

THE DETERMINATION OF PERFORMANCE
EVALUATION STANDARDS, IN THE
PETROLEUM PROCESSING
INDUSTRY

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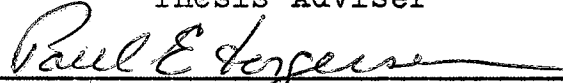
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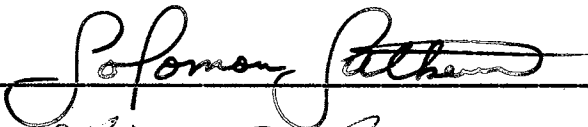
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PREFACE

Standards by which the work of persons engaged in direct labor operations may be measured have long been utilized to increase production and lower manufacturing cost. With the advent of increased mechanization, attention is shifting to the closer examination of indirect labor where formal standards traditionally have not often been applied. The determination of work standards for a large portion of indirect work has been discouraged by the cost of the necessary examination and measurement of work before valid standards could be determined. This dissertation is an investigation into methods which may be used to acquire the data necessary for the determination of valid performance evaluation standards at a cost lower than that incurred by presently used methods of work measurement. Discovery of these lower cost methods of work measurement will encourage the determination of standards by which performance may be evaluated for many types of indirect labor which, at present, lack such standards.

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CHAPTER I

PERFORMANCE EVALUATION STANDARDS

Broadly speaking, a performance evaluation standard is some criterion against which performance may be compared in order to determine the relative merit or value of that performance. In the field of Industrial Engineering, the predominant performance evaluation standard is the time required to perform a job. Nadler (1) defines a time standard as:

... the time an operation or element of an operation, performed with a given method under given job conditions should take when worked on by an operator with the necessary skill and given sufficient training to perform the operation properly, [and] working at ... [a] pace maintainable throughout the day, week, etc.

The word "operation," as Nadler uses it, refers to a set of duties assigned to a man or to a group of men working together as a team. A job consists of one or more operations.

Mundel (2) gives the following definition:

A standard time is a function of the amount of time necessary to accomplish a unit of work:

1. using a given method and equipment,
2. under given conditions of work,
3. by a worker possessing a specified amount of SKILL on the job and a specified APTITUDE for the job,
4. when working at a pace that will utilize, within a given period of time, the maximum physical exertion

such a worker could expend on such a job without HARMFUL EFFECTS.

Within this definition, the following word meanings are intended:

Skill - the ability to do a job in the proper manner; the ability to repeat a definite muscular pattern. Other worker characteristics being constant, the higher the skill, the faster the possible pace before the muscular coordinations fail.

Aptitude - physical fitness for the job.

Harmful effects - the results of excessive physical and mental activity caused by the work, which are not dissipated during the typical usage of the interval between work days.

To use this latter definition of standard time in actual practice, it is necessary to replace the word "function" with a numerical time value and to provide the proper descriptions wherever the words "given" or "specified" occur.

Mundel (2) adds:

Standard times are one of industry's most important measurements and are commonly used for the following purposes:

1. To set schedules. Production schedules are important in planning production and sales programs for an organization. They should permit proper coordination of departments, operations, purchases, and sales. This requires that they be based on reliable measures bearing a known relationship to expected production. Any standard time that is greater or less than that which may be actually expected as typical performance needs a known correction factor for use in schedule making, but is still quite usable ...

2. To determine standard costs. The remarks made under the use of time standards for schedules also apply here.
3. To determine supervisory objectives. A foreman is supplied with men, materials, machines, tools, and methods. It is his job to supervise their coordination to achieve an expected result. Time standards indicate the rate at which he is expected to coordinate his facilities in order to meet schedules and produce goods within the standard costs. Time standards may also help the foreman or supervisor in locating workers who need additional training, who are misplaced, or who have unusual aptitudes or apply themselves with unusual diligence; since the standards serve to indicate typical performance, or some proportion of it, an individual's performance may be evaluated against them.
4. To determine operating effectiveness. A plant usually prices its merchandise prior to manufacture. To do this it must predict how much labor or production-center time will be expended on each phase of the work, and must have a means of continuously comparing performance to predicted performance. For performance predictions, as with schedule setting, the standard times obtained by time studies are usable if they bear a known relationship to the time that will actually be required. Standard times for each operation are used for detailed cost checks on operations and in the determination of the exact places for the application of corrective action to jobs that are not being performed as expected.
5. To set labor standards. This is not necessarily in reference to wage incentives. Labor standards can be the levels of individual or group production deemed satisfactory, and may be applied without financial incentives. The standard times used for this

purpose should be readily attainable by the type of worker who is expected to be average for the job, in order not to make "substandard performance" typical and create a frustrated feeling on the part of the worker. The importance of this can hardly be over stressed. The unattainable standard may lead to some misconceptions, although it is usable if its relationship to possible performance is both known and used in applying the standard. The too readily attained standard may also lead to misconceptions and even to the withholding of reasonable production. Labor standards, properly determined and properly understood, are an asset to both management and labor, since they fix a level of satisfactory activity and protect the interests of both groups.

6. To determine the number of machines a person may run. ... time values for the human parts of the cycle ... [of work where a man works with a machine] ... are important factors in setting up the job method.
7. To balance the work of crews, coordinate or in sequence. Efficient crew work demands an even distribution of work units among the members of the crew. It is the crew member with the longest job who determines the output of the crew. Assembly lines and most crew activities usually achieve higher production and lower cost than individuals doing complete operations, because of the greater automaticity possible with smaller tasks, the specialized tooling and workplaces possible, and the reduction in training time and cost. However, an unequal distribution of work among the crew members can more than offset these gains.
8. To compare methods. As can easily be seen, a standard of consistent difficulty is required to provide an unchanging yardstick for the comparison of two or more methods of performing the same work. [The standard's] ... relationship to possible performance is immaterial.

9. To determine equipment and labor requirements. See remarks under schedules.
10. To provide a basis for the setting of piece prices or incentive wages. Incentive wages are a means of automatic financial supervision. They tend to reward the more productive worker in proportion to his output. They also give rise to worker insistence on management's keeping a steady flow of work during the working day and on eliminating sources of work stoppage such as poor maintenance.

To these uses of time standards should be added the fact that the determination of time standards and the resulting records-keeping often engenders a spirit of competition between men, crews and supervisors which not only increases production but inculcates loyalty to the crew, shift, supervisor and employer.

From the above, it can be seen that time standards in some form are essential to industry.

The traditional field where standard times have been applied in the past is direct factory labor, that labor which may be identified with a specific unit of product. The reasons for this concentration are largely economic. The following factors given by Barnes (3) are those which, if large or increasing, indicate potentially profitable areas for methods improvement and the setting of time standards:

1. The extensiveness of the job, that is, the average number of man-hours per day or per year used on the work.

2. The anticipated life of the job.
3. Labor considerations of the operation, such as:
 - (a) The hourly wage rate
 - (b) The ratio of handling to machine time
 - (c) Special qualifications of the employee required, unusual working conditions, labor union requirements, etc.
4. The investment in the machines, tools and equipment required for the job.

These factors are those typical of direct factory labor. Consequently, it could be expected that funds spent for methods improvement and for setting time standards on direct factory labor would obtain a relatively large return.

These same factors are not typical of indirect labor jobs. Indirect labor is that labor which cannot be associated with specific units of product, e.g., shipping and receiving, material handling, inspection, clerical, janitorial and maintenance labor. The special characteristics of indirect labor have made this field potentially less profitable for the application of methods improvement techniques and for the determination of time standards. Chief among the factors listed by Barnes which has discouraged the examination of indirect labor by the industrial engineer is the first, the extensiveness of the job. By its nature, indirect labor is varied, many diverse operations are performed as a part of one job. The number of times a given task or operation is performed is less than that encountered in direct factory labor. Consequently,

the number of times a methods improvement or a time standard is used on an indirect labor operation is usually less than the usage on a repetitive direct labor operation.

Krick (4) gives the following additional reasons for the industrial engineer's neglect of indirect labor:

Inertia explains this condition in part. It seems that it has been customary from the inception of this field to focus attention on direct labor jobs. That is the way it has always been and for many practitioners it is difficult for them to see doing otherwise. In some instances managements have awakened to the fact that their methods engineers should be spending more time on indirect labor, but they find it difficult to sell the "old timers" on the idea.

The explanation lies in part, though, in the fact that in general there are more difficulties and higher costs involved in improving, standardizing, and measuring indirect labor activities than in direct labor operations. The increased difficulty is attributable mainly to the greater variability of conditions, method and work content found in indirect labor activities. This is true of materials handling, maintenance, repair, janitorial work, tool making, and most indirect labor jobs. In addition, the decision or thought requirements of many indirect labor jobs makes standardization and measurement more difficult. This is true especially of supervisors, engineers, clerks, inspectors, and the like. The difficulty of measuring and standardizing quality is another troublesome factor. Of these factors, the primary deterrent seems to be the greater variability inherent to many forms of indirect labor in contrast to the relatively repetitive and consistent work patterns found in direct labor.

But this preoccupation with direct factory labor is changing. Barnes (3) says:

Until fairly recently motion and time study applications were mainly limited to direct factory labor. However, as more people learned about the objectives, methods and techniques of motion and time study, new uses were found for it. People began to see that its principles are universal and

may be equally effective wherever men and machines are employed.

Krick (4) continues in the same vein:

Although it has not manifested itself to any great extent in actual practice, there has been a noticeable increase in interest in the application of methods engineering philosophy and techniques to indirect labor activity. The reasons for this increased interest and talk are several. First, indirect laborers have been putting the pressure on management to include these jobs under the incentive wage plan. Many indirect laborers must work near and service direct laborers that are on incentive, yet the former are on hourly rate and do not have an opportunity to earn incentive premiums. This situation has caused considerable dissatisfaction, higher turnover, and frequently voiced complaints on the part of indirect labor. This pressure directly affects methods engineering, for before putting these jobs on incentive it is important that they be subject to thorough methods design and work measurement procedures.

Second, as a consequence of the trend toward increased mechanization, indirect labor has for centuries been becoming a greater proportion of the work force. This growth trend has been greatly accentuated by the fact that for decades methods engineers have been hammering away at the direct labor operations in the factory whereas indirect labor has received negligible attention in comparison. Some firms report that indirect labor now constitutes more than half of their total work force, and that it continues to swell at an alarming rate. This somewhat dramatic increase in the proportion of indirect labor is finally attracting the attention of methods engineers and their managements.

