is used."

4. Costs:

Film costs are reduced by increasing frame intervals if the duration of photographic study remains unchanged. Film analysis cost per frame may increase due to a loss of continuity if intervals become too long, but the cost per unit of operation time should be reduced.

5. Interruptions:

Interruptions are more frequent for short intervals. The camera spring must be rewound and film replaced sooner if frame intervals are short. If frame intervals are great enough, the camera can be rewound between frames.

6. Time units:

The time units which will be used to express the final results should be considered in interval selection to minimize or eliminate time value conversion. For example, expressing time values in minutes is simple if each frame represents .01 minutes. Expressing time values in minutes is more difficult if each frame represents one second and unnecessarily difficult if each frame represents 0.8 seconds.

INTERVAL SELECTION

Interval selection consists of a balancing of the factors favoring long intervals and the factors favoring short intervals and adjusting to a position permitting easy calculation of elapsed times in the desired time units. The general idea of this statement is illustreated in figure 11.

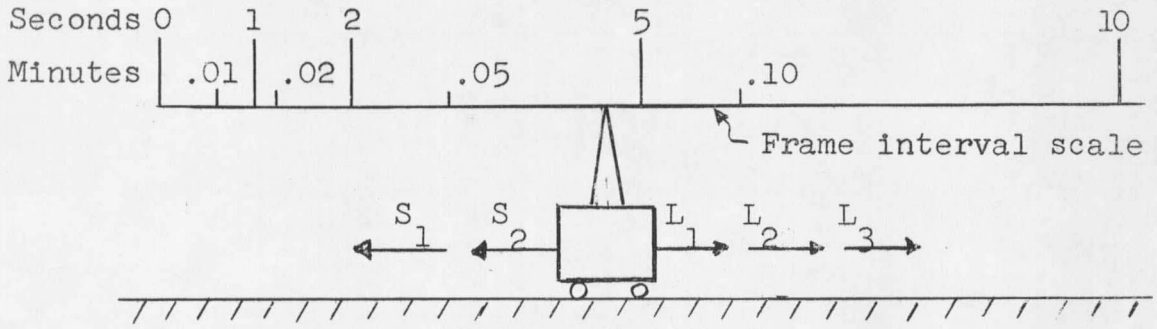


Figure 11: Interval Selection Diagram.

Forces in the diagram:

S_1 = need for greater detail (this demand becomes smaller as interval indicator approaches zero)

S_2 = need for greater accuracy (this demand becomes smaller as interval indicator approaches zero)

L_1 = cost reduction

L_2 = long duration of study

L_3 = interruption reduction

The frame interval scale is marked at values which provide convenient time calculations in the two time units--minutes

and seconds. Further explanation of the diagram may be found in the text of this chapter.

A single frame interval has not been selected as the best for all logging studies. The appropriate interval depends upon the operation itself and the purpose of the study. An interval of one second has been adequate for most logging studies made to date.

Frame interval selection may at some time warrant extensive study. Until a more precise method is available, the following concepts are intended as a guide to selection of an appropriate frame interval.

As a starting point, potential intervals can be limited to selected decimal parts of a minute and selected integer values of seconds. Potential intervals could likewise include selected decimal parts of an hour, day, or other time value.

Limiting the potential intervals in this manner can aid in selecting a time value which permits simple conversion from the number of frames to a corresponding elapsed time for a continuous series of frames. The conversions are, in fact, simple enough to permit strictly mental calculations.

The mental conversion from a one-second interval to elapsed time in seconds is obviously n frames = n seconds. Conversion from a .05 minute interval to elapsed time in minutes can be accomplished in the following manner: number of minutes = $\frac{(0.1)(\text{number of frames})}{2}$ or, in other words,

shift the decimal point of the number of frames one place to the left and divide the result by 2. Similar methods are possible for the other intervals marked on the frame interval scale.

As the selection of intervals becomes more refined and as processing of data becomes automated, simplicity of conversion from number of frames to elapsed time may lose importance. At present, such simple conversions are useful, and the inexact nature of interval selection permits enough shifting of the "frame interval value" to allow choice among values specifically marked on the frame interval scale.

The demand or force S_1 in the diagram represents the need for greater detail of the recorded activity. This detail becomes more complete as the "frame interval" is reduced. As the interval is shortened, the detail is increased; consequently the need, being at least partially satisfied, becomes less intense. The point at which this need or demand becomes zero depends upon the nature of the operation and the purpose of the film. Demands favoring longer intervals may not permit this need to become completely satisfied.

The range of available time values can roughly be divided into three categories applicable to most operations as indicated by the following chart.

Frame Interval (seconds)	Category Description
0 - 1.5	Establish standard times
1.5 - 5	Studies of broad aspects such as machine utilization
5 - 10	Studies of delays and fixed interval work sampling

This chart is, at best, broad and approximate.

The demand force S_2 represents the need for greater accuracy. The point at which $S_2 = 0$ can be calculated if accuracy requirements are known. For example, consider a situation where the maximum permissible error is five percent of the average time of the smallest element and the average time of the smallest element is twenty seconds. In this case the maximum permissible error is one second. An interval of one second will insure that the error in measuring the element will not exceed one second.

The demand force L_1 represents a reduction in the cost to record and analyze a stated period of operation time corresponding to an increased length of frame interval. The cost for the following items is reduced: 1) film and developing costs, 2) replacement battery costs, and 3) film analysis costs. Other costs of data gathering for the stated period will remain essentially unchanged.

Film and developing cost per frame will be a constant regardless of the frame interval chosen. Battery cost per frame is not expected to vary significantly as a result of changing the frame interval. Analysis cost per frame may be greater for larger frame intervals due to loss of continuity, but how much larger, if any, has not been established. Analysis time has run as high as thirty seconds per average frame for simply determining the activity classification of each frame for films taken at ten-second intervals. For analysis requiring 30 seconds per frame and assuming analysis cost of $4.00 per hour, the cost of analyzing a 100 foot roll of film would be $133.00.

To illustrate a cost comparison of a study permitting a choice between a half-second or a one-second interval, the following situation will be considered:

Study two hours of the operation:

a) Transportation cost = $20.00,

b) Film and development @ $10.00 per 100 feet of film,

c) Two men for 6 hours each @ $4.00 per hour for filming operation, $48.00,

d) Analysis cost @ $133.00 per 100 feet of film (assuming analysis time of thirty seconds per average frame),

e) Equipment depreciation @ $.50 per hour,

f) Battery cost @ $1.00 per 100 feet of film exposed at time lapse intervals.

To find the <u>difference in cost</u> between the half-second and one-second interval we need consider only film and development cost, analysis cost, and battery cost. Other costs will remain unchanged for this study. Thus we have:

b) Film and development	$ 10.00 per 100 feet
d) Analysis	133.00 per 100 feet
f) Battery	1.00 per 100 feet

Total of costs that depend on interval = $144.00 per 100 feet.

Using one-half second interval:

$$C = 2 \text{ hrs} \times \frac{2 \text{ frames}}{\text{sec}} \times \frac{\$144.00}{100 \text{ ft.}} \times \frac{100 \text{ ft.}}{4000 \text{ frames}} \times \frac{3600 \text{ sec}}{\text{hr}} =$$

$518.00.

Using one-second interval:

$$C_1 = 2 \text{ hrs} \times \frac{1 \text{ frame}}{\text{sec}} \times \frac{\$144.00}{100 \text{ ft.}} \times \frac{100 \text{ ft.}}{4000 \text{ frames}} \times \frac{3600 \text{ sec}}{\text{hr}} =$$

$259.00.

This two hour study then costs $259.00 less if a one-second interval is used instead of a one-half second interval.

CHAPTER VII
SIZE AND NUMBER OF TIME LAPSE BURSTS

A time lapse "burst," as used here, means a series of consecutive frames exposed without interruption of the fixed interval. For example, consider a case where the interval timer is set for one second, aimed at the subject, and turned on until five cycles of the subject operation are recorded. The camera is then turned off. This represents one time lapse burst. Any forced interruption, such as stopping to wind the camera spring, change film, or replace the battery, also terminates a burst.

A time lapse burst can therefore be any selected length that does not go beyond any forced interruption.

The most common forced interruptions are those imposed by the camera, film, and accessory equipment. Table IV, page 48, lists the times available before occurrences of interruptions due to the limitations of film and camera spring capacities.

It is seen from Table IV that at a one-second interval, a period of 26 minutes, 40 seconds is available without interruption due to camera spring capacity limitations. (Other interruptions such as battery failure may occur sooner if proper precautions are not taken; many of these, however, are preventable.)

With these forced limitations imposed by the time lapse equipment in mind, other factors pertinent to the selection

of size and number of time lapse bursts may be considered.

Intuitively, it is readily apparent that the objective or the type of study to be made is the major factor in establishing the size and number of time lapse bursts. The remainder of the discussion on this subject will consider two of the most useful application of time lapse photography, namely 1) methods review, and 2) time study.

1. Methods review:

Methods review, as used here, is intended to mean a relatively brief look at pattern and sequence of operational events of an existing operation. Some rough estimate of cycle times and proportions of time occupied by various parts of the task may be possible, but a defined statistical reliability is not intended.

Since a defined statistical reliability is not intended, careful definition of parameters and random procedures in sampling can largely be disregarded. Sample size can be minimized also.

In studies having at least some similarity to the "methods review" indicated here, Timmins has suggested time lapse pictures covering six to eight cycles of the operation. (23,p.815) The operation should be recorded in complete cycles, but the six or eight required cycles may be recorded on one or more time lapse bursts.

The reader is warned to avoid using this type of study beyond its intended purpose. Considering the many variables in logging, danger of inaccurate predictions based on the "methods review" is extremely likely.

2. Time study:

Mundel points out that memomotion offers a vehicle for time study. (18,p.303) Motion patterns and time values are recorded by the film. Data is recorded for the same purpose as when a stop watch is used.

Time study is defined by Mundel as "a procedure for determining the amount of time required, under certain standard conditions[1] of measurement, for tasks involving some human activity." (18,p.325) Assuming, then, that certain standard conditions of measurement can be established for each selected logging operation (this may be an unrealistic assumption), data requirements can be determined in a manner very similar to this same determination when stop watch time study is used.

Data requirements for time study are commonly measured in terms of the number of operation cycles to be studied. To determine film requirements it is then necessary to multiply the number of cycles to be studied by an estimate of the time

---

[1] Emphasis supplied by the present author.

per cycle and divide this product by the frame interval. The answer is in terms of an estimate of the number of frames that will be required to complete the study.

Niebel cautions, "The number of cycles to be studied to arrive at an equitable standard is a subject that has caused considerable discussion among time study analysts. Since the activity of the job, as well as its cycle time, directly influences the number of cycles that can be studied from an economic standpoint, one cannot be completely governed by the sound statistical practice that demands a certain size sample based on the dispersion of the individual element readings." (19,p.253)

Some industrial firms have established guides to be used in determining a recommended number of cycles to be time studied. The guides relate N, the number of cycles recommended for study, to functions of other pertinent factors. The following are examples:

$$N = f\ [\text{cycle time}],$$

$$N = f\ [\text{cycle time, annual activity}],$$

$$N = f\ [\text{cycle time, annual activity, dispersion}].$$

None of the examples allows for changing working conditions, which obviously presupposes a standardized workplace.

Where cycle times vary appreciably due to changing work conditions, it may be appropriate to establish several sets of "standard conditions" and use one of the guides to determine a

value of N cycles to be used for each set of standard conditions.

To illustrate establishment of a set of standard conditions, the following might describe one set of standard conditions for felling:

1. Saw, chain, gasoline 26 cycle engine, 5 to 6 cubic displacement,
2. Tree diameter: 14 to 16 inches,
3. Slope: 10% to 20%,
4. Distance from previous tree: 10 feet to 20 feet.

Other factors may also be expected to relate to cycle time and could be included in the list. Other sets of standard conditions can be set up to include cycles that will not fit this set. Factor ranges within a set of "standard conditions" can be increased or decreased to fit the accuracy requirements.

With the sets of "standard conditions" appropriately established, a guide such as the following one may be used: (19,p.253)

Cycle Time in Minutes	Recommended Number of Cycles
.10	200
.25	100
.50	60
.75	40
1.00	30
2.00	20
4.00- 5.00	15
5.00-10.00	10
10.00-20.00	8
20.00-40.00	5
40.00-above	3

To illustrate use of this approach, consider a situation involving twenty sets of "standard conditions" with cycle time groupings as follows:

Set Numbers	Cycle Time Category
1 - 5	.75
6 - 15	1.00
16 - 20	2.00

Determine minimum possible film footage to record required number of cycles in accordance with the following guide and using the method of establishing sets of standard conditions. Assume 1 second interval.