A third factor generating interest in application of methods engineering to this type of activity has been the tremendous growth of that segment of the business world referred to as service industries, which encompasses wholesaling, warehousing, retailing, transportation, finance, and many others. And not to be ignored is the growth of government. These trends have contributed to a general increase in interest in the indirect labor payroll and the vast cost reduction potential therein. Another factor that is forcing more interest in indirect labor is the fact that

many firms have grown so large that the efficiency of the organism has become heavily dependent upon if not limited by the communication system, the upkeep of facilities, and the effectiveness of the flow of product between operations. These functions are performed by indirect labor. Therefore, it has become apparent to some that not only for direct cost reduction purposes, but also to improve the overall functioning of the business enterprise, it is highly desirable to direct more methods engineering effort to indirect labor activity.

It should be noted that this quotation from Krick refers specifically to methods engineering. However, since methods engineering necessarily precedes and is logically and customarily followed by work measurement and the establishing of time standards, Krick's comments apply equally to these latter subject areas. In support of this contention and as a summary of the above, the following comments by Niebel (5) are offered:

The non-repetitive task, characteristic of many indirect labor operations, is more difficult to study and determine representative standard times for than is the repetitive task that is performed over and over again. Since indirect labor operations are difficult to standardize and study, they have not been widely subjected to methods analysis. Consequently, this area usually offers a greater percentage potential for reducing costs and increasing profits through time study than any other.

In view of the contribution to be made to industry by the application of time standards to indirect labor, this dissertation has as its principal objective the development of methods of determining indirect labor time standards in those areas where this determination is not now economically feasible. As Krick (4) states:

There is a dire need for development of new descriptive and analytical techniques for application to this [indirect labor] rather different type of activity.

Bentley (6) says that the "three principal areas of activity" where performance evaluation standards are commonly applied are labor, materials and equipment. He adds:

The labor unit of measure with the greatest significance is the man-hour unit ...

The standard for materials can be either in terms of number and type of materials used for the particular job or in terms of approximate money values and comparison made with an approximate index for a standard.

The standard for equipment can be in terms of equipment and hours used or translated into approximate money values and a comparison made with an appropriate index for a standard.

Mundel (2) was quoted above as saying that a time standard requires specification of methods, equipment and working conditions used or encountered in performing a job. Nadler (1) adds that in addition, "Raw materials are identified completely, giving such information as heat number size and shape, weight, quality, and previous treatments." On the same subject of information to be specified in a time standard, Mundel (2) includes "Product, material specifications and identification as related to the operation and work unit."

It can be seen then, that included in a time standard is not only the time allowed for a worker to complete a specific job, but also a specification of the methods,

materials and equipment to be used on the specific job and, if important, a description of working conditions. In broader terms, if man's performance is to be meaningfully evaluated, it proves economical to specify the more pertinent factors in the man's environment. Hence, a time standard, as defined, properly includes the specification of other factors beside the expected time required for a job. The factors which must be specified in a valid time standard constitute a quantitative measurement of the "three principal areas of activity," time, materials and equipment, which specification Bentley (6) calls "performance evaluation standards." Therefore, in order to more accurately describe the criteria developed in this dissertation, the term "performance evaluation standards" will be used instead of the term "time standard." In these criteria to be developed, the time allowed to perform the job will be of primary importance and, as Bentley (6) was quoted above, "The labor unit of measure with the greatest significance is the man-hour unit ..."

CHAPTER II

INDUSTRIAL MAINTENANCE

In Chapter I, the maintenance function in industry was cited as one example of indirect labor. Industrial maintenance has for many years been increasing in its relative importance as an element of production cost. Probably the prime reason for this relative increase in maintenance costs is the fact that as industry mechanizes more of its operations, it requires fewer direct labor workers. This factor increases the relative number of maintenance (and other indirect labor) workers. Increased mechanization naturally requires more maintenance labor and usually, since industrial machinery is becoming more complex, higher-paid labor. Harold Chandler, of Ernst and Ernst industrial consultants, is quoted by Villers (7) as saying:

Approximately 5% of every sales dollar is consumed on the increasing costs of plant maintenance that now exceed \$14 billion annually. And as more and more factory processes are mechanized and higher speeds, temperatures and pressures are introduced, maintenance expenditures will increase more rapidly.

Essentially, the purpose of the industrial maintenance function is to assure the continued, effective operation of industrial plant. Voris (8) writes:

The functions of plant maintenance, in their broadest possible application, usually are the design, specification, construction, layout and upkeep of:

1. buildings and grounds
2. plant equipment
3. plant utilities.

The Production Handbook gives a similar definition:

The task of maintenance is to keep buildings and grounds, service equipment, and production machinery in satisfactory condition according to the standards set by management. The work assigned to the maintenance department usually includes removals and installations of equipment. (9).

To this, Broom (10) adds:

Plant Maintenance consists of all of the various activities required to keep the factory building, processing and handling equipment, and tooling in standard working condition.

Plant Maintenance is not only a broad function, but also a very important one. It is intended to keep all production facilities constantly in service, if possible. It tends to minimize machinery and equipment breakdowns. It greatly reduces the interruptions to production operations and tends to preclude shipping delays to customers.

As in other indirect labor areas, the application of performance evaluation standards to maintenance work has only just begun. Charles E. Knight (11) in the Maintenance Engineering Handbook discusses the problems involved in determining these standards as follows:

Work scheduling is one of the most effective tools that can be used in improving the efficiency of any maintenance department.

Most repetitive repairs can be profitably studied for the best approach, and a standard procedure developed. A typical standard practice sheet should include specifications for the tools required, the necessary parts and

supplies, a sufficiently detailed print of the equipment indicating the components with sufficient clarity for the craftsman to follow the instructions, a step-by-step procedure with complete notes to cover any unusual or critical steps and a close approximation of the time required. The development of these sheets is time-consuming and expensive and rapidly changing conditions and equipment may make them obsolete quickly.

A few companies have established work-measurement programs where it is theoretically possible to set a definite standard for maintenance costs at varying levels of activity and then compare actual performance against this standard ... If properly administered and used for the purpose intended, such a standard can be extremely useful in maintenance management. Unfortunately, the overhead cost of most work measurement programs detailed enough to be useful for this purpose is high and can be justified only by a large plant or by an industry having many similar plant operations. In this case a study by an independent industrial engineering firm may be practical.

The above comments by Knight are typical of other authors who recognize the need for valid performance evaluation standards for maintenance tasks. For further discussion of this problem, see Middleswart (12), Broom (10), Voris (8), and Heritage (13).

As a measure of the importance attached to the determination of performance evaluation standards for maintenance, several varied approaches have been made toward the solution of this problem.

Rotroff (14) says:

Estimating is probably the most crude method [of determining performance evaluation standards] and one of the first to be used by industry. It is generally based on opinion only, or past performance records modified by opinion. Experience has shown this to be a most unsatisfactory

technique. Prejudiced by inaccuracies in production records, delays and other hidden conditions, the resultant standards are extremely inconsistent one with the other.

A somewhat better approach could be described as the historical record, performance-ratio system in which maintenance records are examined to determine ratios of maintenance cost or personnel performance in terms of time to some current statistic such as pounds of product produced, dollar value of plant investment for a certain area, man-hours, machine-hours, etc. Such standards are more expensive to develop and maintain than the estimated standards described by Rotroff and are limited in usefulness because of their lack of specific detail. One obvious deficiency of this type of system is that it does not specify the methods, materials and equipment to be used on specific jobs. The main value of the historical record, performance-ratio system of establishing performance evaluation standards is then as a control mechanism, a post facto examination of performance. The value of the performance evaluation standard determined in this manner for planning and scheduling future operations depends upon records of time, methods, materials, and equipment kept supplementary to cost records. Since these further records add considerably to the cost of determining performance evaluation standards, they are seldom recorded. Some industrial firms, nevertheless, continue to use the historical record, performance-ratio system in the belief that further

refinement of performance evaluation standards is uneconomical. For recent applications of this system, see Luck (15) and (16).

Of time study as a technique for determining performance evaluation standards, Krick (4) says:

Because of the unusually high degree of variation in method, work content, and quality, stop watch time study in many cases is too time consuming to be practical. The same is true to an even greater degree of the use of predetermined motion times. Work Sampling is more suitable for indirect labor measurement because it provides a sample of many workers, jobs and conditions and yields a grosser standard or set of standards, which is what should be sought for highly variable indirect labor tasks.

For an example of an application of the "predetermined motion times" Krick speaks of, see Vlahos (17).

Middleswart (12) also considers work sampling an appropriate technique for determining performance evaluation standards for maintenance work. He says:

This [work sampling] system is usually aimed at personnel performance only. However, certain cost data may be compiled, in addition to the sampling data, which will help plant management to evaluate maintenance performance ... The work sampling is done by making a series of random observations of personnel engaged in maintenance work. The observer records the activities of the craftsman according to predetermined categories. Some of the categories are for productive work; others are for non-productive work. Sufficient observations are made each reporting period to ensure sufficient statistical accuracy for the conclusions to be reported.

One obvious deficiency of this type of statistical system is that it does not in itself attack the problem of methods. A craftsman may be working diligently but using a very wasteful or inefficient method. He could, however, be reported as working usefully by the observer, since it is

the man's productive activity and not his method which is being observed.

In describing a work sampling wage incentive application at the Johns-Manville Corporation, Barnes (3) writes:

It is apparent that work sampling will be valuable in supplementing the other forms of time study -- especially in measuring crew or group operations, materials handling, inspection, clerical, and indirect labor operations. There should also be many advantages in applying work sampling to auditing existing standards. In brief, the advantages and disadvantages are as follows:

ADVANTAGES. (1) As compared to stop watch time study, an industrial engineering labor-time saving of 17% could be realized in future applications of this type. An additional 20% could be realized in clerical work if IBM mark-sensing cards were used for the observation and production recaps.

(2) The study can be completed earlier by the use of work sampling, especially in the case of crew standards.

(3) A more representative sample of the production, delays, and other time factors can be taken. In case of this standard, it was possible to study 9 days for each crew member in 9 days, instead of 1 day for each member as would have been the case by continuous stop watch studies.

DISADVANTAGE. It is more difficult to observe faulty methods. This could be minimized through preliminary analysis and frequent checks on method throughout the study.

For further examples of work sampling as a technique for the examination of indirect labor, see Moder and Halladay (18), Torgersen (19), Bogenrief (20), MacNiece (21), and Mahaffey (22).

It can be seen that work sampling is being used to determine performance evaluation standards in several areas of indirect labor. The primary advantage of this technique is that of cost. Barnes (3) says:

It usually requires fewer man-hours and costs less to make a work sampling study than it does to make a continuous time study. The cost may be as little as 5% to 50% of the cost of a continuous time study.

Because of the lower cost of work sampling, accurate, useful standards may now be determined in many areas of work in which the amount or volume of work is too low to justify the expense of work measurement and setting standards by the other methods described above.