Solution:

Set Number	Cycle Time Category	Recommended Number of Cycles	Film Footage to Record
1	.75 min.	40	45
2	.75	40	45
3	.75	40	45
4	.75	40	45
5	.75	40	45
6	1.00	30	45
7	1.00	30	45
8	1.00	30	45
9	1.00	30	45
10	1.00	30	45
11	1.00	30	45
12	1.00	30	45
13	1.00	30	45
14	1.00	30	45
15	1.00	30	45

Solution is continued on page 91.

Set Number	Cycle Time Category	Recommended Number of Cycles	Film Footage to Record
16	2.00 min.	20	60
17	2.00	20	60
18	2.00	20	60
19	2.00	20	60
20	2.00	20	60

Total film footage (minimum) = 975 feet.

If random sampling is not used in this time study (as is the case in common industrial practice) several cycles can be recorded on a single time lapse "burst." It is then merely necessary to use a large enough quantity of bursts to record the required number of cycles for each set of "standard conditions."

CHAPTER VIII
FILM AND OPERATION IDENTIFICATION

THE NEED FOR IDENTIFICATION

Early films of logging operations quickly revealed a need for some means of recording certain pertinent information in the form of short notes in addition to the information normally recorded on the film. Notes recorded on loose field sheets were not entirely satisfactory. Relating field notes to the proper films proved to be difficult, particularly since the films required two weeks for development and were out of our hands during that time. Once the films were returned, there remained the difficulty of keeping the sets of complimentary notes and films together.

An apparent solution called for the use of titles that could be filmed right along with the rest of the action. Titles could be used to identify films and operations and to record brief but important notes relative to the logging operation under study.

EARLY FILM TITLING ATTEMPTS

The first approach to film titling involved the use of chalk and a small blackboard (8" x 10") for writing the notes. The blackboard was then held in front of the camera while a few frames were exposed.

Use of the blackboard and chalk proved the value of titling. The problems of relating complimentary notes and

film strips were eliminated along with the requirement for any special efforts to keep notes and films together.

The blackboard and chalk solution did, however, leave room for improvement. The blackboard was awkward to carry, particularly in our mountainous, tree-covered studio.

Certain light conditions resulted in notes that were nearly impossible to read on the finished film. (Many of the notes came out clear; however, an example of poor results occurred on a film of an operation in very bright light for which the title board was held in the shade. The lens opening, being set for filming the operation, was so small that the shaded notes on the developed film were very faint.)

When only one man was operating the camera and preparing the titles, uncertainty existed as to whether or not the blackboard was being held in a position to be entirely photographed. Also it was necessary to guess what size of letters should be used for notes.

A more suitable method of titling was sought through experimentation. Cards of varied dimensions were inscribed with notes using assorted pens with inks of varied types and colors, and using assorted pencils with leads of varied types and colors. Letter sizes were varied in overall dimensions and in width of lines used. The various cards thus prepared were then filmed during the filming of actual logging operations.

As a result of this experiment, ordinary 3" x 5", white, lined cards ($\frac{1}{4}$ inch space between lines) were selected along with a mechanical pencil with standard size soft mark sensing lead for titling materials.

Engineering style capital letters $\frac{1}{4}$ inch in height were chosen, and the standard lines of $\frac{1}{4}$ inch spacing on the cards served well as guide lines.

The cards, pencils, and leads selected could be obtained from stationery stores. All, including extra lead, were easily carried in the field. Lead did not create the hazards of messes that ink does, nor was it affected by the extremes of ordinary outdoor temperatures.

FINAL SELECTED IDENTIFICATION TECHNIQUE

The most recent choice in film and operation identification materials differs somewhat from the use of cards described above. The three by five inch cards have been replaced by surveyors' field note books and the mechanical pencils with standard size soft mark sensing lead have been replace by wooden engineering drawing pencils with a 4H classification.

The field note book is spiral bound. The page dimensions are $4\frac{1}{2}$ inches by $7\frac{1}{4}$ inches. The pages are marked with horizontal lines spaced $\frac{1}{4}$ inch apart. Vertical lines divide the left hand page (of the opened book) in six columns. The right hand page has vertical lines spaced 1/8 inch apart.

The field book, which will fit the hip pocket of most trousers, has five major advantages over cards and maintains the favorable characteristics of the cards. The advantages are the following:

1. Notes recorded on films and other supplementary notes can easily be kept together.
2. Note book provides its own writing surface.
3. Note book is easily handled in field.
4. Note book has better moisture reistance.
5. Page surface permits use of harder pencil to obtain adequate line thickness.

As mentioned, the mechanical pencil with soft lead was replaced by a wood pencil with harder lead. The harder pencil became suitable due to the change in writing surface. Wood pencils can now be used because the harder lead will stay sharp longer than the soft lead.

A usable procedure for film and operation identification is outlined by the following steps:

1. Photograph specially marked cover of field note book.
2. Prepare title sheet of an inside page of notebook. Use $\frac{1}{4}$ inch engineering letters (capitals).
3. Photograph the title sheet.

Details of these steps follow.

1. Photograph cover of field note book:

The field note book that is being used can be identified

by lettering the cover with an ink marker. Identification marking should correspond to some filing system. One possible system would be to label field books with the photographer's name and the number of the book in a series prepared by the photographer.

2. Prepare title sheet:

The film title sheet should be prepared using $\frac{1}{4}$ inch capital engineering letters. Letters should be dark to minimize the probability of good legible pictures. Figure 12 is a sample sheet indicating minimum information that should be photographed.

3. Photograph the title sheet:

By photographing the title sheet, important identifying information is recorded. Further information can be added on succeeding pages and photographed or simply kept in the field note book.

This latest method is most easily used in the field. The black letters on white background are nearly always readable on the finished film if camera lens opening is correct for filming the operation. One man can sight through the viewfinder and at the same time reach far enough to hold the notes far enough from the camera to photograph the entire page in proper position. A suitable size of letters has now been established. Summarily, this is a practical field film titling method.

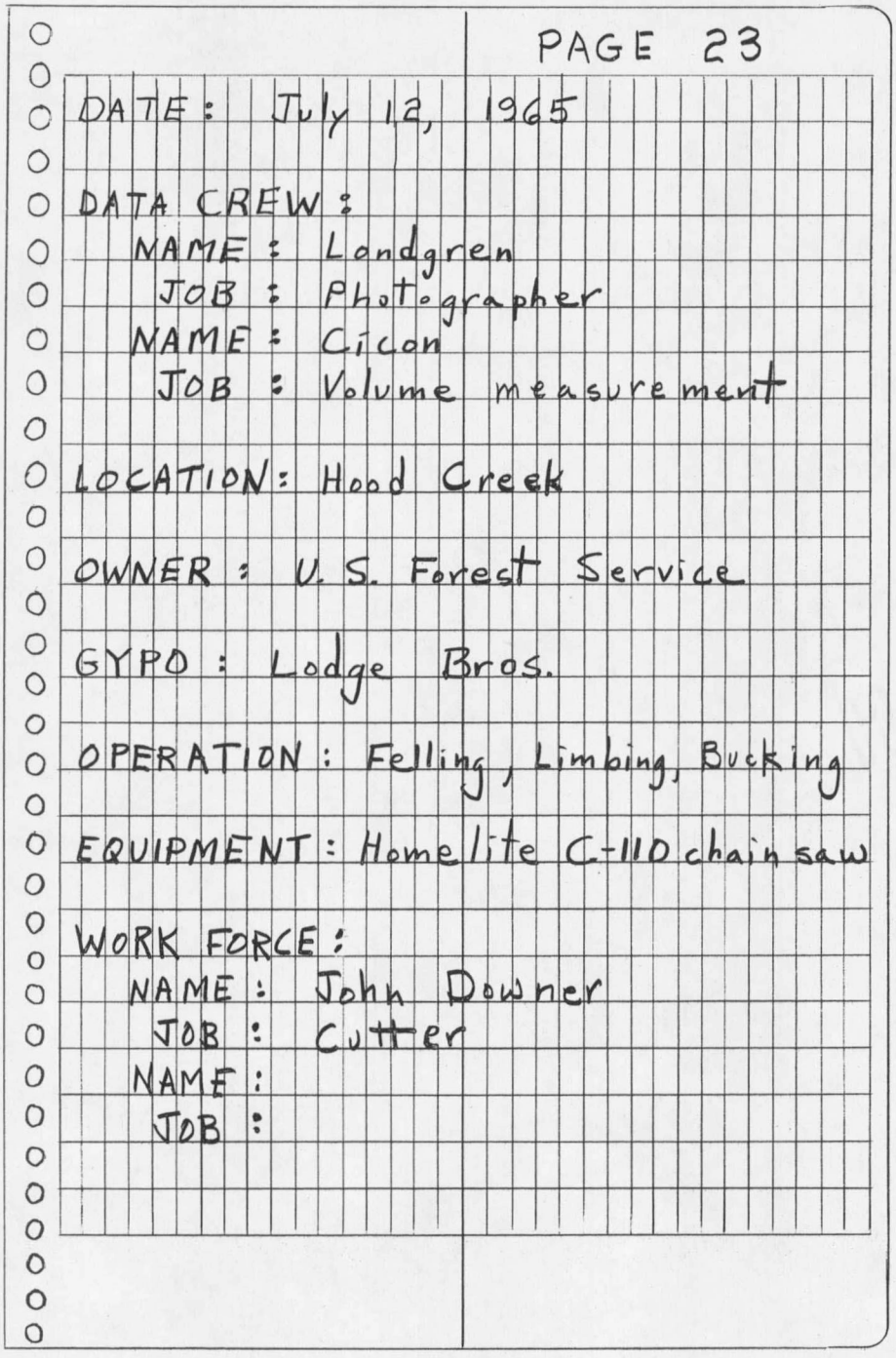


Figure 12: Film title sheet, as it appears on a page of the field note book. This information is minimum. More pages can be added as needed.

CHAPTER IX
THE PROBLEM OF VIEW OBSTRUCTIONS

"VIEW OBSTRUCTIONS" AND LIMITATIONS THEY IMPOSE

The camera will only record what it can see. Obstructions that can block the view of an operation (and thus render photographic data gathering useless) can come in many forms. The following is a list of view obstructions commonly encountered in the study of logging operations:

1. Standing trees,
2. Fallen trees,
3. Terrain,
4. Undergrowth,
5. Logs,
6. Men,
7. Machines.

The effect of view obstructions limiting data collection ranges from complete obliteration of the required data to no loss due to obstructions. The percent effectiveness of a photograph subjected to view obstructions will be partly controlled by what data is required.

To clarify the previous paragraph, consider one frame in which a feller is crouched at the base of a tree, his back to the camera. The tip of his saw blade can be seen, along with flying wood chips. This normally would be sufficient to indicate the feller was engaged in the felling of a tree. If that were all the data required of the frame, no loss due to

obstructions would be experienced. However, if the required data were a description of the position of his hands on the saw, all data would be lost. The obstruction in this case is the feller's own body.

If the photographer has a clear understanding of what data will be required from the finished film, he can usually anticipate during filming the loss of data due to obstructions.

DEALING WITH VIEW OBSTRUCTIONS

For study of logging in its natural environment, view obstructions do exist. If the camera is to be used for gathering of data, obstructions can occasionally be moved or avoided to minimize loss of data. Usually avoiding the obstructions is the practical method since moving of trees, hillsides, etc. is far too costly and would probably interfere with the logging operation.

Moving closer to an operation often eliminates many view obstructions. Of course, the hazards to data gatherers may increase by moving closer. Also the field of view may become small enough that important data is lost simply because it is outside the camera's field of view.

Moving the camera to change the line of sight sometimes helps to avoid view obstructions. Of course, it may be that this will only exchange one set of obstructions for another

set, perhaps less objectionable. This method has sometimes worked in actual practice.

Illustrations in figures 13 through 15 show the most frequently useful positions for the camera in filming felling, limbing, bucking, and loading (heel boom) operations. No truly successful position has been found for filming of skidding operations, which usually move from point to point over an area too large to be photographed effectively from any one position.