Even with this reduced cost, however, there remain many types of work upon which it remains uneconomical to determine performance evaluation standards even with the lower-cost method of work sampling. This dissertation is, in part, an examination into still lower cost methods of arriving at these standards in order that a greater portion of industry should gain the benefits of the application of performance evaluation standards. Chapter III will describe a typical segment of industry which would benefit from the development of lower cost methods of determining standards.

One other method of determining and applying performance evaluation standards should be discussed, however, before the subject of maintenance is left.

Niebel (5) says:

Where the number of maintenance and other indirect operations is great and diversified, the task of developing standard data and/or formulas to preprice all indirect operations may appear to be more costly than the expected savings brought about by the introduction of time standards. In order to reduce the number of different time standards for indirect operations, there has been an effort by some engineers to develop universal indirect standards.

Probably the most widely used of these "universal indirect standards" systems is "Universal Maintenance Standards" developed by the Methods Engineering Council under the direction of Harold B. Maynard and G. J. Stegemerten, President and Vice-President respectively of this organization. Maynard and Stegemerten (23) in discussing the application of performance evaluation standards to maintenance work write:

The catch -- and it's the one that has held back the application of standards to maintenance work for years -- is the high cost of developing standards for the great variety of non-repetitive jobs that make up maintenance work. Job standards set by individual time study are out of the question. Such a system requires too high a ratio of time study men to maintenance men.

Standard data or time formulas are a better answer. But the time and cost required to compile and apply standard data are still deterrents ...

To get away from the high costs of development, attempts have been made repeatedly to develop standards from historical cost data. These attempts have almost always been unsuccessful because of the unreliability of historical records.

Then, Maynard and Stegemerten go on to describe their own approach to the problem of developing standards:

To simplify this task, Methods Engineering Council has developed over 125 standard-time

formulas, which after checking and adjusting to existing conditions can be used to set standards on most maintenance jobs. Any unusual work not covered by the formulas can be measured by individual time study.

These universal indirect standards have been used in several large organizations. For one such successful application, see Kornfeld (24). However, their high installation cost (\$25,000 - \$50,000) precludes usage in medium and small organizations. Too, the authors make no claim for the accuracy of measurement of the system. Universal Maintenance Standards is designed to provide relatively "loose", i.e., inaccurate, standards so that maintenance workers may be paid incentives on the basis of their performance over a week's or month's time in comparison with the Universal Maintenance Standards standards. The theory is that inaccuracy, in the form of excessive times allowed for certain assigned tasks, will be offset by inadequate standard times for other tasks if the time period over which the comparison is made is long enough. Improvement in maintenance performance is obtained because the maintenance worker is paid in proportion to the amount by which he exceeds the standard over the predetermined time period for comparison. Even if this is true, however, many of the other advantages of performance evaluation standards cited by Mundel in Chapter I are reduced in value, or lost entirely, through the use of the Universal Maintenance Standards system.

CHAPTER III

PETROLEUM REFINERIES

Although the equipment in a petroleum refinery appears complicated, it is in principle, quite simple. The majority of this equipment is associated with one of three main refining processes. These processes are:

1. Distillation and Fractionation
2. Cracking
3. Polymerization and Alkylation.

Distillation and Fractionation

In passing through a modern refinery, petroleum is subject to a great many operations. Many of these operations are separations of the petroleum into its various components by the distillation process. In the majority of refining processes, crude oil is refined to produce only the following products:

- a. Fuel gas
- b. Gasoline
- c. Naphthas
- d. Kerosene
- e. Furnace Oils

f. Diesel Oils

g. Fuel Oils.

Each of these products has a distinct boiling point. Distillation may be defined as the separation of a liquid mixture containing several components with different boiling points into its components by heating the mixture and recovering the separated components by condensation.

In order that the separation of a mixture such as crude oil may be efficient, i.e., in order to recover the maximum amount of each of the various components, more than one distillation step is required. In each distillation step, the vapors that are evolved carry off a portion of higher boiling point material which, if subject to a second distillation, can be separated out. For this reason, a series of distillation steps is necessary in making a desired separation in order to obtain maximum recovery of the desired fractions. When a separation is made by such a series of distillations, it is termed fractionation. In fractionation, the vapor formed in distillation is brought into contact with a condensing medium (known as a reflux) so that a portion of the vapor is condensed to a liquid. If this liquid, which is known as condensate, is allowed to contact vapor from a distillation process, heat is transferred from the vapor to the condensate. The lighter portion of the condensate is revaporized while the heavier portion of the vapor is condensed and, therefore, the condensate remaining has a relatively lower boiling point and

is purer than the vapor which was originally contacted with the condensate. By repeating the contact between vapors with progressively higher average boiling points and partially condensed vapors in a series, the desired separation between the products may be obtained by fractionation. The number of steps required for the separation is dependent upon the ease of separation and the specifications of the desired products. These two factors must be taken into consideration in the design of equipment for commercial fractionation.

The two main pieces of equipment used for distillation or fractionation are the shell still and the pipe still. But, as Hengstebeck (25) writes, "Shell stills have been almost completely supplanted by 'pipe stills' which are cheaper to build and operate."

A modern pipe still is shown in Figure 1. In this unit, the heat for vaporization is supplied by heating the crude oil in a furnace or heater. This heated crude oil is charged into the bottom of a distillation column and the vapors rise through the column, contacting the condensed liquid flowing downward; as a result, the lightest materials concentrate at the top of the column, the heaviest materials at the bottom, and the intermediate materials between. Desired products are withdrawn at appropriate points.

Since some lighter product is always carried off with the heavier products, steam "strippers" are often used to

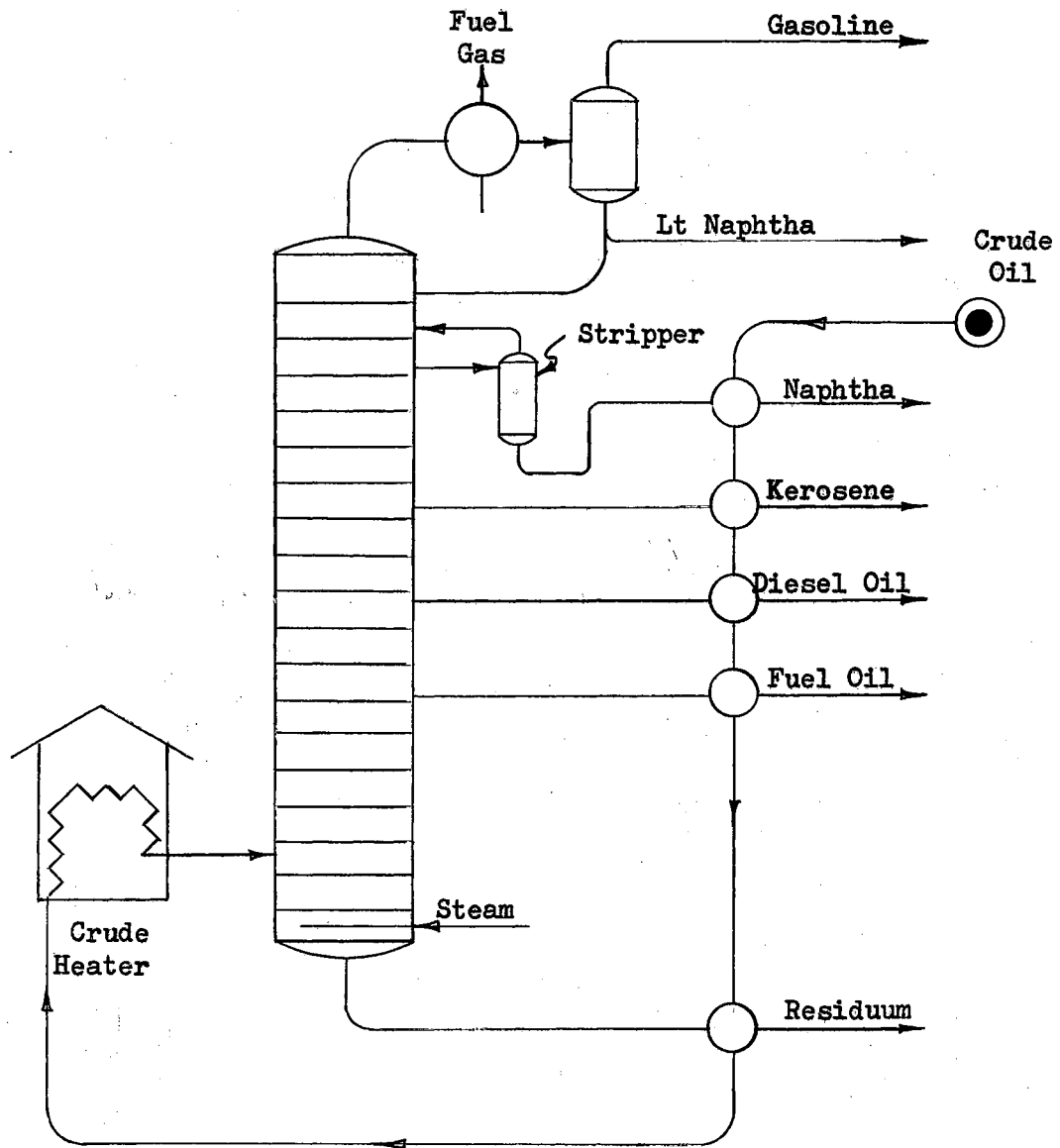


Figure 1. A Pipe-Still Crude-Distillation Unit
(A Schematic Diagram)

re-volatilize the lighter constituents and feed them back into the column.

Some materials have too high a boiling point or are too sensitive to heat to be distilled at atmospheric pressure. Because boiling points decrease as the pressure is lowered, such materials can often be distilled under vacuum. Vacuum distillation units are very similar to atmospheric crude distillation units, except that the large vapor volumes at lower pressures require that columns be much larger. Vacuum columns as large as 40 feet in diameter are in operation.

In a fractionating tower, the vaporized portion of the crude oil passes upward through one or more perforated "trays" or separators across the diameter of the tower. "Bubble cap" trays, shown in Figure 2, are the type usually employed. These bubble caps are partially submerged in liquid or reflux. While the vapor passes upward from one tray to another through the bubble caps, the liquid flows downward through the tower from one tray to another.

Cracking

Cracking as a petroleum-refining process was first used before World War I to increase the proportion of gasoline stock obtainable from crude oil. It had previously been discovered that the molecular form of petroleum could be changed by the application of heat and pressure. The result of this application of heat and pressure was a

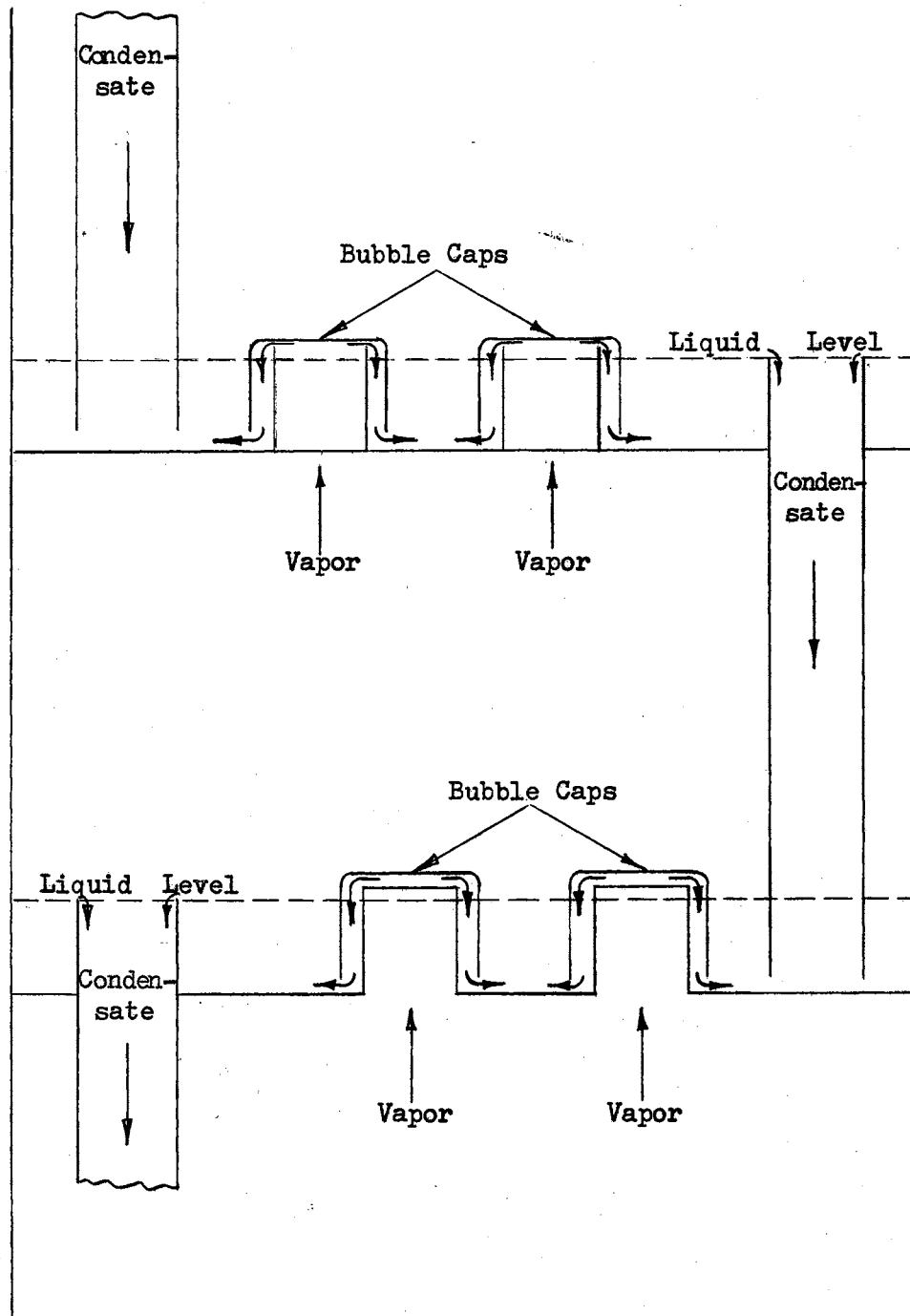


Figure 2. Trays and Bubble-Caps of Fractionating Column

greater quantity of gasoline stock produced per unit of crude oil and an improvement in the characteristics of this stock over that produced by distillation.

Thermal cracking is accomplished in a vessel quite similar to that used for distillation. The raw stock is charged into the vessel, lighter components are driven toward the top and heavier components are taken from the bottom. Vessels are usually designed to process products within a relatively narrow range of characteristics and are, of course, of heavier construction than distillation towers in order to withstand the greater pressures developed.

Shortly after the development of thermal cracking catalytic cracking, a much more economical process, was discovered with the result that thermal cracking is now much less often used than catalytic cracking.

A catalyst is defined as a substance which speeds up or accelerates a chemical reaction without itself undergoing a chemical change. The catalysts used in petroleum refining include activated clay, aluminum hydrosilicates, fullers earth, aluminum chloride, sulphuric acid, chromium, nickel and aluminum oxides.

The primary advantages of catalytic cracking over thermal cracking are due to the ability of the catalytic process to subject the petroleum charge stock to more severe conditions and thereby obtain higher conversions and higher quality gasoline than is physically possible with

the thermal type of cracking units. This advantage is largely due to the fact that the heavy residue from the process is deposited on the solid catalyst, where in the thermal cracking unit residue cannot be removed during operation.

A modern catalytic cracker is shown schematically in Figure 3. This diagram is typical of the Houdrifiow and the Airflow Thermoform processes. In this diagram, catalyst flows by gravity from the disengaging hopper to the reactor. Here, the "charge stock" or petroleum product to be cracked is sprayed over the catalyst and the products resulting from the action of heat, pressure and catalysis are drawn off near the bottom of the reactor.

The catalyst is stripped of most petroleum components by steam admitted near the bottom of the reactor and then falls into a second vessel called a regenerator or regeneration kiln. Here most of the petroleum residue is burned off. The catalyst then falls through the lift engaging hopper whence it is blown to the catalyst hopper and is then ready for subsequent identical cycles.

Catalysts are solid materials with acidic properties. Most of the catalyst used in cracking is in the form of pellets three to four millimeters in diameter. Catalysts gradually lose their effect in use because of adsorption of metals, high temperatures and petroleum residue which is not burned off. Consequently, catalysts must be replaced periodically. The life of the catalyst is dependent

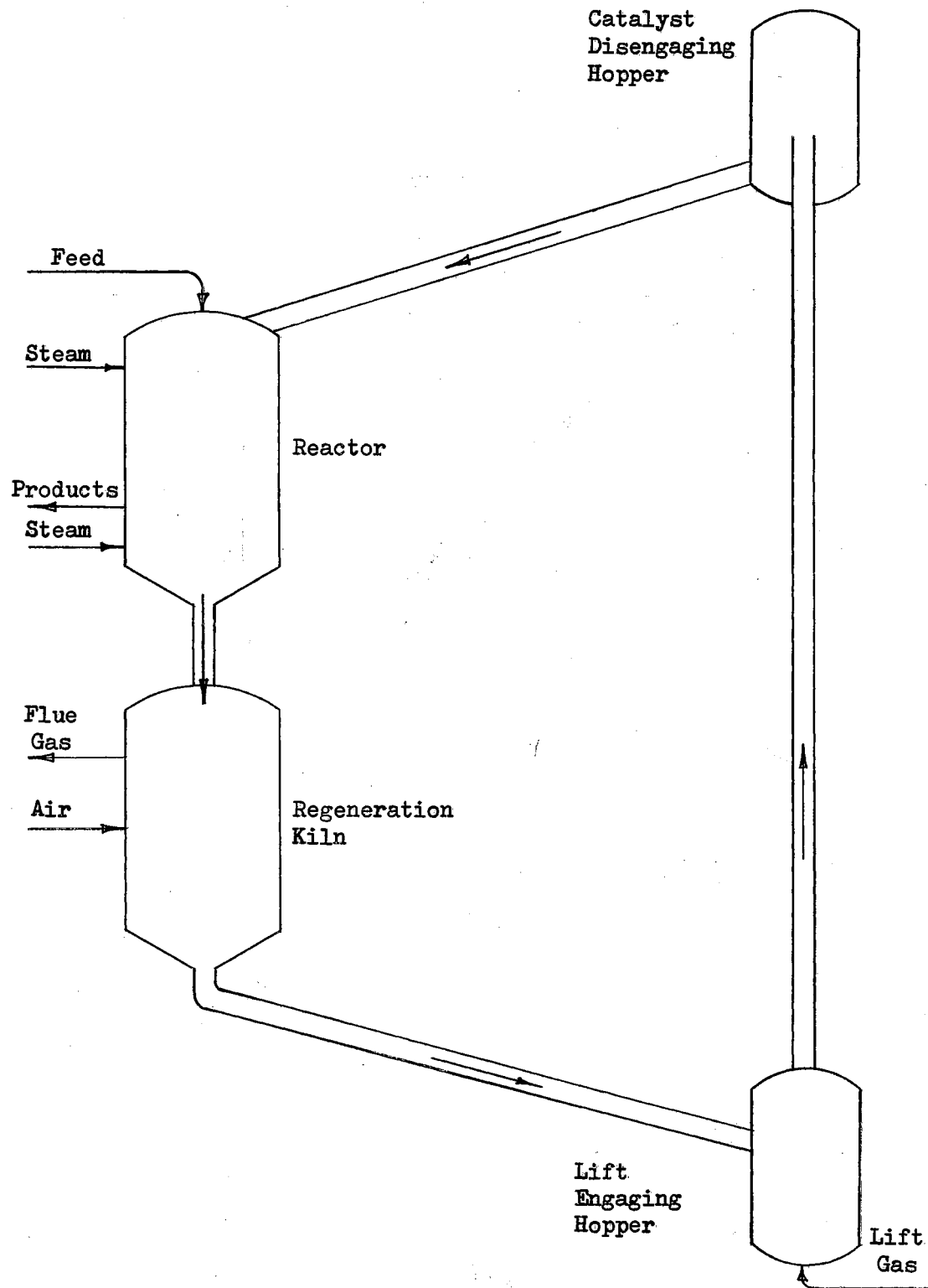


Figure 3. Schematic Diagram of a Gas-Lift Moving-Bed Catalytic Cracking Unit

upon a number of variables, but could be said to average about one year in constant usage.

Polymerization and Alkylation

Cracking was developed to produce a greater amount of gasoline from the heavier constituents of crude petroleum. This same demand for more gasoline encouraged research into means of producing gasoline stock from the lighter constituents of crude oil. Polymerization is a process whereby two or more small hydrocarbon molecules called olefins are combined to produce a larger molecule. Thus, any product of distillation or cracking lighter than gasoline stock may be subjected to the polymerization process. Commercial polymerizations have been carried out with propanes and butanes as feed stock.

A polymerization reaction may be carried out by means of heat and pressure, and, as such, occurs in thermal and catalytic cracking plants. Most of the residue or "coke" that is found in thermal cracking units is a mixture of heavy, high molecular weight polymers. As in the cracking process, it was found that the introduction of a catalyst into the polymerization process resulted in improved characteristics of the product and a more economical process.