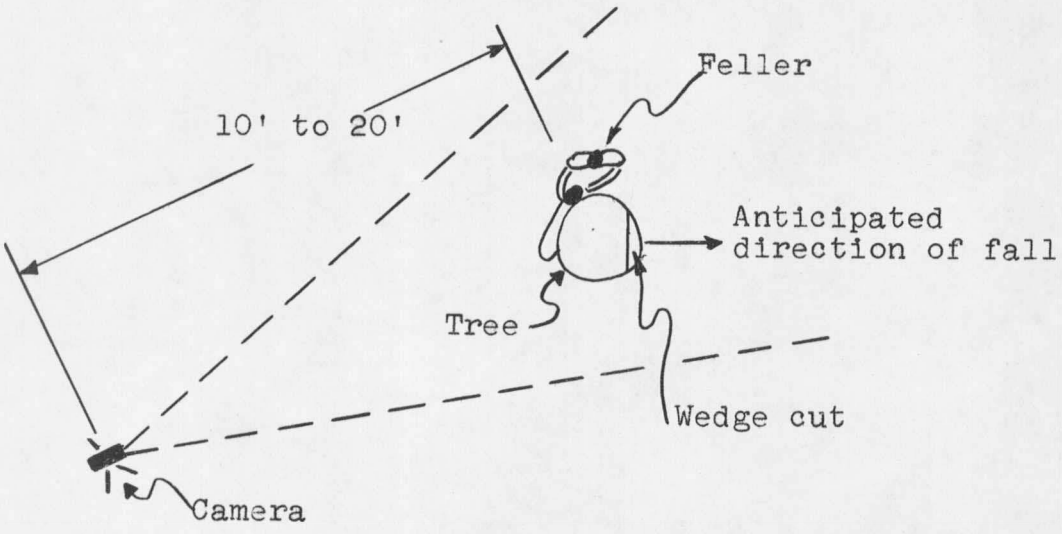


Figure 13: Most frequently useful camera position for felling.

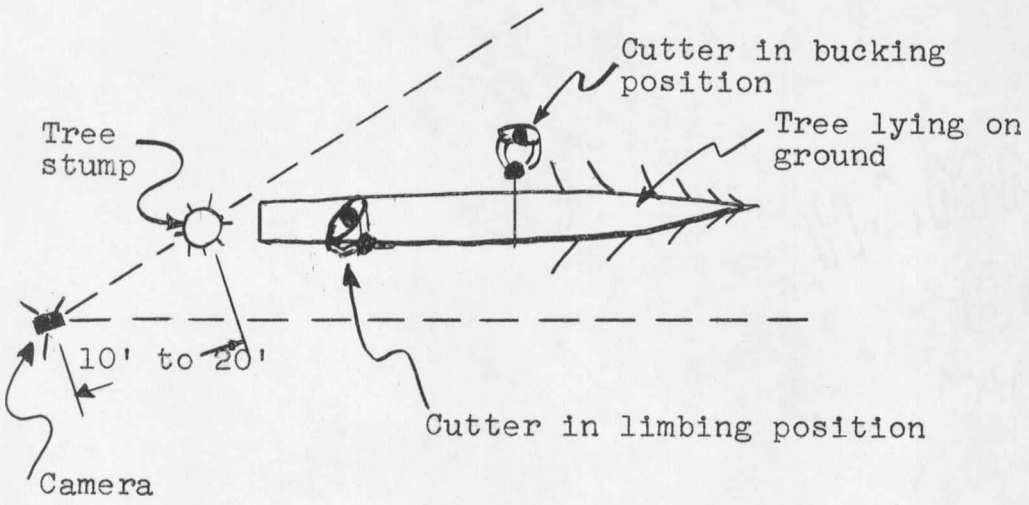


Figure 14: Most frequently useful camera position for limbing and bucking.

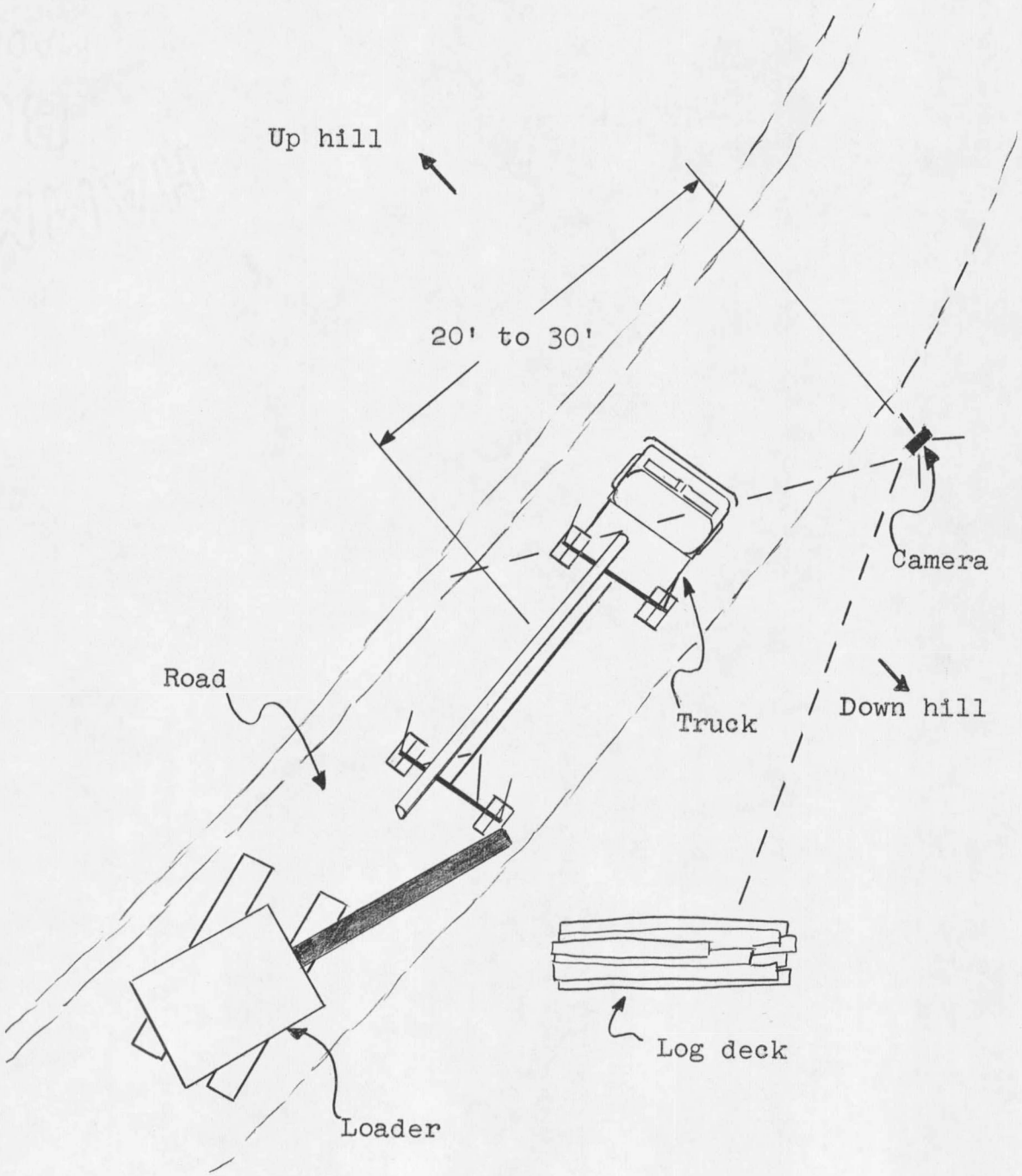


Figure 15: Most frequently useful camera position for loading with a heel boom loader.

CHAPTER X
ENVIRONMENT AND OPERATION FACTORS INFLUENCING TIME LAPSE PHOTOGRAPHY OF LOGGING

To intelligently approach the problem of recording data by means of time lapse photography, certain characteristics of the logging operations and the logging environment need to be recognized. This chapter will discuss the principal characteristics of "factors which influence photography." The selected factors are those which have caused the greatest problems within the scope of the author's experience.

THE MOVING WORK SITE

Felling is carried on in a new location, i.e. "work place," for each cycle. Limbing involves a moving operation during removal of limbs of successively smaller size from a single tree and travel to each successive tree to be limbed. Very large areas are frequently covered by a single "skidding turn." Loading is a relatively stationary operation in which many cycles may be completed from a single location.

Many of the operation moves described in the previous paragraph must be accompanied by relocation of the camera. Sometimes simply aiming the camera in a different direction is sufficient, but frequently a move to another location is necessary for one or more of the following reasons:

1. Operation moves behind a view obstruction.
2. Camera is located in what is to become an extreme hazard area.

3. Camera-to-subject distance becomes too long or too short.

THE CHANGING LIGHT INTENSITY

For proper exposure, film and lens opening must be matched to light intensity. For each change in light intensity, a rebalance of light intensity, film, and lens opening is necessary. The light intensity does change in the logging environment. The following are common causes:

1. Rotation of the earth,
2. Operation movement,
3. Cloud movement,
4. Shade removal (i.e. trees felled),
5. Camera movement.

THE SHORT CYCLE TIME

Some logging operations take less than a minute per cycle under certain conditions. An operation such as felling may require a move every cycle. A smooth move without loss of data within the logging environment is difficult. Frequent moves of this type may slip out of the realm of the possible. In effect, short cycle time simply intensifies problems resulting from the relocation of the work site.

THE TERRAIN AND ITS COVER

Mountainous country brings special problems to photography of logging. Quick, smooth camera relocation is hampered by steep slopes. Slippery ground conditions, such as

wet grass or loose rock, amplify the problems. Hills and valleys sometimes obstruct the view of an operation.

Fallen trees and undergrowth often hamper the photographer's movement during camera relocation. These same fallen trees and undergrowth, along with standing trees, frequently obstruct the camera's "view" of the operation under study.

THE WEATHER

Logging is carried on under varied weather conditions. Deviations from warm, dry weather call for protective clothing for data gatherers. Protective clothing can make operation of the camera difficult (i.e. gloves or mittens for cold weather protection), and it can hamper the photographer's movement during camera relocation.

Snow, rain, and dew often produce slippery ground and logs. Wind increases the hazards of falling limbs and trees (see Chapter XV which discusses safety in data gathering).

Cold weather reduces the useful life of the batteries which power portable equipment such as the intervalometer.

THE HAZARDS

A discussion of the most common hazards that data gathering observers face in the logging environment is reserved for Chapter XV.

THE WORKER'S COOPERATION

Experience indicates that cooperation received from a worker has a close relationship to conversations held with

this same worker PRIOR TO THE GATHERING OF ANY DATA about his operation. (It is unswise to take even a still picture of the operation without a preliminary explanation.)

The preliminary conversation is to include a straightforward, honest explanation of the planned study (the explanation should be complete enough to satisfy the worker, but not so long as to bore him or interfere unduly with his work). Once the worker is content with his understanding of the proposed study, ask his permission to go ahead with the gathering of data. Where this procedure has been followed, workers have generally given excellent cooperation.

CHAPTER XI
STANDARD SPEED AND SLOW MOTION MOVIES FOR STUDY OF LOGGING OPERATIONS

Movies at speeds ranging from 16 frames per second to 64 frames per second can be taken with the Kodak K-100 camera. This fact has been pointed out in Chapter IV. The speed selector on the camera is marked at speeds of 16, 24, 32, 48, and 64 frames per second.

Micromotion study, a highly refined technique for detailed analysis of operations at an existing work center, employs the use of camera speeds in this range. A speed of 1000 frames per minute is the most popular for micromotion study because it is nearest to normal motion picture speed and because the intervals are decimal fractions. This speed is available on the Kodak K-100 camera, but it is not marked. It lies somewhere between 16 frames per second (960 frames per minute) and 24 frames per second (1440 frames per minute). The author knows of no practical means of accurately setting the Kodak K-100 camera at 1000 frames per minute; however, many cameras designed for micromotion study provide an accurate speed of 1000 frames per minute.

A very detailed analysis of an existing operation is possible through frame by frame study of movies taken at standard camera speeds of 16 frames per second (960 frames per minute) or at the faster speeds that are available.

Much of the earlier discussion relative to time lapse photography (i.e. film selection, amateur photographers, film and operation identification, view obstructions, logging environment, and safety) also applies to standard speed and slow movies. Three factors that become more critical with high film speeds are the following:

1. Time available for operation recording,
2. Cost,
3. Exposure time.

Only forty feet of film can be exposed with the Kodak model K-100 camera before it is necessary to rewind the camera main spring. At a speed of 16 frames per second the maximum uninterrupted running time is one minute and forty seconds. The running time gets even shorter as the camera speed is increased (see Table IV).

At a speed of 16 frames per second the cost of film and film processing alone amounts to $2.40 per minute of recording time (assuming film cost plus processing cost totaling $10.00 per one hundred foot roll). Analysis cost will, of course, depend upon the information to be extracted. For an analysis rate of two frames per minute and a single analyst's time costing a minimum of $3.50 per hour, film analysis will amount to $28.00 per minute of operation recording time.

In the assumed situation discussed in the previous paragraph, the sum of costs for film, film processing, and

analysis is $30.40 per minute of operation time recorded. Other costs (i.e. photographer's time, transportation, camera depreciation and repairs) are not included in this amount. Further discussion of data costs is included in Chapter XIV.