Alkylation is a similar process in which the olefin molecule is combined with a somewhat heavier molecule, such as methane. The result is a gasoline stock with a higher octane rating than can be produced by polymerization.

Since the demand for higher octane gasoline is increasing, alkylation is becoming a more popular process regardless of its considerably higher construction and operating costs.

Probably the most common polymerization catalyst is phosphoric acid. As shown schematically in Figure 4, the feed stock is first pretreated to remove impurities and then passed over a bed of catalyst. Volatile gasses are removed from the resulting product leaving a high octane gasoline stock.

To be sure, there are a large number of different processes used in modern petroleum refineries. The great majority of these, nevertheless, are closely related to one of the three processes described above.

Heat Exchangers

One other important piece of refinery equipment should be discussed before proceeding further. This piece of equipment, in essentially the same physical form, performs several different functions and, hence, is variously called a heat exchanger, cooler, condenser or heater.

Nelson (26) writes:

The ultimate source of heat in the refinery is the steam boiler and the ... pipe still. Indirectly, heat is obtained or saved from the various petroleum products by cooling them with the raw charging stock. These products, at a high temperature, are passed through tubular equipments called heat exchangers, vapor heat exchangers, vapor condensers, or tubular coolers. If the two materials that exchange heat are liquids, the

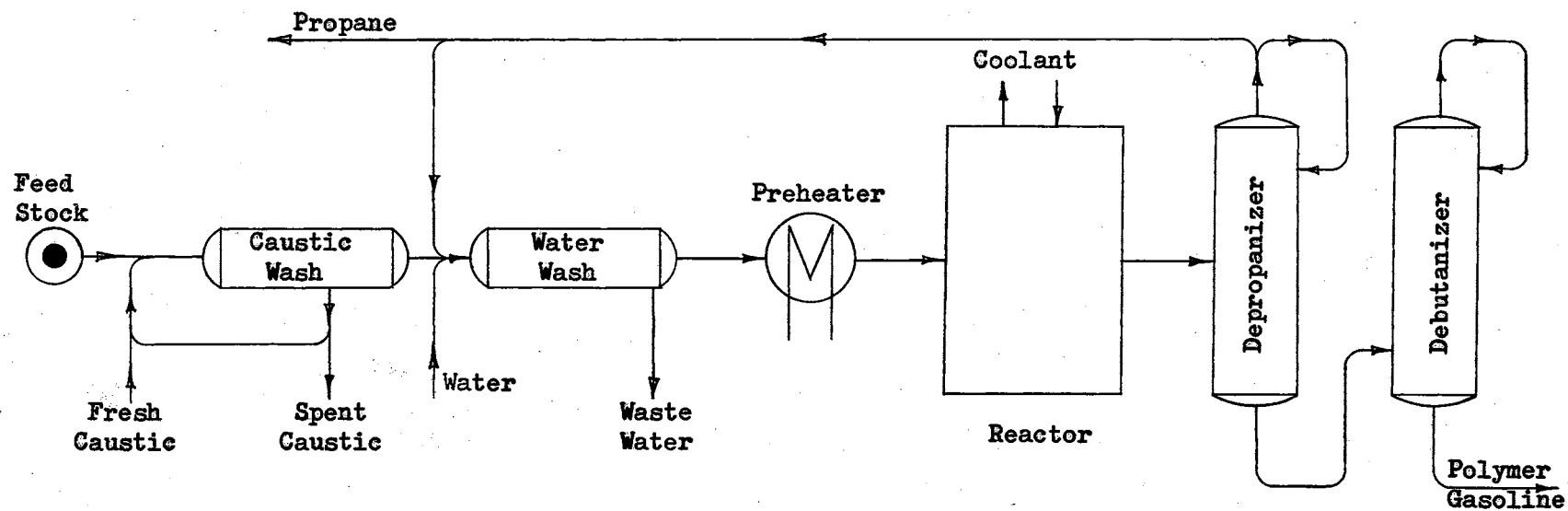


Figure 4. A Schematic Diagram of a Phosphoric Acid Polymerization Unit

equipment is referred to as a heat exchanger. If the hot material is a vapor and is cooled without much condensation, the equipment is called a vapor heat exchanger. If the vapor is condensed, the equipment is called a condenser, and the equipment subsequently used to cool the condensate is usually referred to as a cooler or after-cooler.

Since the function of this type of equipment is the exchange of heat, equipment performing the functions described by Nelson will be referred to as heat exchangers. Figure 5 shows the type of heat exchanger which, according to Nelson, is most often used in petroleum refineries. As can be seen in Figure 5, the tubes are free to expand and contract longitudinally by pushing the floating head back and forth within the shell. If, for example, this heat exchanger is to be used to preheat crude oil before sending the oil through the distillation process, steam could be circulated through the tubes of the exchanger and the crude oil pumped around these tubes in the direction shown by the arrows. The crude oil then absorbs heat from the tubes without the steam and oil mixing. In the parlance of the refinery then, the steam is passed through the "tube side" and the crude oil through the "shell side." Nearly all heat exchange equipment is similar in function and design.

Petroleum refining is essentially a continuous process. Ideally, petroleum refining equipment would function 24 hours a day, seven days a week. Being a continuous process, petroleum refining is somewhat similar to the

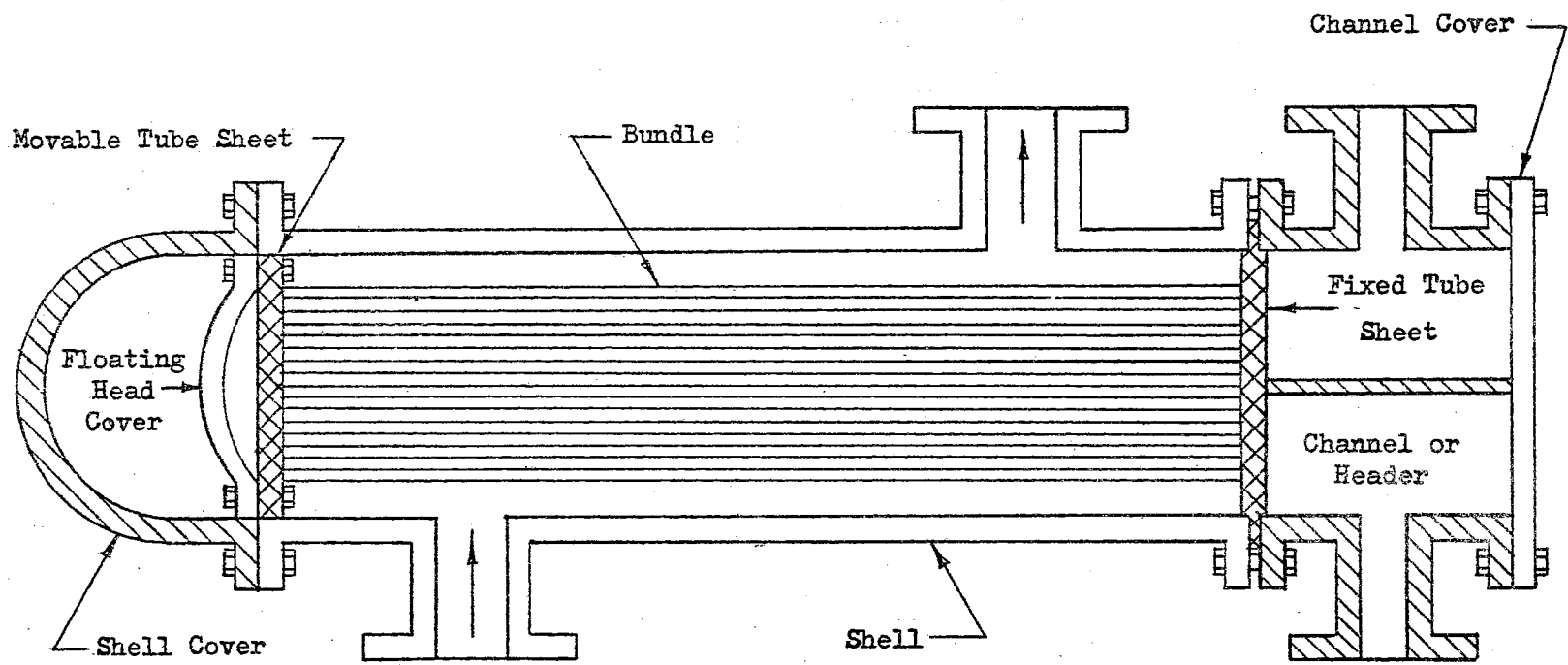


Figure 5. Shell and Tube Heat Exchanger

production of automobiles on a production line. That is, if one production unit in a sequence malfunctions or breaks down, the remaining units in that sequence cannot continue to function. Assuring the continuity of operations in either of these processes is then a problem of the utmost importance. This assurance of continuity is the chief function of the maintenance department.

Most petroleum processing equipment is capable of functioning continuously for extended periods of time. To assure continuity, duplicate facilities are provided wherever possible so that in the event of a malfunction or breakdown, these duplicate facilities may be used until the original piece of equipment is repaired or may be continued in use with the original piece of equipment held in reserve. However, with the trend toward more expensive processing equipment, duplicate facilities are not feasible in many cases. For example, a relatively small catalytic cracker capable of processing 5-6,000 barrels of feed stock per day would cost around \$2,000,000 to build at today's prices according to Noel (27).

Since mechanical equipment is not capable of running indefinitely without repair and since unplanned shut-downs are usually quite expensive, it is customary in the petroleum industry and nearly all other continuous process industries to shut down periodically for a major repair. In the petroleum refinery, this shut-down is called a "turn-around" and repairing, cleaning, or overhauling a piece of

major refinery equipment during this time is referred to as "turning the unit around."

Most refinery equipment is now capable of running for extended periods of time without repair. Consequently, it is customary in most refineries to "turn-around" production units once each year. (It is necessary to turn-around some older units more frequently, sometimes as often as once per month.) Normally, all units in an integrated process are opened and inspected. On the basis of this inspection plus a list of needed repairs made up by supervisory and operating personnel, cleaning and repair work are accomplished as quickly as possible.

Noel (27) estimates that the world outside the Iron Curtain nations has some \$20 billion invested in petroleum refining equipment. Using one week as a rough estimate of the average turn-around time, some \$400 million represents the cost of equipment idled at any one time by the turn-around in these refineries alone. In addition, much of the chemical processing industry and, to some extent, all continuous process industries share the same problems. In order to estimate the cost of the turn-around to industry, to the cost of idle facilities one should add the net profit from the sale of products which would have been produced during the time equipment is shut down, given that a market for these products exists, the fixed costs involved and the cost of extra labor hired for turn-arounds. It can be seen then that the turn-around is a

major item of expense to industry.

Industrial engineering techniques practiced by graduate industrial engineers, and quite often by those without formal industrial engineering training, have resulted in major changes in the portion of industry characterized by short cycle, repetitive operations. Through motion and time and economy studies, many products are now being produced at a fraction of their former cost. Now, as it has been explained above, industrial engineers and others are becoming increasingly interested in extending these and other techniques from concentration on direct factory labor to the study of indirect labor of all types up to and including, management.

It has been mentioned previously that the technique called work sampling has extended considerably the type of work which can economically be studied. In other words, this technique in many cases can be used to study work at a lower cost than that of the time study or the production or all-day study. Consequently, improvements can be made and performance evaluation standards may be set on types of work in which the potential profit through methods improvement and standardization is not so great as that associated with the typical direct labor job. Work sampling, however, although less costly than other, more traditional work measurement methods, leaves many areas of work which remain uneconomical to measure and for which to set performance evaluation standards.

The turn-around in the petroleum refining industry has been chosen as typical of that general type of work which is still uneconomical to study by existing work measurement methods. Many turn-around jobs are performed only once each year. The potential saving on these jobs is relatively small as compared to the potential saving on more repetitive jobs and, therefore, the "budget" for work study and standardization is necessarily small. The cost of inefficiency on these relatively seldom performed jobs is judged by management to be less than the cost of developing performance evaluation standards and these jobs will continue to be planned, scheduled and controlled in an informal and a variable manner until management determines that a net benefit is to be derived through establishing definitive standards.

As evidence of the fact that quantitative performance evaluation standards, as they have been defined above, are seldom determined and utilized, the literature of the field shows few references to this subject. See Adams (28), Allen (29), Carmine (30, 31), Warne (32), and Tippit (33). Each of these articles relates the advantages of planning, organizing, scheduling and controlling refinery maintenance and/or turn-around work; but significantly, none of these authors shows evidence of using performance evaluation standards in their most usable and valuable form, i.e., based on the time required to perform a specified task.

In further investigating the application of performance evaluation standards to refinery maintenance work, the writer interviewed operating and maintenance supervisors from four major oil companies, two independent oil companies, one large chemical manufacturing company and a vice-president of the Methods Engineering Council. This latter firm is an industrial engineering consulting firm which, among its other functions, sells and installs the Universal Maintenance Standards system. The chemical manufacturing company and one major oil company, being subsidiaries of the same corporation, were conducting a study to determine the feasibility of jointly installing the Universal Maintenance Standards system. In conjunction, these two firms employ some 5-600 maintenance men so that the high initial cost of installing Universal Maintenance Standards could be "amortized" over a large amount of work. According to the vice-president of the Methods Engineering Council, this installation would be the first such installation of Universal Maintenance Standards in the petroleum industry. The other oil companies, ranging in size from small to major in terms of output, felt that the benefits to be derived from installing Universal Maintenance Standards were not great enough to offset potential savings within a reasonable "payout period."

Several other interesting facts with reference to performance evaluation standards were discovered during these interviews. First, without exception, the personnel

contacted were very much interested in the development of more accurate performance evaluation standards, particularly if these standards could be obtained at an economical cost. The chemical plant mentioned above was, at the time of the interview, in the process of installing a maintenance planning section in which experienced maintenance foremen were to plan and schedule regular maintenance work on the basis of historical records and personal experience. If it were decided that the Universal Maintenance Standards system was to be installed, these same men would be taught the system and continue their work using these standards. This method constituted the most organized system of maintenance planning and scheduling found among the firms interviewed.

The remainder of the firms depended upon an informal system of planning and scheduling. Maintenance and operating management in this system determine the work to be done and the general sequence of work required to complete it. The maintenance foreman is then scheduled by providing him with a list of jobs to be performed and the sequence in which they should be done. Control of maintenance tasks is accomplished in an equally rudimentary manner usually consisting of accumulating material and labor costs charged to a particular unit of equipment. This type of control is aimed more at identifying units which are overly expensive to maintain than at the effective use of labor.

The persons contacted also stated reasons for their

belief that determination of performance evaluation standards for turn-around work would be difficult. First, much petroleum refining equipment is closed in normal operation and, thus, is not susceptible to internal inspection. Therefore, exact determination of the work to be done cannot be accomplished before the equipment is shut down, opened and inspected. At this time, work must proceed with all possible speed because of the usually considerable cost of "down time," i.e., the time during which the unit is inoperative. This factor, it is contended, allows little time after opening a production unit for planning and scheduling.

In answer to this contention, subsequent conversation and observation revealed the following:

1. Experienced refinery equipment operators and engineers can diagnose with accuracy the ills of this equipment by operating characteristics. For example, in heat exchangers used to pre-heat crude petroleum, the petroleum is passed through the "shell side" and in time sediment and residue begin to build around the water or steam tubes (see Figure 5, p. 34). Using a simple formula taking into account the inlet and outlet temperatures and flow rates, the amount of deposition or "fouling" can be accurately determined. Cleaning time required, then, is a simple extrapolation of this information.

2. Inspection techniques have been and continue to be improved. For example, a device which operates on the "sonar" principle of transmitting and receiving sound waves is in operation in many refineries. With this device, the thickness of pipes, vessels, valves, etc., may be determined without taking them out of operation. In this way, the need for replacing equipment worn dangerously thin may be determined without dismantling the equipment and the job may be adequately planned and scheduled in advance of the turn-around.
3. Much work in the turn-around is routine and is determined in advance of actual turn-around. For example, if the turn-around plans call for shutting down a fractionation tower for the purpose of overhauling the interior, then in all probability all of the trays in the tower will be removed and replaced rather than removing and replacing only the trays found defective upon inspection (see Figure 1, p. 24). The thinking here is that it is relatively less expensive to replace all trays as long as the unit is out of service than to risk the chance that a used tray inspected and judged satisfactory will malfunction later during the normal operation of the unit. This

latter case might very possibly idle a sequence of equipment worth several million dollars. In addition, some pieces of equipment give no evidence of impending failure. These units are replaced routinely without inspection.

A rather special circumstance in connection with this particular piece of equipment is that since there are a limited number of entrances or "man ways" to the tower, all of the trays between the entrance and a single defective tray to be removed would have to be moved to provide egress for the defective tray.

4. There is a distinct possibility that production units could be opened for inspection and then allowed to sit idle while further planning and scheduling are accomplished. Here, the crew of men who open the unit could proceed on to the opening of other units and then return when necessary work was specified, planned and scheduled. Involved would be some loss of efficiency due to travel time for men and equipment; however, the equipment used in opening equipment consists primarily of hand tools, chain hoists and/or trucks and, consequently, crew and equipment are relatively easy to move.

A second difficulty in determining performance evaluation standards asserted by those interviewed has to do with the number of "variables" inherent in the measurement of indirect labor. The more important of these variables are enumerated as follows:

1. Variation in the amount and character of work required in repairing and cleaning closed production units. This is essentially what has been discussed above.
2. Variation in the time required to perform identical work. One person may require widely different amounts of time to perform the same task. This is a variable which will be encountered wherever work is performed by man. This same variation is encountered, for example, in assembly work which is repetitive direct labor. Two people performing the same job can also be expected to require different amounts of time (and material) to accomplish the same task. This, too, is a variation inherent in all manual labor. These two factors reduce the exactness of performance evaluation standards but have not precluded the wide usage of such standards in industry.
3. Variation in quality. Quality levels naturally vary in manual operations between different persons and in the work of the same person.

This is another variation inherent in direct as well as indirect labor and for which appropriate provision can be made.

4. Variation in physical environment. Turn-around work is for the most part necessarily performed outdoors. Thus, the weather, i.e., temperature, wind, humidity, produces variations in working conditions seldom encountered on indoor jobs. The same job may be performed at various locations, e.g., inside a tower, standing on the ground or on a platform. The same job may take longer at night because artificial lighting is not adequate. Some bolts which appear identical may rust more than others.

These physical variations are a serious deterrent to work measurement and establishing standards. This is so not because the effect of physical variations cannot be accurately measured, but because the cost of doing so is often greater than the benefits to be derived from the measurement. In other words, the limiting factor is one of economy.

The problem of providing usable performance evaluation standards for work in which conditions are widely variable can be attacked in at least two different ways. First,

produce a single standard for a particular job assuming specified "average" or "ideal" conditions and empirically modify the standard to fit the actual conditions encountered. As a compromise between accuracy and economy, this standard would be less accurate than a standard designed to meet specific circumstances, but on the other hand would be economically justified. And, in most cases, being in existence, the standard would be considerably more valuable than no standard at all. A second method of surmounting the economic problem would, of course, be to reduce the cost of providing standards. This will be discussed below:

5. Variation in methods used to perform work.

It is asserted that in addition to the variations in the manner of performing maintenance and turn-around work listed above, that quite often there are variations in methods, materials and equipment used, crew sizes, and crafts of the men utilized in doing the same job. These are precisely the things which are specified in a performance evaluation standard. This assertion is analogous to saying that the patient is ill because he has not received the cure. In other words, the standard would

specify the best-known combination of these factors in order to do the job most economically. In setting a standard, not only has the best-known method been specified, but a source of considerable variation has been removed.

In summary then, to answer the objections to determining performance evaluation standards for turn-around tasks in particular, and for long-cycle, non-repetitive jobs in general, it could be said that, due to the necessary compromise between cost and accuracy, standards for these jobs will probably be less accurate than those feasible for short cycle repetitive jobs. Nevertheless, in view of the many advantages of these standards, including their proven ability to increase productivity and lower costs, every effort should be made to find ways in which performance evaluation standards may profitably be applied to segments of industry where they have not previously been applied.

As Davidson (34) says in the 1952 edition of his book:

a. There are methods of solution which do not require time standards of the conventional type, and which may provide solutions in some cases superior to those resulting from the application of time study methods; and,

b. No single basis, with its associated techniques, is likely to provide for each function the most appropriate type of time standard or estimate.

The problem defined in this section may be somewhat analogous to weather forecasting. While

comparatively free from human factors, meteorological phenomena nevertheless involve highly complex relationships. For some purposes, it may be desirable to have a prediction of precipitation on a small area within some specified period of several hours duration. Some other function may require estimates of the mean precipitation in a large region, such as a watershed, over a period of months. The bases and techniques for the two types of forecast are not identical. Both, however, have their foundations in fundamental knowledge and theory of the phenomena.