For time lapse films, exposure time of the Kodak K-100 movie camera is a constant, regardless of the time lapse interval chosen. For movies at standard camera speed or faster, exposure time depends upon the camera speed selected. For all camera speeds from 16 to 64 frames per second the exposure time is less than the exposure time for time lapse photography.

Since exposure time does change with a change in camera speed, the lens opening for constant light conditions requires readjustment when the camera speed is changed. It may also be necessary to select a faster film to compensate for shorter exposure time.

USEFULNESS OF MOVIES AT 16 TO 64 FRAMES PER SECOND

Movies in this camera speed range are useful for work pace rating and for very detailed analysis of such things as intricate hand movements. Cost is prohibitive to permit use of camera speeds in this range primarily for gathering of motion-time data in non-repetitive work encountered in logging. Such speeds, however, would be justifiable if the results of findings could be used to simplify or improve the

logger's work. This implies, of course, than an effective training program could be set up to train the present or new loggers in better logging methods.

CHAPTER XII
STOP WATCH TIME STUDY FOR LOGGING OPERATIONS

As mentioned in Chapter VII, Mundel has defined time study as, "a procedure for determining the amount of time required, under certain standard conditions of measurement, for tasks involving some human activity." (18,p.325) Stop watch time study implies that a stop watch will be used for measurement of appropriate time values.

Using Mundel's definition of time study, it is necessary to establish and prescribe the "standard conditions" accurately enough, and within narrow enough limits, to permit the determination of a standard time that is equitable for prediction of time requirements for all operations fitting the standard conditions.

In many industries a single operation can be described by a single set of standard conditions. Standardization tends to insure that the conditions of one cycle will not be significantly different from the conditions of another cycle unless a planned methods change is installed. In logging, standardization of certain conditions is beyond the economical control of man (i.e. slopes, size and location of trees, ground conditions, etc.).

The standard conditions can be established, however, to cover very broad ranges so that only elemental time values will need to be measured and recorded for each cycle studied. Using this approach, the resulting elemental times of a sample

(which truly represents the entire population) can be expected to show rather large variation. Variation may be too large to permit determination of a meaningful "standard time" in the classical meaning of the term.

Establishing sets of "standard conditions," as described in Chapter VII, can be expected to reduce the variation of elemental times within each set. It then becomes necessary to make other measurements in addition to elemental times so that the cycle can be categorized in the appropriate set.

STOP WATCH VERSUS CAMERA

Elemental time values can be measured with either a stop watch or a time lapse camera. Other measurements (such as ground slopes, distances moved or traveled, tree or log sizes, or ground conditions) to place a cycle in the appropriate set of standard conditions will usually need to be made by some other independent means, regardless of whether the stop watch or the camera is used for measuring time values.

Since either stop watch or camera can be used for measurement of elemental times, selection of one over the other should be based upon a comparison of the advantages of each in light of the circumstances to be encountered. For this reason, some advantages of each are brought out in the following lists and discussion.

Advantages of stop watch over camera:

1. Data is immediately available.
2. Time data and standard conditions measurements can be recorded together.
3. Equipment investment is small.
4. Equipment is easily carried.
5. View obstructions present less of a problem.
6. Data cost may be lower.
7. Moving work site is less of a problem.
8. Avoids field-of-view limitations.
9. Avoids recording interruptions inherent with camera.
10. Data analysis is less costly.

Advantages of camera over stop watch:

1. Elements can be selected deliberately and with great care when film is analyzed under "office" conditions.
2. Choice of elements can be changed without a need for new field data.
3. Variation in sequence of events is more easily handled.
4. Foreign elements present less of a problem.
5. Film permits more detailed elemental breakdown.
6. Permanent record and reference.

STOP WATCH ADVANTAGES:

1. The first advantage attributed to the stop watch is that data is immediately available. By comparison, when the camera is used, it is necessary to wait after initial data gathering until the film is developed. In our experience, processing time has usually run about two weeks. This delay, however, may not be very important in long range studies.

2. When stop watch time study is used, "standard conditions" data can be recorded on time study forms along with time measurement data. It is possible, but less convenient, to record similar standard conditions data on film. Each film, however, could be accompanied by a "standard conditions" data sheet suitably keyed to the film.

3. By comparison with time lapse photography equipment such as that used in this study, the equipment needed for stop watch time study represents a much smaller initial investment. First cost of the original time lapse equipment used in this study (see figure 2) was 980.00 dollars. Stop watches used in this study range in price from 15.50 to 34.00 dollars.

4. The stop watch is obviously physically smaller than the camera and time lapse adaptation and is more easily carried.

5. View obstructions are not usually a serious problem in stop watch time study of logging operations. The

obstructions can usually be avoided by a relatively unencumbered analyst. Also, sound as well as sight can be helpful in determining just what is occuring at any point in time. The problem of view obstructions when the camera is used for data gathering is discussed in Chapter IX.

6. Cost of data will depend upon what data is collected and also the method that is used for gathering the data. Generally, where very specific time study data is required, and where it is possible for one man using a stop watch to gathering adequate data, stop watch time study will provide summarized data at a lower cost than is possible using the time lapse camera. For further discussion of data gathering costs see Chapter XIV.

7. Moving the camera to follow a moving work site often results in blurred pictures and lost data. The moving work site should cause little difficulty for stop watch measurement.

8. The camera has a limited field of view (see figure 4). Anything occurring outside this field of view will not be recorded by the camera. Stop watch measurements avoid this limitation of the camera.

9. The camera is limited in its continuous recording capacity by such things as the number of frames that can be exposed between interruptions. The principal interruptions include stopping to wind the camera main spring and putting

new film in the camera, and occasionally, failure of the intervalometer battery to provide sufficient electromotive force to actuate the camera. Use of the stop watch avoids these interruptions introduced by the camera.

10. When stop watch time study is used, the analyst can begin immediately to summarize his data (assuming the snapback method of stop watch time study is used[1]). When the camera is used, the analyst must first extract time values from the film before he can begin to summarize his data. The time required to extract data from the film adds cost to the study.

CAMERA ADVANTAGES:

1. & 2. Irregularity of many logging operations places certain important advantages on the side of the camera. For example, selection of elements for breakdown of cycle time may be difficult. Films permit a preliminary study to select and define the elements. Then the film can be rerun to measure time values as precisely as desired. Where necessary, elemental breakdown can be changed and time values remeasured on the same film.

3. Sometimes the sequence of events is difficult to predict in logging operations. This can be confusing during

---

[1] For a discussion of the snapback method see reference 19, page 245.

stop watch time study. A film can be rerun as often as necessary to sort out the elements.

4. Since with a film it is possible to see the exact same operation more than once, an opportunity is provided to isolate the foreign elements and then view the film again to determine elapsed times. This opportunity does not exist with stop watch time study.

5. Stop watch time study must be planned to allow time to record data during the study. The operation cannot be stopped to allow time for recording this data. Therefore, elements must be large enough to provide data recording time. The film resulting from time lapse photography of an operation can be stopped while data is recorded, then continued. A much more detailed breakdown is therefore possible when the camera is used.

Neither stop watch nor camera can be selected to the complete exclusion of the other in the collection of time study data. Chapter XVI will describe a proposed data gathering system that will employ both methods.

CHAPTER XIII
WORK SAMPLING FOR LOGGING OPERATIONS

Work sampling is a statistical technique used to estimate the fractions of an "operation time" consumed by various activity classifications and their elements.

The "ratio delay" study, a forerunner of modern work sampling, considered only two activity classifications. These classifications were 1) working productively and 2) not working. Either or both of these classifications can be divided into a larger number of more specific classifications in the application of modern work sampling.

In addition to its use in estimating the percentage of "operation time" consumed by various activity classifications, work sampling, under certain circumstances, has been used successfully to establish time standards for operations. 1) Estimating percentage of operation time consumed by various activity classifications and 2) establishing time standards are the two main uses of work sampling. (3,p.3)

WHY WORK SAMPLING?

Time study can be used to gather the same type of information as that supplied by a work sampling study, but work sampling is frequently faster and less costly. Also, work sampling measurements may be made with a statistically sound pre-assigned reliability if sampling is properly done.

Discussions of work sampling--including explanations of how and why it works, the statistical concepts on which it

is based, and procedures for conducting a work sampling study--may be found in various references including Work Sampling by Ralph M. Barnes (reference number 3).

Rather than include here an extensive discussion of work sampling, the reader is invited to refer to reliable standard works to acquire a general understanding of work sampling. This discussion will then be limited to special considerations in relating work sampling to logging operations, followed by a discussion of the possible application of work sampling using fixed rather than random intervals for logging studies.

LIMITATIONS OF WORK SAMPLING FOR LOGGING

Barnes lists thirteen advantages and seven disadvantages of work sampling as compared to continuous time study.

Of significance to logging is his first disadvantage which states, "Ordinarily work sampling is not economical for studying a single operator or machine, or for studying operators or machines located over wide areas. The observer spends too great a proportion of his time walking to and from the work place or walking from one work place to another. Also, time study, elemental data or motion time data are preferred for establishing time standards for short-cycle repetitive operations." (3,p.5)

On the basis of Barnes' first disadvantage, ordinary work sampling will probably not be economical for felling,

limbing, and bucking operations, since these operations are usually performed by one man. Where several cutters are working a single chance, they must each work far enough from the others to avoid the possibility of endangering the others or of being endangered by them.

This first disadvantage will not apply to certain loading operations since it is not uncommon for a loading operation to involve three or more men, a machine for loading, and one or more trucks.

Skidding sometimes involves just one man operating one machine but at other times involves several men and machines. Where several men and machines are involved, Barnes' first disadvantage is not present unless the total operation is scattered to an extent that will not permit adequate observation of the entire operation.

The validity of conclusions reached on the basis of work sampling will relate to the extent to which the sample is representative. For operations having wide daily fluctuations the required number of observations may need to be spread over a period of several weeks. (In certain logging operations seasonal fluctuations may suggest spreading the observations over an entire year for truly representative samples.)

If the usual "work sampling" is to be used in the study of logging operations, some of the assurance of a truly

representative sample will probably need to be sacrificed because it is often necessary to travel long distances (25 miles round trip is about a minimum) to reach a logging chance. Thus it is not economical to spread a study over several weeks during which time rather limited information is gathered.

In logging it will seldom, if ever, be possible to apply work sampling to obtain the high (and predictable) accuracy and low cost (relative to time study) it has provided in other industries.

An important limitation of work sampling is that it presents average results. It does not provide information about the deviations from the average. Thus, for studies aimed at finding the extent to which deviations in the operation relate to certain deviations of the operation environment, work sampling information will not be sufficient.

As mentioned earlier in this chapter, in many industries determination of time standards is one of the two most common uses of work sampling. This application of work sampling will probably not be particularly useful for logging operations. Barnes indicates (3,p.80) that for short-cycle repetitive operations, time study, elemental data, or motion-time data would be preferred in most instances for determining time standards.

Work sampling is not likely to yield the high and predictable level of accuracy at relatively low cost in logging studies that is possible in certain other industries. Further, it is not likely to be useful in setting time standards for logging operations. This is not intended to imply, however, that practical applications of work sampling to logging are nonexistent. Potential use of work sampling for logging is discussed in the following section.

APPLICATION OF WORK SAMPLING IN LOGGING STUDIES

Work sampling involving small samples that fall short of providing high assurance of being representative can still serve as a useful tool in determining general objectives. (3,p.27) It can aid in determining to what extent, and in what sequence, each of an operation's activity classifications warrants further study. It can assist, in effect, the planning of studies that will yield the highest return on research investment.

FIXED INTERVAL WORK SAMPLING

The statistical reliability of work sampling depends upon random observations. Most references discussing work sampling indicate random observations are obtained by instantaneous activity classifications at random times. It has been suggested that random observations can also be obtained by making instantaneous activity classifications at fixed

intervals provided the activity being observed follows a random pattern. (11,p.268)

Logging intuitively appears to involve random operations. The randomness appears more regularly in the time required for any element in successive cycles than in the sequence of elements (even though element sequence is not always consistent).

If fixed interval sampling of random operations does satisfy requirements for random observations, and if logging operations are in fact random, work sampling for logging operations can be simplified. The author's experience indicates that fixed interval sampling is much easier than sampling at random intervals when studies are made under woods conditions. Fixed interval studies at an interval of one minute have been found to allow reasonable time for recording data and watching for hazards.

If fixed interval sampling does not adequately provide for randomness of observations, information obtained by this method should still be sufficiently representative for use in determining general objectives.