Davidson adds in the 1957 edition of Functions and Bases of Time Standards:

A new requirement is imposed upon time standards which are to be suitable for production planning purposes. To be useful in planning for production of a new product, or of an old product by means of a new or revised process, time "standards" must be available before production commences. Such "standards" might better be called estimates of the average production rate which will be attained in operation or "required time forecasts." The difference in terminology is advisable, we think, in view of the difference in functions. Where time standards may be used in a wage payment system they actually serve as a standard, or basis, from which incentive earnings are computed. Where time standards may be a useful means of accomplishing cost control, the standard together with its control limits serves as a basis for comparison ...¹

Cost control is a function which we found to be inadequately defined in the literature of time study. Usually the term has been employed to describe any activity or result of an activity which pertains to costs. Many of the activities or results to which writers on the subject often allude as cost control can better be described as cost reduction, and quite obviously can be accomplished with or without the establishment of time standards. The modern concept of a control function requires not only a standard but limits by which variation from the standard is judged to be significant or not significant. Time is only one of the

¹Italics supplied.

many variables through which cost control might be accomplished. In some instances it may not be at all useful. Though its end purpose is also economic, labor productivity control can be differentiated from cost control and is a function where the appropriate kind of time standards may have considerable application.

CHAPTER IV

MEMOMOTION

Memomotion is a technique developed by Marvin E. Mundel (2) who writes:

Memomotion 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 ... Memomotion may ... be used to study the flow 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.

Memomotion film bears a closer resemblance to a series of individual photographs than to motion picture films exposed at normal speeds. To analyze memomotion film, a special projector is used which allows each frame or photograph on the motion picture film to be projected individually and to remain motionless on the projection screen as long as the analyst requires. The analyst who wishes to examine the activities of a worker, a machine or some other phenomenon records the state of activity or condition of that in which he is interested in one frame or photograph and then advances the film frame-by-frame to note successive changes in that activity. The projection of memomotion

film is therefore quite similar to a series of slides shown by a slide projector. With memomotion film in which photographs are made at regular intervals, the analyst is able to determine the exact interval of time between successive photographs.

To continue with Mundel's comments:

Memomotion study finds its primary field of use with any of, or any combination of, the following:

- a. Long cycles.
- b. Irregular cycles.
- c. Crew activities.
- d. Long period studies.

It is used for the following reasons:

1. It will record interrelated events more accurately than visual techniques. In addition, it facilitates studying tasks which consist of irregular sequences of events that cannot be predicted in advance and for which records of both method and time are desired.
2. It reduces film cost to about 6 per cent of the cost with normal film speeds and consequently reduces the amount of film to be analyzed without reducing the period covered.
3. It permits rapid visual review of an extended period of performance. When a film taken at one frame per second is projected at the normal speed of 16 frames per second it permits viewing a film of an hour of operation in four minutes. In addition to saving time, viewing with a compressed time scale brings to light novel aspects of the subject being studied. It is often instrumental in developing new ideas for better methods.

In addition to these advantages of using memomotion study, Nadler (1) gives the following advantages in general of filming work:

The most detailed and accurate procedure for gathering data for analysis of work involves motion pictures. Motion pictures represent a record of the work which has been performed and a technique for communicating to foremen, workers and others ideas about what is happening and what is being done. Motion pictures dramatize situations to all concerned, presidents to the workers. Motion pictures can focus attention to any point or motion in an operation. Motion pictures can help "sell" improved methods, partly by pointing out inefficiencies of the original method. In many types of work situations, motion pictures are the only way of getting a good analysis of the work. For example, work which requires crews of three, four or more men is frequently difficult or impossible to analyze to obtain exact interrelationships among the men by either the observation or discussion procedure. Motion pictures can be run forward and backward to obtain the exact relationships among the individuals. Motion pictures can be taken at various speeds to obtain the proper amount of detail for a given situation.

Memomotion, developed within the last 15 years, has opened up new areas of work study, especially those which have the characteristics described by Mundel.

Mundel (2) recommends the following equipment for memomotion study:

Sixteen-mm camera (8-mm film is not quite adequate) with an f1.5, 1-inch lens or better, or an f1.2, wide angle (12-mm) lens. The wide angle lens is used most frequently. The camera should have a good spring motor and a variable speed for taking pictures. However, a motor drive is preferable to a spring motor. The camera should have a shaft to which the motor drive can be attached ...

The ideal setup includes a synchronous motor drive for the Eastman Ciné Special which provides speeds of 60, 100, 1000 and 1440 (sound speed) frames per minute with a gear shift for rapid change from speed to speed.

A projector used for film analysis must have specific features somewhat different from the conventional projector. The optical system must have heat filtering sufficient to permit prolonged

examination of single frames. A frame-by-frame advance of the film, forward or backward, must be convenient; the projector should have a built-in frame counter ... Obtaining the exact relationship between the two hands or the members of a crew is much easier with film than with actual observation, since the film can be stopped and the action held still from step-to-step during the analysis. Each frame may be individually examined and notes made of the method and the time for each step.

The memomotion technique was first used for research in preparing an article for Life magazine in 1945, and it was first used in industry in 1947. (35). For more recent applications of the memomotion technique, see Earle (36), and Anne Shaw (37).

CHAPTER V

THE MEMO-ACTIVITY CAMERA

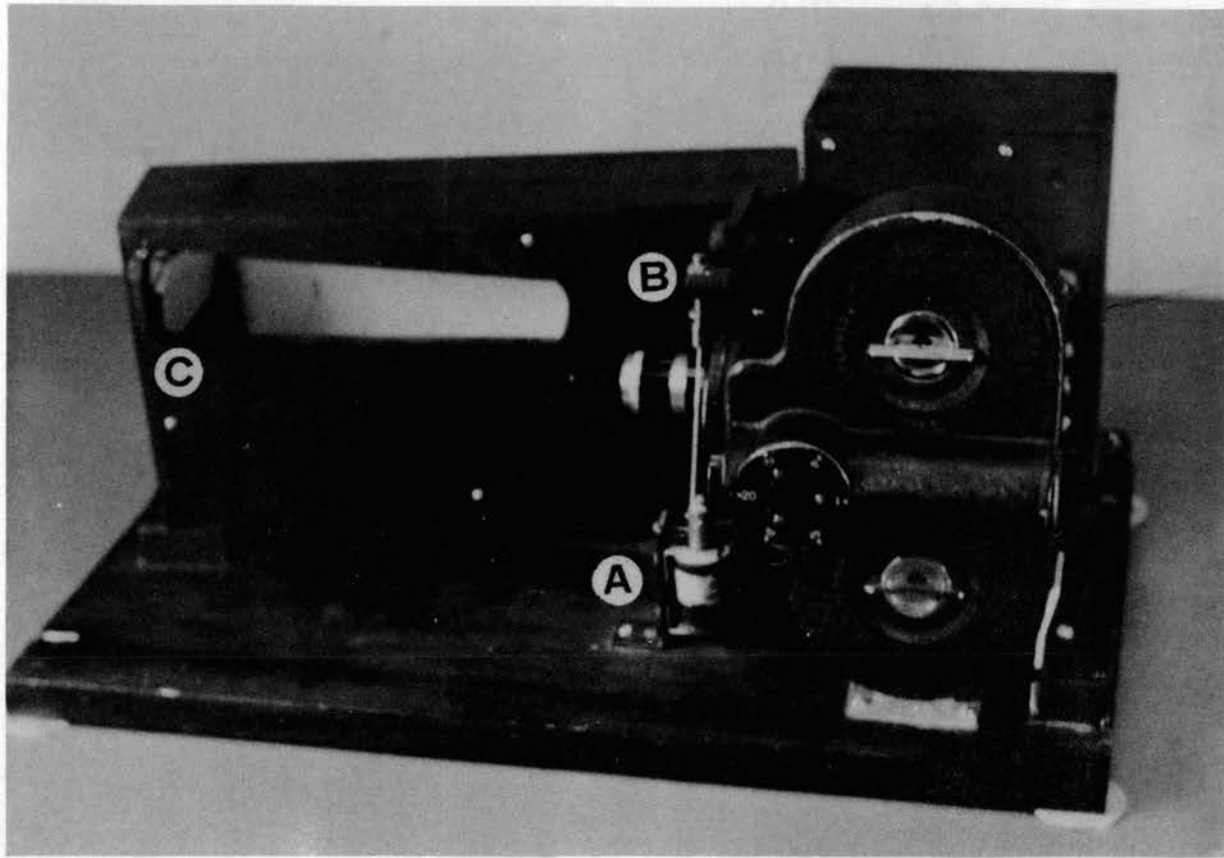
A camera somewhat similar to the memomotion camera has been designed and developed by the School of Industrial Engineering and Management at Oklahoma State University. This camera is called the memo-activity camera because its principle and use are an extension of the memomotion technique. The first model of the memo-activity camera is shown in Plate I. The camera is actuated by a solenoid (A) which depresses the film button of the camera (B). Included in the camera's field of view is a mirror (C). This mirror reflects the image of a watch so that the film, when exposed and developed, carries on each frame the exact time at which the exposure was made.

It is possible to determine the elapsed time between various frames of film if the rate at which the film was exposed is known and by counting the number of frames between two points on the film. By using the expression:

$$\text{Number of minutes between two events} = \frac{\text{Number of frames exposed between two events}}{\text{Exposure rate in frames per minute}},$$

the actual elapsed time between events which have been

Plate I. The Memo-Activity Camera



filmed may be determined if the filming was continuous at the same rate between events. Thus, the total elapsed time for a job or some other phenomenon may be determined by continuous filming at a known rate and subsequent counting of the number of frames exposed. But counting the number of exposures or frames in a memomotion study has several disadvantages. Some of these disadvantages are:

1. Since memomotion films are exposed at various rates (usually 50, 60, or 100 frames per minute), there the possibility that the rate of exposure at which the film was made could become unknown. There is no notation on memomotion film of the speed of exposure and loss or misinterpretation of records would greatly reduce the value of memomotion studies.
2. Conversion of times in terms of fractions of a minute allows chance for error.
3. Analysis of micromotion film requires a special projector with a frame counter.
4. Frame counting for long cycles requires the analyst to mentally or manually record the number of times the frame-counting dial revolves since the dial records only 100 frames per revolution.

5. Frame counting allows the calculation only of relative time where absolute time may be of importance. For example, the analyst might wish to know if "breaks" were taken by workers at the same time each day or shift or if workers started or quit work at variable times.

With reference to the possibility of overcoming some of these disadvantages of memomotion by including a clock in the scene photographed, Mundel (2) says:

A clock is seldom used, since a large area is often covered with the camera -- either by getting far enough away from the area of activity or by "panning" around it, thus making it extremely difficult either to obtain a large enough image with the typical microchronometer or to keep a clock in view.