CONCLUSIONS REGARDING WORK SAMPLING FOR LOGGING OPERATIONS

In light of the discussion included in this chapter, fixed interval work sampling is recommended as an aid to be used in the planning of more intensive logging studies.

Other uses of work sampling which require more assurance of a representative sample appear to be of doubtful value at this time.

CHAPTER XIV
COST OF DATA

To acquire data it is necessary to pay for the services of people and equipment. The total cost of data will depend upon the nature of data to be gathered, how much data is required, degree of detail, degree of refinement, and when, where, how, and by whom the data is to be gathered.

To make valid comparisons between alternative methods of data gathering, one must consider more than just the costs of raw data. Raw data, of course, refers to such things as the film strip that has not been analyzed, the work sampling study that has not been summarized, and the continuous stop watch time study for which elemental times are yet to be extracted. A valid cost comparison must consider the data in each case brought to the same level of utility.

To illustrate the point of bringing data from various sources to the same level of utility, consider a situation where a time standard is to be determined on the basis of either a film strip or a continuous stop watch time study. A convenient point at which each has the same level of utility occurs where each element has determined for it the elapsed time occurring in each of the cycles studied. To reach this point with a film strip it is necessary to analyze the film frame by frame, counting the frames in which the element appears, and on the basis of frames in which this element appears the elemental elapsed time is calculated. In the

case of continuous stop watch time study, the elapsed time for each element is determined by subtracting the stop watch reading at the beginning of the element from the reading at the end of the element.

After data from alternative acquisition methods have been brought to the same level of utility, further reduction of this data will be the same for either method. Thus comparisons of costs beyond this point are not necessary in the selection of the data gathering method to be used. This is not intended to imply that further cost studies to determine cost of an entire study plan execution are unnecessary. Even the best data gathering method may be so costly that a complete study plan should be scrapped.

The costs to be considered in this chapter can be divided into two classifications as follows:

1. Cost of raw data,
2. Cost of reducing raw data to usable information.

The second classification will be discussed only to the point of illustrating cost comparisons of data obtained by alternative means brought to the same level of utility.

COST OF RAW DATA

From our field experience during the current forestry research project, the following are cost items that had to be considered in determining the total cost of raw data:

1. Salaries,
2. Insurance,
3. Transportation,
4. Equipment,
5. Supplies,
6. Expense allowances.

1. Salaries:

The data gathering techniques considered in this thesis all require human services. These human services are generally obtained by agreement with each individual that he will receive compensation in the form of a salary or wage in exchange for his services.

Establishment of appropriate salary levels for data gatherers is beyond the scope of this thesis. Instead realistic rates (such as $3.50 per hour, including overhead) will be used here. The wage or salary should reflect not only the skills and knowledge a data gatherer must possess to execute his function, but also the undesirable aspects of the job (such as hazards he will face).

Personnel hired for other functions as well as for data gathering frequently will receive a higher salary or wage rate than others hired strictly for data gathering. In most cases they will continue to receive this higher rate during periods where their work consists entirely of data gathering.

This factor must be recognized when preparing study plans with cost predictions.

Appropriate wage rates for various data gatherers may very well cover a range comparable to the range of knowledge and abilities required to perform the tasks.

The cost of salaries and wages applied to data gathering can be expected to include more than the salaries payable just for the time during which data is being gathered. The following is a list of activities for which salaries or wages are normally paid and which may be chargeable to the data collection function:

1. Receive instructions,
2. Procure equipment,
3. Procure supplies,
4. Prepare equipment,
5. Load supplies and equipment,
6. Inspect and service vehicle,
7. Travel to operation,
8. Explain intentions to loggers,
9. Gather data,
10. Travel to lunch site,
11. Return to operation,
12. Gather data,
13. Return to headquarters,
14. Unload supplies and equipment,

15. Clean equipment,
16. Turn in equipment,
17. Turn in unused supplies,
18. Report progress and problems,
19. Personal time.

The above list may not be all inclusive, but it does include the items that were actually observed to be the most common. Most of the items are listed in a typical daily sequential position. Some items that commonly occur more than once during the day have been arbitrarily lumped in one position (such as item 19, personal time).

Table VIII presents a typical eight hour day devoted to data gathering. Time values indicated are not representative of every data collection day, but they are realistic. The percent of the day actually available for data collection is shown for this hypothetical day.

Computation of the cost of salaries per hour of time actually devoted to the gathering of data can be illustrated by assuming the day described in Table VIII and a salary rate of $3.50 per hour. Computations for this situation are as follows:

Wages paid/man day = ($3.50/hour)(8 hours) = $28.00,

Data gathering hours/man day = 2.501,

$$\text{Wages paid/data gathering hour} = \frac{\$28.00}{2.501} = \$11.20.$$

TABLE VIII
TYPICAL EIGHT-HOUR DAY
DEVOTED TO DATA GATHERING*

	ACTIVITY	ELAPSED TIME (hours)	PORTION OF DAY AVAILABLE FOR DATA GATHERING
1.	Receive instructions	0.333	
2.	Procure equipment	0.083	
3.	Procure supplies	0.083	
4.	Prepare equipment	0.167	
5.	Load supplies and equipment	0.167	
6.	Inspect and service vehicle	0.167	
7.	Travel to operation		
	a. In vehicle	1.500	
	b. On foot	0.250	
8.	Explain intentions to loggers	0.167	
9.	Gather data	1.000	1.000 hours=12.5%
10.	Travel to lunch site	0.083	
11.	Return to operation	0.083	
12.	Gather data	1.501	1.501 hours=18.8%
13.	Return to headquarters	1.500	
14.	Unload supplies and equipment	0.083	
15.	Clean equipment	0.083	
16.	Turn in equipment	0.083	
17.	Turn in unused supplies	0.000	
18.	Report progress and problems	0.167	
19.	Personal time	0.500	
	TOTALS	8.000	2.501 hours=31.7%

*This typical eight-hour day devoted to data gathering shows the breakdown of time consumed by various activities. This does not represent any form of time standard but is instead a realistic picture of a possible situation.

The computations shown on page 129 indicate that costs of raw data are inflated by portions of a data gathering day spent in non-data gathering activities. It is to be recognized that the day described in Table VIII is but one of many possible activity breakdowns for a data gatherer's day. Figure 16 illustrates the salary cost per man data gathering hour versus hours spent in activities other than actual data gathering. An eight-hour work day and a salary level of $3.50 per hour are assumed.

2. Insurance:

Chapter XV indicates that observers gathering logging data may frequently be exposed to serious hazards. Extra insurance coverage may be advisable for people engaged in this activity. The cost could easily be as high as that for loggers themselves. Recent premiums for loggers insured by the State Industrial Accident Board of Montana have been 14% of base salary.

3. Transportation:

Current transportation is generally in the form of some type of over-the-road passenger-carrying vehicle. High clearance, a transmission with a low gear permitting very low travel speed at relatively high engine speeds, and a locking differential are recommended characteristics of the vehicle. Occasionally road conditions make all-wheel drive desirable. The cost of the latter may easily amount to 12 cents a mile

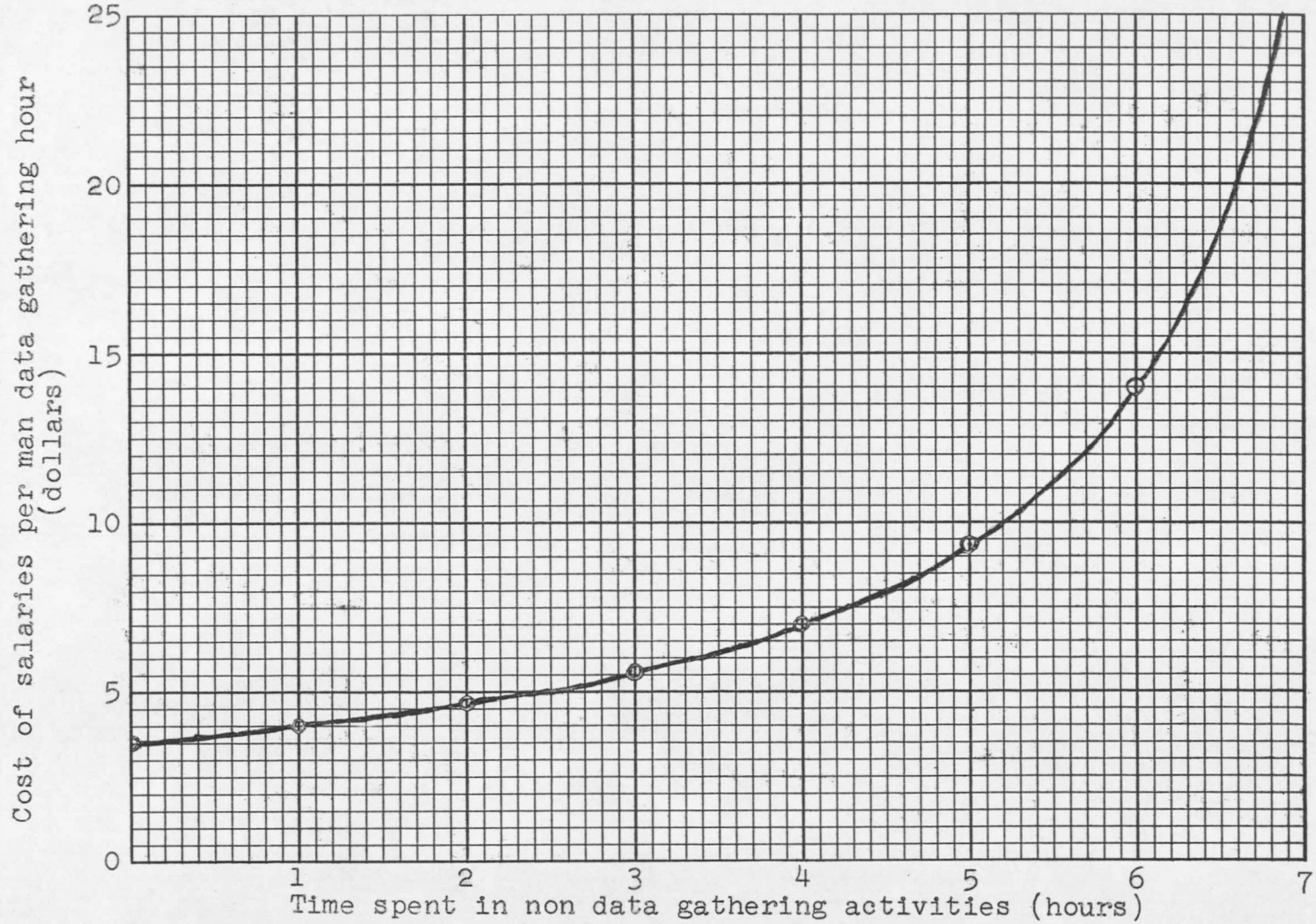


Figure 16: Graph of rise in cost per data hour of a man's salary as increasing portions of his day are consumed by related activities (eight hour day assumed).

for a frequently used vehicle and as high as 25 cents a mile for one used less than 4,000 miles per year.

Project assessments for vehicle use can be made in many ways. In this thesis the typical car rental approach will be assumed. The vehicle use assessment for a project will be determined as follows:

Total charge = (daily charge)(number of days used)
+ (charge per mile)(miles driven).

Many organizations will already have their own methods of assessing for vehicle use. In such cases, or in those cases where readers feel they have better methods, the approach suggested here can readily be replaced.

4. Equipment:

Gathering of operational data usually involves the use of equipment of various types. For example, one study of the felling, limbing, and bucking operation required the following equipment:

1. Time lapse camera,
2. Stop watches (2),
3. Range finder,
4. Loggers tape,
5. Inclinometer.

Equipment costs should be charged against the projects for which they are used. These costs would include purchase

price and any maintenance and repair costs that become necessary.

It is suggested that smaller equipment be considered in the same manner as supplies and that the purchase price of each new item be charged to the first project requiring its use. Larger equipment, such as the time lapse camera and accessories, may be depreciated over its predicted useful life. Then the project costs will include the appropriate depreciation charge plus assessments for repairs and maintenace on the larger equipment.

5. Supplies:

Items such as film, batteries, pencils, and field notebooks may be charged on an as-needed basis. Supplies will have very little, if any, carry over value to the next project.

6. Expense allowances:

Some data gathering sites are located so far from the research laboratory or other home base of operations that daily travel to the data gathering site and return to the home base becomes impractical. To illustrate this point, consider a situation in which data gatherers work an eight-hour day and are not expected to travel on their own time. Then any location requiring four hours or more to travel to the operation site and a like amount of time for the return trip leaves no time for data gathering.

The typical solution to this type of problem is to set up a temporary "field headquarters," such as a motel room or cabin, which is closer to the data gathering site. Personnel are then commonly compensated for the expenses of living away from home through the provision of some form of expense allowances.

Studies in locations close enough to permit daily round trips and still allow time for data gathering will sometimes be more economical if a field headquarters can be established that is closer to the operation. The appropriate choice should then be based on a comparison of total costs of gathering all the data required for a study or on the cost per unit of data gathered.

SUMMARY OF RAW DATA COSTS

A cost computation sheet for the day described in Table VIII might resemble the example illustrated in Table IX.

Assuming that the cost sheet of Table IX is for the day described in Table VIII and that the activity breakdown of Table VIII applies to both men, the cost for that day amounts to $23.20 per man data gathering hour. Computations are as follows:

Total cost for day = $116.40,

Data gathering time, each man = 2.501 hours,

Total data gathering time, two men = 5.002 hours,

$$\frac{\text{Total cost}}{\text{Total data gathering time}} = \frac{\$116.40}{5.002 \text{ hr.}} = \$23.20/\text{hour.}$$

TABLE IX
DAILY COST SHEET*
(sample)

Date: July 7, 1965		
Salaries:		
1 man at $3.50 per hour		$28.00
1 man at $4.50 per hour		36.00
Insurance:	10%	6.40
Transportation:		
Vehicle reservation		5.00
Mileage charge $.15/mile x 80 miles		12.00
Equipment charge:		8.00
Supplies:		21.00
Expense allowance:		none
Total cost for day:		$116.40

*A sample daily cost sheet for data gathering performed by two men. The equipment charge is for the use of time lapse movie equipment. Supplies include field notebooks, pencils, and two rolls of color film. Film price is assumed to include a charge for processing.

The relationship of cost per man data gathering hour to the portion of data gatherer's day spent in other activities is illustrated for the cost of a man's salary in figure 16. This same relationship considering <u>total costs</u> rather than cost of a man's salary will usually follow a pattern very similar to that of figure 16.

COST OF REDUCING RAW DATA TO USABLE INFORMATION

Early in this chapter it was mentioned that valid comparisons between alternative methods could only be made if the data were brought to the same level of utility. This is because the cost of extracting required information from the raw data will seldom be the same for two or more different methods of obtaining the raw data.

For example, in one case where time lapse films were taken with a ten second interval, analysis of the film simply to determine the elemental phase pictured in each frame proceeded at the rate of two frames per minute on the average. Thus, a single one hundred foot roll of film would require more than four days of an analyst's time for this simple analysis.

Information similar to that described in the previous paragraph has also been obtained by fixed interval work sampling using only a watch, field notebook, and pencil. An interval of one minute was used (yielding one-sixth the number of readings for a given time period as the time lapse method). Thus the number of reading was reduced by this method, but identification of elemental activities was already provided in the raw data.

A COMPARISON OF TWO METHODS FOR OBTAINING SELECTED INFORMATION

An estimate of the percent of total on-the-job time spent in each of five activity classifications is sought. The two

methods for obtaining the information are mentioned briefly in the previous two paragraphs. The first involves time lapse photography at a ten second interval followed by film analysis. The second involves simple recording of the activity classification in a field notebook at one minute intervals.

For comparison of the two methods we need consider only the differences. Many items will be the same or very nearly the same in both cases. The following list includes many of the items that will be the same (essentially) regardless of the method chosen:

1. Daily cost of salaries,
2. Daily cost of insurance,
3. Daily cost of transportation,
4. Daily cost of expense allowances.

Differences between the two methods include the following:

1. Time lapse equipment more costly,
2. Time lapse supplies more costly,
3. More data gathering interruptions with time lapse photography,
4. Time lapse provides more frequent readings,
5. All time lapse data is visual; alternative method also permits use of sound for element identification,

6. Data reduction much more costly with the use of films.

From the list of differences it appears that choice between the two methods of gathering data should be based on a comparison of the value of more frequent readings obtained using time lapse photography against the higher cost and slightly reduced period of study.

A time lapse study of, say, six hours duration at a ten second interval requires 2160 frames. Analysis of this film strip at a rate of two frames per minute requires one and one-half days. If approximately a six hour study can be made in one day, then the extra cost associated with time lapse photography in this one day example includes an additional one and one-half days of analyst's time, purchase and development of one roll of film (assuming the unused portion is not saved for another study), and the extra cost associated with use of the time lapse camera and accessory equipment on the day raw data is gathered.

The foregoing example is not indicative of all comparisons involving time lapse photography as one of the data gathering alternatives. For example, an operation description may in some instances be adequately covered with nothing more than a time lapse film. Comparable descriptions by other methods may be much more costly than the film record, or may even be impossible.

Costs of obtaining raw data and of reducing this data to useful information are high. These costs are an extremely important consideration in the design of any logging study both for selection of the method that minimizes cost of information and for determining whether or not the information is worth the price.

CHAPTER XV
SAFETY IN DATA GATHERING

Logging is a hazardous industry. Of 166 industry classfications listed in Accident Facts, a publication of the National Safety Council, logging industry had the fourth highest injury "frequency rate" and the fifth highest injury "severity rate." (1,p.36-37) The only industries with higher frequency rates were underground anthractie coal mining, the harbor equipment segment of marine transportation, and the sugar beet industry. Industries with higher severity rates were underground anthracite coal mining, underground bituminous coal mining, the structural and ornamental metal work segment of the construction industry, and the underground mining of metals. Accident frequency rates and severity rates for selected industries are presented in Table X to more fully illustrate the nonenviable accident record of logging.

"Frequency rate" and "severity rate" are terms established by safety engineers. They are used in classifying data in Accident Facts. Definitions of these terms are reproduced here to clarify the previous paragraph.

> "Frequency rate is the number of disabling work injuries per 1,000,000 employee-hours exposure."
>
> "Severity rate is the total days charged for work injuries per 1,000,000 employee-hours exposure. Days charged include actual calendar days of disability resulting from temporary total injuries, and scheduled charges for deaths and permanent disabilities. These latter charges are based on 6,000 days for a death or permanent total disability, with proportionately fewer days for

permanent partial disabilities of varying degrees of seriousness."
(1, inside back cover)

An observer gathering logging data can readily subject himself to many typical hazards encountered in logging. In fact, some of the hazards are more dangerous to the data gatherer than to the logger since attention to details of data gathering often distracts one's attention away from potential "widow makers" and disablers.

SOME CAUSES OF LOGGING ACCIDENTS

Although the author has not made an extensive examination of logging accident reports, a brief survey of the files of the Industrial Accident Board at its offices in Helena, Montana, indicates that loggers are most frequently killed by 1) the limb of a tree which is either falling or "flying," 2) a falling tree, or 3) a falling log, (i.e. a section of a tree). These also appear to be the most critical hazards for data gatherers.

FALLING OR "FLYING" LIMBS

A standing mature lodgepole commonly has some limbs that are no longer securely attached to the trunk. An observed characteristic of the lodgepole is that as it matures it loses its lower limbs. Trees with limbs still in place but not securely held are common at cutting time when mature trees are harvested.

TABLE X
ACCIDENT SEVERITY AND FREQUENCY RATES FOR
SELECTED INDUSTRIES FOR YEARS 1959 - 1961

Severity Rate	Severity Rank	Industry	Frequency Rate	Frequency Rank
14,379	1	Anthracite mining	79.01	1*
7,680	2	Bituminous mining	26.45	7
5,935	3	Structural & ornamental metal work	25.76	10
5,587	4	Metal mining	26.36	9
4,767	5	LOGGING	32.32	4
3,537	8	Highway construction	30.46	5
3,329	9	Nonmetal mining	18.46	21
3,245	10	Heavy construction	26.37	8
2,658	12	Stevedoring	19.16	18
2,656	13	Sand and gravel	20.55	17
2,529	15	Harbor equipment (transportation)	42.17	2*
2,410	16	Construction work, not building	22.57	13
2,079	19	Mining, surface	8.73	19
1,976	20	Concrete products and ready mix	21.58	15
1,691	24	General building construction	18.68	20
1,657	26	Saw mills	22.27	14
1,543	30	Wood preserving	16.06	23
1,478	32	Wrapping paper	5.66	103
1,472	33	Sugar, beet	33.69	3*
1,221	42	Private yards (shipbuilding)	10.96	45
1,098	48	Pulp mills	6.23	96
888	59	Paper mills, unspecified	7.03	83
737	70	High explosives	1.95	153
695	79	Park employees (municipal)	18.82	19
583	92	Structural steel fabrication	10.01	53
539	94	Agricultural (machinery)	6.08	97
327	125	Wood containers	9.06	64
276	132	Furniture	8.04	73
222	143	Heavy electrical equipment	2.13	146
39	166	Small arms ammunition	.37	166

Ranks among 166 industries listed in Accident Facts (1,p.36-37) are indicated for the industries included in this table.

*Frequency worse than logging.

The limbs can fall or fly as a result of one of several possible causes. The more common causes are included in the following list:

1. Wind,
2. Brushed by another tree,
3. Movement of tree when felled,
4. Whip action as standing tree straightens after being bent by a falling tree brushing the standing tree,
5. Trees bumped in skidding operation,
6. Maturing of tree.

1. Falling limbs, a result of wind:

Wind can and does free dead limbs that have remained in place on a standing tree. The effect of wind on the limbs of trees left standing becomes greater as other trees in the immediate vicinity are felled. Standing trees are thereby left more exposed. Naturally, strong winds are more often critical than light breezes.

2. Falling limbs, a result of being brushed by another tree:

Limbs may be knocked loose when a falling tree brushes a standing tree. The causes of trees falling will be discussed later in this chapter.

3. Falling and flying limbs, a result of movement of tree when felled:

Occasionally a limb is so loosely attached to a tree that

just the movement of the tree as it starts to fall will cause the limb to fall. It is also possible for a limb to be snapped free, as a tree hits the ground, sharply enough to effectively "throw" the limb.

4. Falling and flying limbs resulting from whip action of standing tree:

A falling tree can fall against another tree. Sometimes the falling tree will cause the standing tree to bend severly and then will pass on by. The standing tree thus bent and released will tend to "whip" back to its natural position. A weak branch can be thrown with dangerous speed as a result of this whip action.

5. Falling limbs from trees bumped in skidding:

Trees bumped in a skidding operation may be jarred sufficiently to knock off weak limbs. The tree may be bumped by the skidding machine or by the "drag" of logs being skidded.

6. Falling limbs resulting from maturing of a tree:

Occasionally a limb will fall even though there is no "apparent" external force. This is not common but can result simply from the support strength becoming insufficient for the weight of the limb, particularly when the limb dies. Usually an external force such as wind will cause a limb to fall prior to the time when it would fall due simply to its own weight. Maturing of a tree (accompanied by the death of some of its limbs) normally combines with other factors

causing limbs to fall and is therefore an important, but seldom a singular, cause.

FALLING TREES

Falling trees are an integral part of the "felling" operation as currently practiced. Even though the desired result of the operation is that the tree should fall to earth, the feller has only limited control over the fall. He has some control over what direction the tree will fall and usually can exercise some control over the time at which the tree will begin to fall. That is about the extent of his control, and even the direction and timing of the tree's fall can be sufficiently influenced by other factors so as to make the feller's control insignificant.

Wind is perhaps the most unpredictable factor limiting a feller's control over direction and timing of the tree's fall. The typical lodgepole top acts very much like a large sail placed on top of a high mast. The effect of wind on the tree top can be far greater than the uninitiated might suspect judging from the breeze he feels a few feet off the ground.

In addition to the felling operation, there are other causes resulting in falling of standing trees. A list of common causes follows:

1. The felling operation (already discussed),
2. Wind,
3. Being struck by other trees,

4. Tractors or other machines bumping or pushing against standing trees. This is expecially true of pine trees with shallow root systems due to rocky soils;
5. A "drag" of logs bumping or forcing against a tree while the drag of logs is being skidded.

Falling trees, causes other than felling:

The chances of a tree falling as a result of causes other than the felling operation are greater for dead trees than for living trees. There are two reasons for this. First, dead trees are weaker, especially if partly rotted, than living ones. Second, dead trees or trees with serious rot conditions are not marketable and are often left standing when sound trees are felled. They are therefore left exposed to the full impact of wind and to other possible forces mentioned in the list of causes of trees falling.

FALLING LOGS

Logs can roll off a loaded or partly loaded truck, or they can come loose from the tongs of a loader or jammer skidder. In any of these situations, the falling logs are potential killers to anyone in the path of fall. The author himself observed no situation where a data gatherer needed to come into the potential path of fall of a log. Data gatherers, however, should bear in mind the importance of keeping a safe distance from loaded trucks, loaders, and jammer

skidders since the first accident due to a falling log is also usually the last.

ADDITIONAL LOGGING HAZARDS

Although the hazards already discussed appear to be the most frequent killers, there are others, including the following:

1. Rolling logs,
2. Power saws and other cutting tools,
3. Unsure footing,
4. Machines used in logging.

PRECAUTIONARY STEPS FOR DATA GATHERERS TO AVOID THE CAUSES OF LOGGING ACCIDENTS

An obvious method of avoiding injuries inflicted by falling or "flying" limbs, falling trees, or falling logs is to avoid being struck by any of them. This can best be accomplished, of course, by staying out of the woods.

Staying out of the woods, however, is not a satisfactory "problem solution." To gather much of the desired data about logging, data observers must go into the woods and must, in fact, stay relatively close to the operations (at least this is the case if present work study methods are used).

A realistic solution involves some risk of injury to the data gatherer. However, this risk is to be minimized as far as possible. A first step is to understand the dangers involved. The second is to avoid the dangers, unless they

cannot be avoided in gathering the data; and if they cannot be avoided, proceed with care.

Where appreciable risk is present, the value of the data should be weighed against probable cost due to the risk of gathering it. Even if one takes a "concerned about money only" attitude, it is well to bear in mind that accidents are very costly.

(13, Chapt. 3)

DRESS FOR SAFETY

Where safety devices are available, use them; where they are not, work to secure them.

A hard hat worn in the woods may turn a killer of a falling limb into a source of momentary (or relatively brief) discomfort. Of course, in the case of a falling tree or log the hard hat is not apt to provide much protection. However, the chance of reducing the effect of some hazards makes the hard hat worth wearing.

Boots featuring good traction and ankle support should be worn. Trousers should be stagged, or if they are not stagged, they should not be too long. Cuffs on trousers must be avoided. Do not wear a wide belt. If your pants will not stay up, use suspenders. Do not wear a scarf. If your neck gets cold, try a turtle-neck sweater.

Avoid <u>all</u> loose ends in wearing apparel.

BE ALERT FOR HAZARDS

Wearing the safest clothing possible reduces the dangers only a small (although significant) amount. Common hazards have been discussed. Study them until they are well understood, then watch for them constantly and avoid them at whatever cost of time may be required.

Be on the alert also for other hazards not included here, recognizing that this is by no means an all inclusive summary of logging site dangers.

Lastly, do not let familiarity breed contempt for danger. One cannot win a psychological warfare with snags and falling trees.

CHAPTER XVI
A PROPOSED DATA GATHERING SYSTEM

Earlier chapters have discussed four methods of data gathering in considerable detail. These methods are 1) time lapse photography, 2) standard speed and slow motion pictures, 3) stop watch time study, and 4) work sampling. This chapter deals with the problem of combining the four methods into an effective system which is aimed at obtaining the greatest data value for the lowest investment.

Difficulties and drawbacks sometimes associated with each method have been discussed in earlier chapters. For the most part, adversities and the problems they present will not be repeated here. Instead the potentials of the system will be presented for non-restrictive conditions. The reader is directed to earlier chapters for discussion of method limitations for each data gathering method.

The most effective combination of the four data gathering methods into a data gathering system will depend upon the circumstances of each situation encountered. Therefore, since the number of possible situations is large, this chapter attempts only to indicate what the system can and cannot do (using only the four methods listed in the first paragraph of this chapter) and guide planning of the system for economical application to particular situations.

CAPABILITIES OF THE SYSTEM

The capabilities of the system are, in effect, the combined capabilities of the four data gathering methods. Thus if a data requirement can be met by any method employed in the system, it can be met by the system. Table XI indicates individual method capabilities and total system capabilities for gathering typical types of information.

A data gathering system composed of the four data methods examined in this thesis can be used to gather some but not all of the types of data described in Table XI. In some cases simple additional aids can be used to obtain information outside of the capabilities of these four methods. Additional aids would include items such as pedometers for measuring distances workers walk in performing logging operations and instruments for measuring the ground slope in the area of the operation. These additional aids are, however, outside the scope of this thesis.

Most data that can be obtained with the system can be obtained with more than one of the individual methods. In these cases it becomes necessary to select a method or methods for most efficient gathering of required data.

PLANNING THE DATA GATHERING SYSTEM

Selection of the method or combination of methods for most effective gathering of required data may be based on a comparison of two factors, namely 1) cost of gathering data,

TABLE XI
INDIVIDUAL METHOD CAPABILITIES AND TOTAL SYSTEM CAPABILITIES FOR GATHERING TYPICAL TYPES OF INFORMATION

Data Description	Data Gathering Method: Time Lapse Photography	Standard Speed & Slow Motion Pictures	Stop Watch Time Study	Work Sampling	Aggregate of Four Part System
1) Elapsed times	Yes	Yes	Yes	No	Yes
2) Distance measurements	No	No	No	No	No
3) Operation time apportionment	Yes	Yes	Yes	Yes	Yes
4) Methods record	Yes	Yes	Yes	No	Yes
5) Motion study data	Yes	Yes	No	No	Yes
6) Operator rating	No	Yes	Yes	Yes	Yes
7) Delays	Yes	Yes	Yes	Yes	Yes
8) Environment variables (other than time and distance)	No	No	No	No	No
9) Multiple man & machine data	Yes	Yes	No	Yes	Yes

Columns under data gathering methods answer the question, "Is this type of data normally obtained through application of this method?"

and 2) value of data in terms of results, giving due consideration to difficulties and drawbacks associated with each method considered.

The following section discusses in general terms the comparative merits of the methods that can be applied to gather each type of data listed in Table XI. More specific comparisons can be made when specific data requirements for a particular study are determined.

1. Elapsed times:

Elapsed times can be recorded through application of three of the four data gathering methods studied here, namely: a) time lapse photography, b) standard speed and slow motion pictures, and c) stop watch time study. Selection of one over the other two will depend upon the situation.

Stop watch time study is generally the least costly where sufficient and satisfactory data can be obtained. Cost of time study is not a great deal less than the cost of time lapse film records. However, by the time film is analyzed to extract elapsed time data, cost of film data can be several times the cost of stop watch time study data.

Time lapse photography, though more costly than stop watch time studies, may in certain cases have sufficient value to override the extra cost. Four situations where this may occur are the following: 1) greater accuracy required, 2) operation too irregular for time study, 3) multiple men

and machines to study simultaneously, and 4) avoid disputes over time data.

Standard speed and slow motion pictures should rarely, if ever, be used in logging for elapsed time measurements due to excessive costs of the films and film analysis, the extremely short period that can be studied with one roll of film, and the infrequent need for the detail of time breakdown obtainable with such a film. The only exception visualized by the author at this time is the possibility of a motion study of a machine operator which requires extremely accurate time values related to the motion patterns.

2. Distance measurements:

Crude approximations of distance measurements can sometimes be taken from films (either time lapse or standard speed and slow motion pictures); however, most distance measurements are expected to require use of tape measures, range finders, and other measuring devices.

3. Operation time apportionment:

Operation time apportionment data can be obtained with any of the four methods studied here. The author's experience indicates ranking of the four methods from the least costly to the most costly will generally be as follows: 1) work sampling, 2) stop watch time study, 3) time lapse photography, and 4) standard speed and slow motion pictures.

Fixed interval work sampling using an interval of one minute or greater will generally be found to be the most easily applied of the four methods for situations where data obtained by this method is adequate.

Operation time apportionment using time study data or time lapse photography will seldom be economical unless other data requiring one of these methods is also required. It is doubtful that standard speed or slow motion pictures will ever be useful for operation time apportionment.

4. Methods record:

Either time lapse or standard speed and slow motion pictures or elemental breakdown by stop watch time study can be used to obtain a methods record. Appropriate selection will depend upon cycle time, consistency of cycles, and method detail desired. Time lapse films will, of course, be less costly but will also be less detailed than standard speed or slow motion movies.

5. Motion study data:

Highly refined and detailed motion study data can be obtained with standard speed and slow motion pictures. Such data may be of importance for studies of operators' movements to control various logging machines.

Movements of a logging machine itself may be sufficiently recorded by time lapse photography, particularly if shorter intervals such as one-half second or one second are used.

6. Operator rating:

Movies taken at standard speed and then projected at the same speed can be reviewed several times and by several people to arrive at an operator rating. The rating is then, of course, based on the small interval of time covered by the particular film record. Several rating films can be taken at different times and for different working conditions in order to minimize bias due to a single observation. Bias for any one particular film can be minimized through a combined rating of several people (provided these people are capable of proper rating and strive to give an accurate rating). Care must be taken, however, that the period rated is truly representative of the typical work period.

Rating may also be accomplished as part of a stop watch time study or a work sampling study. Generally, the person making the study can rate the operator periodically throughout the study, but the rating will be subject to bias imposed by the best judgment of one individual. This is, however, the most common method. Necessarily the lone rater must be highly objective in his work and be thoroughly trained.

7. Delays:

The amount of time occupied by delays can be determined by an "operation time" apportionment study. Placing delays into specific categories can be handled in the same way.

Work sampling will generally be the least costly method of obtaining this data as indicated on page 155.

Methods data (see page 156) records are expected to be of the most value in studies aimed at eliminating or reducing delays.

8. Environment variables (other than time and distance):

Environment variables refer to such things as ground conditions; snow, rain, wind, and other weather variables; slopes; condition of machines and tools; and many others. Some may be recorded on film by the photographic techniques, but many will require supplementary data gathering aids.

9. Multiple man and machine data:

This is really just a special case which may require any of the first eight types of data listed in Table XI.

Previous discussions will generally apply to this special case with one exception. The one exception is that stop watch time study is frequently impractical for collecting multiple man and machine data.

STUDIES REQUIRING MORE THAN ONE TYPE OF DATA

The preceding discussion applies primarily to studies involving independent data collection for each of several kinds of data in a given study.

Many studies require simultaneous collection of data of several types. Data gathering systems may then be designed to use more than one data gathering method or to collect two or

more types of data using one data gathering method; it is also possible to use more than one method with each method being used to collect one or more types of data.

To design a system for collection of several types of data, specific data requirements must be known. Rather than attempt to enumerate and analyze all the possible data requirement combinations that could occur, the author will discuss only one typical situation.

PLANNING A DATA GATHERING SYSTEM: AN EXAMPLE

Suppose for a particular operation the following data is required:

1. Methods record,
2. Total cycle time for 20 cycles,
3. Element time breakdown for 10 cycles,
4. Operator rating.

Assume total cycle time normally falls in the range of one to two minutes. This same information is required for a large number of similar operations, so that careful consideration of the methods to be employed is warranted. For purposes of illustration, let it be assumed that only the four methods of data gathering examined in this thesis can be used.

Table XII repeats a part of Table XI for the four types of data required in this example. It may be noted that "stop watch time study" and "standard speed and slow motion pictures" are the only data gathering methods capable of

obtaining all of the required data. From this one might make the highly uneconomical decision to obtain all the required data by recording twenty cycles on film using standard speed or slow motion photography for all twenty cycles (call this alternative #1).

TABLE XII
PORTION OF TABLE XI*

Data Description	Data Gathering Method: Time Lapse Photography	Standard Speed & Slow Motion Pictures	Stop Watch Time Study	Work Sampling
Methods record	Yes	Yes	Yes	No
Elapsed times	Yes	Yes	Yes	No
Operator rating	No	Yes	Yes	Yes

*This table repeats the part of Table XI which is appropriate to a selected example situation. Columns under data gathering method answer the question, "Is this type of data normally obtained through application of this method?"

A considerable saving from alternative #1 could be realized by filming one cycle at standard speed and then filming 19 cycles using time lapse photography (call this alternative #2). All cycles could be used for the methods record and total cycle times of 20 cycles. Any ten could be used for element time breakdown. Operator rating could be done using the cycle filmed at standard speed. This assumes, of course, that the one cycle filmed at standard speed is actually

representative of the average; otherwise, enough cycles would need to be filmed to obtain a statistically significant sample--at least five cycles.

Still further cost reduction might be possible if ten of the twenty cycle times were recorded by stop watch time study. Rating could be accomplished either by recording one cycle at standard speed and analyzing the film strip or as part of the stop watch time study (alternative #3).

If elements are known and readily discernible, all data could be obtained with a stop watch time study (alternative #4). This could conceivably require an even smaller investment.

Many other combinations of the four methods are possible and will provide the required data. It becomes apparent that consideration of all possible alternatives could become an unwieldly problem, and selection will therefore generally be based on an analysis of a relatively small number of alternatives chosen intuitively in the first place. As mentioned earlier in this chapter, selection of the one alternative for actual use can then be based on comparison of data costs and data value for the several alternatives.

CHAPTER XVII
CONCLUSIONS RELATIVE TO THE HYPOTHESES

THE MAJOR HYPOTHESIS

The major hypothesis underlying this thesis submitted that a data gathering system for logging is feasible. Material presented in this thesis neither proves nor disproves the major hypothesis, but it does present considerable support of a positive nature.

The author believes it is worth mentioning that one great data gathering system to cover all possible data requirements may very well be impractical, although specific systems to match specific data requirements appear very useful and practical.

Literature studied in connection with this thesis generally describes specific data gathering methods or systems designed to deal with acquisition of specific data. After attempting to conceive a great data gathering system to meet all data needs in logging studies, the author suggests that this approach is commonly avoided due to the enormity of the problem relative to the value it might provide.

THE SECONDARY HYPOTHESIS

The secondary hypothesis is concerned with the relationship of data cost to data value. Much more information relative to data cost and data value is needed before valid conclusions relative to this secondary hypothesis can be stated.

CHAPTER XVIII
RECOMMENDATIONS FOR FURTHER STUDY

Several possible areas of further study have been exposed in connection with this attempt to produce a data gathering system. Some have already been mentioned throughout this thesis. This section briefly mentions some specific areas for possible further study.

CATALOGUE SPECIFIC DATA GATHERING SYSTEMS

Although it may be impractical to develop one great data gathering system to cover all possible data requirements in logging, it appears practical and perhaps desirable to describe specific data gathering systems applied to specific situations (including costs and value of data) and to catalogue these specific systems for further reference.

MEASUREMENT OF LOGGING ENVIRONMENT VARIABLES

Techniques for measuring some of the many variables in logging (particularly those affecting logging costs) warrant further study. Currently this problem is largely unanswered, particularly where the variables are to be measured and related to particular cycles of logging operations without interfering with the operations.

IMPROVE ON DATA GATHERING METHODS ALREADY ANALYZED

This includes such things as recommended equipment modifications included in Chapter IV and relating to time lapse equipment. Some work has already been done in this area (for examples see Appendix I), but much more work can still be done.

APPENDIX

APPENDIX I

Two modifications to the original time lapse photography equipment have been made since the beginning of this study. They are the following:

1. Intervalometer modification,
2. Suitcase replacement by back pack.

The modifications are discussed separately in the following sections.

INTERVALOMETER MODIFICATION

The original intervalometer has been modified from a unit with a continuous range of speeds to one with a choice of two speeds, each of which is specifically and positively selected. For practical applications, the continuous speed selection range permits only approximate selection.

The modification has resulted in simplified operation and reduced weight, bulk, and awkwardness of time lapse photography equipment.

SIMPLIFIED OPERATION:

The modified intervalometer permits specific, positive interval selection. Thus it is possible to eliminate the clock. Operation simplifications resulting therefrom may be found on pages 55 through 63.

REDUCED WEIGHT, BULK, AND AWKWARDNESS:

Reduced weight, bulk, and awkwardness have resulted from elimination of the clock and clock arm as well as physical

physical changes in the intervalometer itself. The weight reduction is illustrated in Table XIII. Reduced size (bulk) of the intervalometer is illustrated in figure 17. Awkwardness has been reduced by 1) elimination of clock and clock arm, 2) reduced size and weight of intervalometer, and 3) attaching modified intervalometer directly to camera support. The photograph of figure 18 illustrates the comparable awkwardness of the original and modified time lapse equipment.

TABLE XIII
ILLUSTRATION OF WEIGHT REDUCTION RESULTING FROM INTERVALOMETER MODIFICATION AND CLOCK ELIMINATION

Item	Original Weight	Weights After Modification
Camera with attached actuator-counter	6.53 lbs.	Unchanged
Light meter	0.45 lbs.	Unchanged
Tripod assembly	4.45 lbs.	Unchanged
Intervalometer	5.50 lbs.	1.92 lbs.
Cable, 10 feet (modification has shorter cable)	0.37 lbs.	0.17 lbs.
Clock arm assembly and clock (part of assembly retained as support for camera and intervalometer)	1.75 lbs.	0.53 lbs.
Titling pencil and field note book	0.22 lbs.	Unchanged
Film, per 100 foot roll	0.43 lbs.	Unchanged
Carrying case	14.35 lbs.	Unchanged
Total	34.05 lbs.	29.05 lbs.

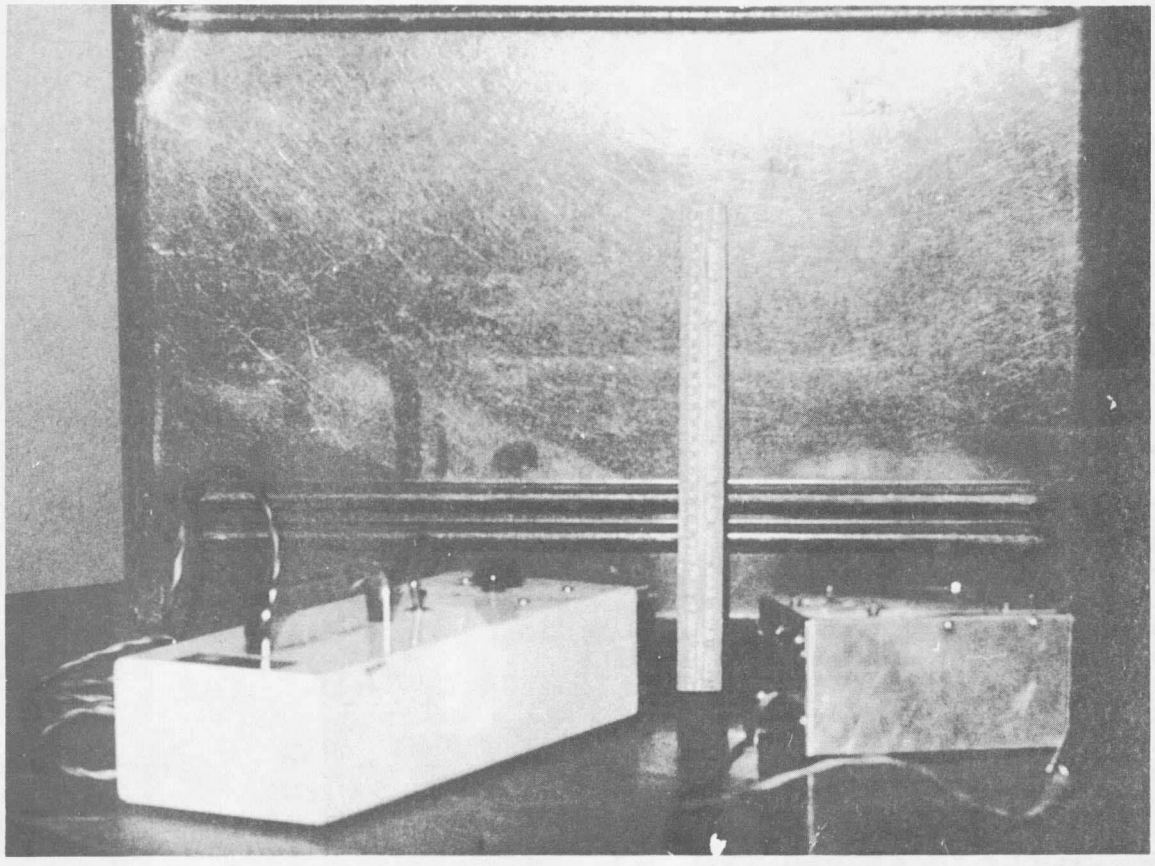


Figure 17: This shows a comparison of the physical size of the original and modified intervalometers.

Figure 18: The photograph illustrates comparable awkwardness of the original and modified equipment set up and ready for field use.

SUITCASE REPLACED BY BACK PACK

As mentioned on page 51, the equipment carried in the original suitcase creates a heavy load poorly distributed on the carrier for woods travel. The suitcase has been replaced by a specially made compartmentized canvas bag mounted on an aluminum pack frame. The resultant weight reduction is illustrated in Table XIV. Figure 19 illustrates the old and new equipment carriers ready for use.

TABLE XIV
ILLUSTRATION OF WEIGHT REDUCTION RESULTING
FROM REPLACEMENT OF SUITCASE WITH BACK PACK

Item	Weights with Suitcase	Weights with Back Pack
Camera with attached actuator-counter	6.53 lbs.	Unchanged
Light meter	0.45 lbs.	Unchanged
Tripod assembly	4.45 lbs.	Unchanged
Intervalometer	1.92 lbs.	Unchanged
Cable	0.17 lbs.	Unchanged
Support for camera and intervalometer	0.53 lbs.	Unchanged
Titling pencil and field note book	0.22 lbs.	Unchanged
Film, per 100 foot roll	0.43 lbs.	Unchanged
Carrying case (or back pack)	14.35 lbs.	7.17 lbs.
Total	29.05 lbs.	21.87 lbs.

Figure 19: This is an illustration of the old and new equipment carriers loaded and ready for woods travel.

In addition to weight reduction and better load position for the carrier, the new pack sack provides pockets for several items that cannot be carried in the original case. Addition items that can be carried in the pack sack are as follows:

1. Pencils,
2. First aid kit,
3. Extra batteries for intervalometer,
4. More film,
5. Screwdriver (for changing batteries),
6. Camera and equipment fully assembled for operation.

LITERATURE CITED

1. Accident Facts, National Safety Council, 1963 Edition.

2. Barlament, R. L. "Photographic Work Sampling--New Cost-Control Technique," Textile World, Vol. 108, No. 9, (September, 1958) pp. 52 - 53.

3. Barnes, Ralph M. Work Sampling, Second Edition, New York: John Wiley & Sons, Inc., 1957.

4. Carson, Gordon B., Editor, Production Handbook, Second Edition, New York: The Ronald Press Company, 1959.

5. Cesario, Frank J. Jr. Monte Carlo Simulation of Some Logging Operations, A thesis submitted in partial fulfillment of requirements for a Master of Science degree in Industrial Engineering at Montana State College, June, 1965.

6. Cine-Kodak K-100 Cameras, Rochester, New York: Eastman Kodak Company.

7. Dick, L. C. "Use of Movie Equipment in Reducing Mill Labor Costs," Paper Trade Journal, Vo.. 147, No. 35 (September 2, 1963), pp. 28 - 31.

8. Downs and Dodge, Editors, Who's Who in Engineering, Eighth Edition, New York: Lewis Historical Publishing Company, Inc., 1959.

9. Fondahl, J. W. "Photographic Analysis for Construction Operations," American Society of Civil Engineers--Proceedings Journal, Vol. 86 (J. Construction Division), No. CO2 (May, 1960) Pt. 1, Paper No. 2483, pp. 9 - 25.

10. Glossary of Motion Picture Nomenclature, Montana State College Department of Film and TV.

11. Haines, I. L. "Work Sampling by Fixed Interval Study," Journal of Industrial Engineering, Vol. 9, No. 4 (July - August, 1958), pp. 266 - 268.

12. How to Use the Kodak Cine Ektar 63mm f/2 Lens, Rochester, New York: Eastman Kodak Company.

13. Industrial Safety, Edited by Roland P. Blake, Third Edition, New Jersey: Prentice - Hall, Inc., 1963.

14. Kodak Cine Ektar Lens 15mm f/2.5, Rochester, New York: Eastman Kodak Company.

15. Kodak Cine Ektar II Lens 25mm f/1.9, Rochester, New York: Eastman Kodak Company.

16. Maynard, H. B., Editor-in-Chief, Industrial Engineering Handbook, First Edition, New York: McGraw-Hill Book Company, Inc., 1956.

17. Mundel, M. E. "Memomotion Study Technique Simplifies Work Analysis," Factory Management & Maintenance, Vol. 107, No. 6 (June, 1949), pp. 84 - 85.

18. Mundel, M. E. Motion and Time Study, Principles and Practice, Third Edition, New York: Prentice-Hall, 1960.

19. Niebel, Benjamin W. Motion and Time Study, Third Edition, Homewood, Illinois: Richard D. Irwin, Inc., 1962.

20. Noller, C. W. "How You Can Use Motion Picture Equipment," Flow, Vol. 7, No. 12 (September, 1952), pp. 74 - 77, 89.

21. Ostwald, P. F. "Using Memomotion Study to Determine Production Delays," Journal of Industrial Engineering, Vol. 14, No. 4 (July - August, 1963), pp. 208 - 211.

22. Rowe, A. J. "Time Lapse Camera," Modern Materials Handling, Vol. 8, No. 6 (June, 1953), pp. 67 - 69.

23. Timmins, A. A. "Memomotion--Valuable Work Study Technique," British Cast Iron Research Association Journal, Vol. 8, No. 6 (November, 1960) pp. 812 - 820.