It can be seen that the memo-activity camera by including the image of the watch on each photograph, obviates all of the disadvantages cited above except number three. Plate II shows the mechanism which puts the image of the watch on the mirror at point C. It is necessary to "fold" the distance between the camera lens and the clock with mirrors in order to reduce the apparent size of the watch. The image of the watch (D) is reflected from mirror (E) to point C where it is photographed.

The memo-activity timing mechanism is shown in Plate III. The timing wheel (F) is driven at a speed of two revolutions per minute by an electric motor. As the timing wheel turns, the pins marked 1, 2, and 3 strike the

Plate II. The Memo-Activity Camera

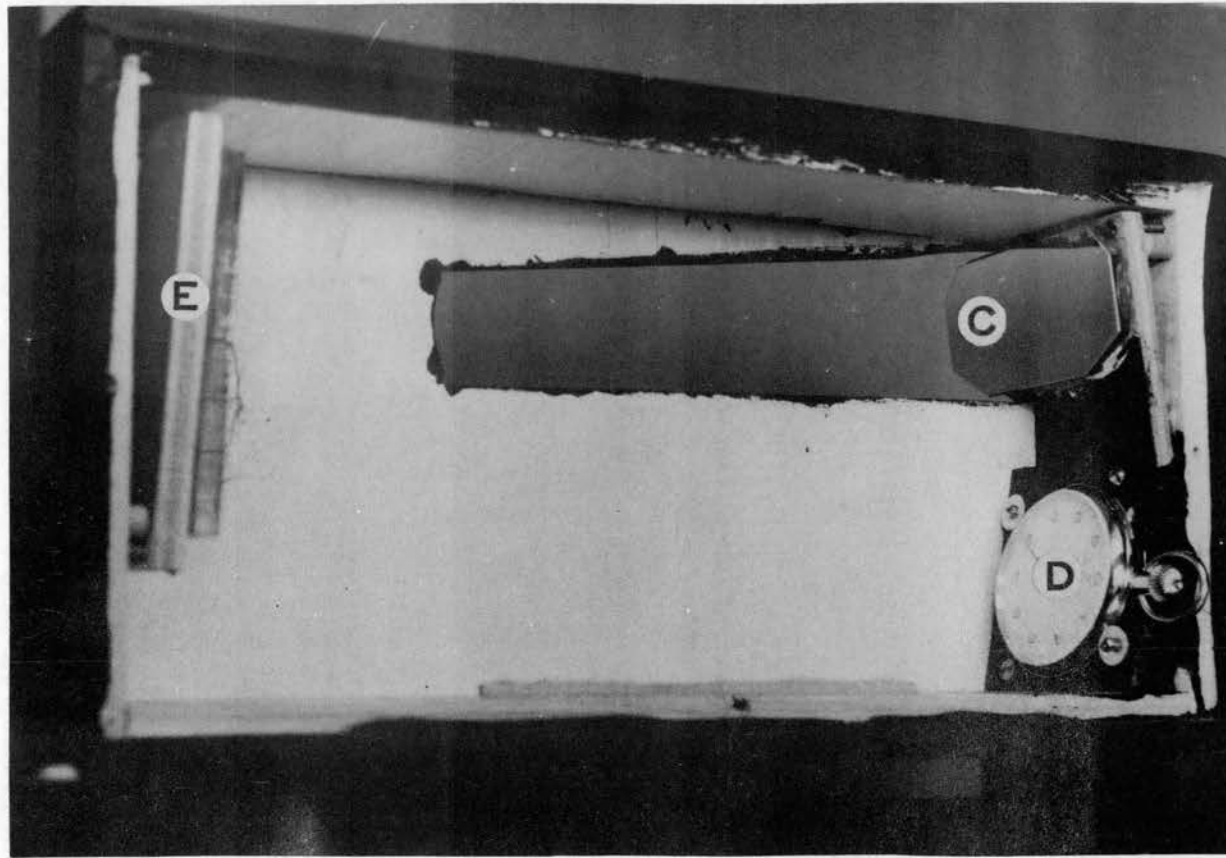
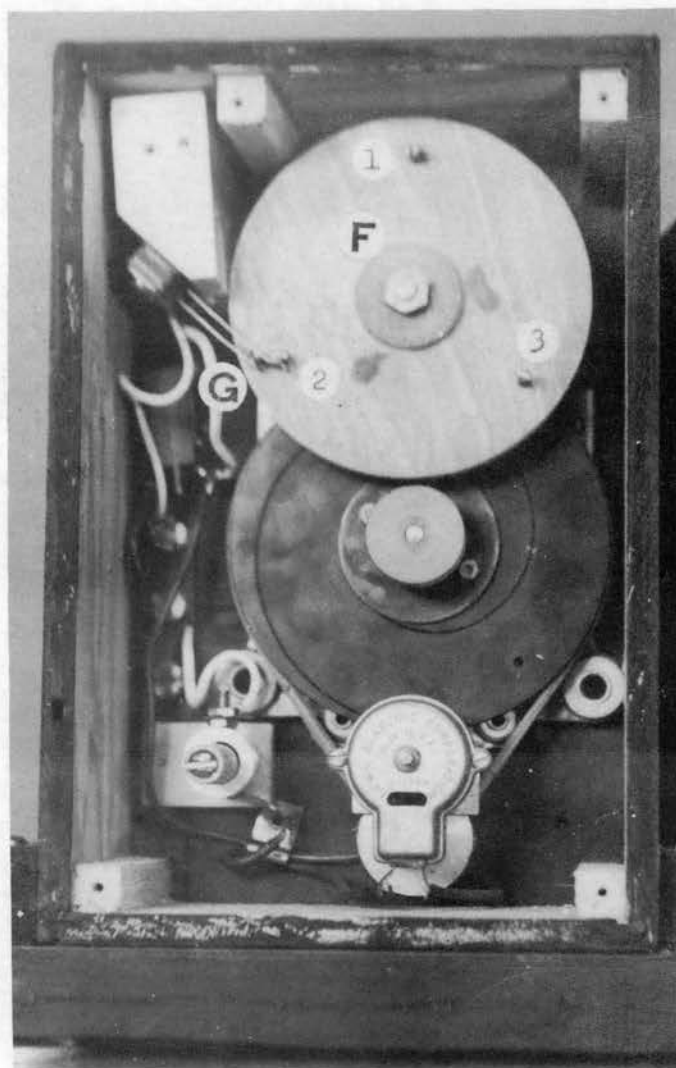


Plate III. The Memo-Activity
Camera

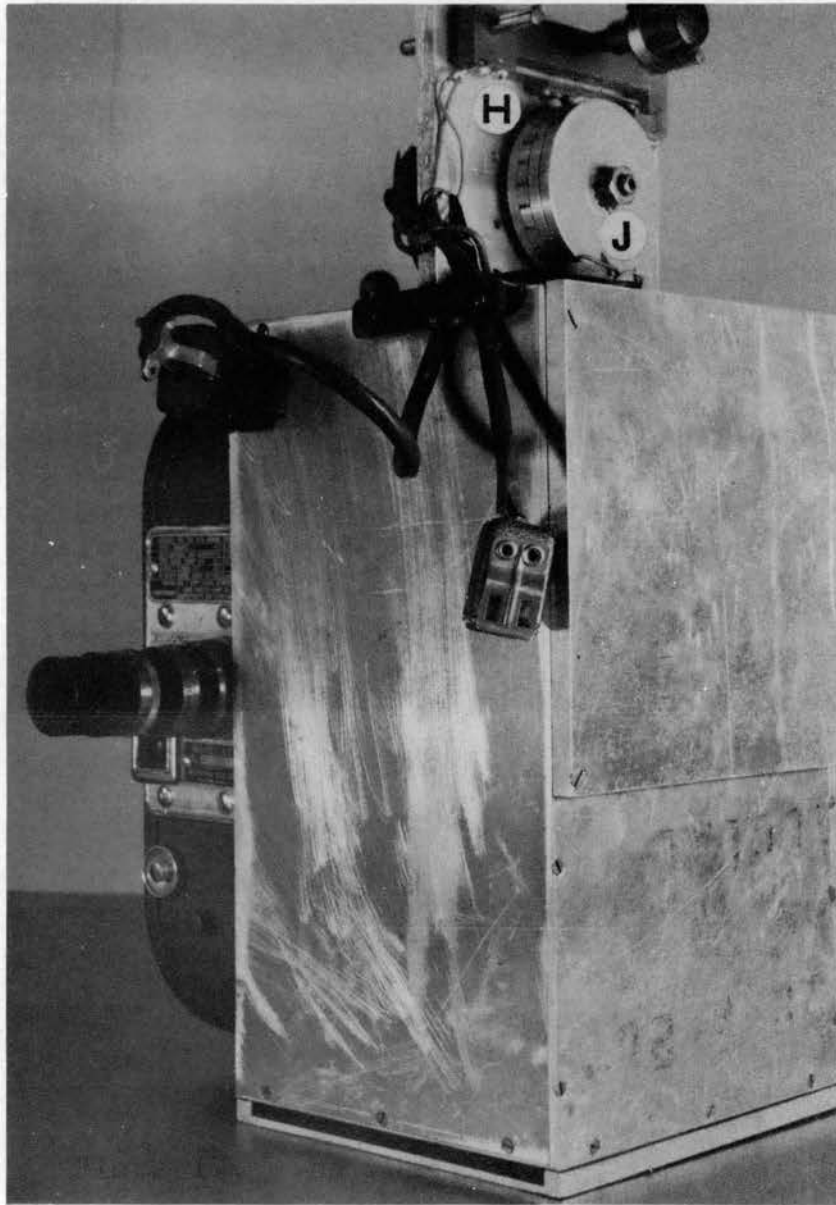


contact (G) which closes a circuit and causes the solenoid to depress the film button on the camera briefly so that only one frame of film is exposed. With three pins in place, the rate of exposure is six frames per minute and with two of these pins removed, two frames per minute.

Films made with this camera showed that the concept was valid and led to the design and construction of the second model shown in Plate IV. The major changes incorporated were the use of an internal optical system to transmit the image of a watch onto the film, the use of a synchronous electric motor to drive the camera instead of the previous spring drive and the use of a follower (H) bearing on a notched wheel (J) to time exposures. Four different wheels with various numbers of notches are mounted and the follower is capable of being moved so that two, 10, 50, or 200 exposures may be made per minute. A schematic diagram of the memo-activity camera is shown in Figure 6.

A second major innovation of the memo-activity camera is the speed at which film is exposed. Where the memomotion technique normally exposes film no slower than 50-60 frames per minute, the memo-activity camera takes as few as two exposures per minute. It is evident, then, that less detail in filmed activities can be detected with the memo-activity camera; but, this slower speed makes possible important savings in the cost of making and analyzing films. In addition, although less important is the fact

Plate IV. The Memo-Activity Camera



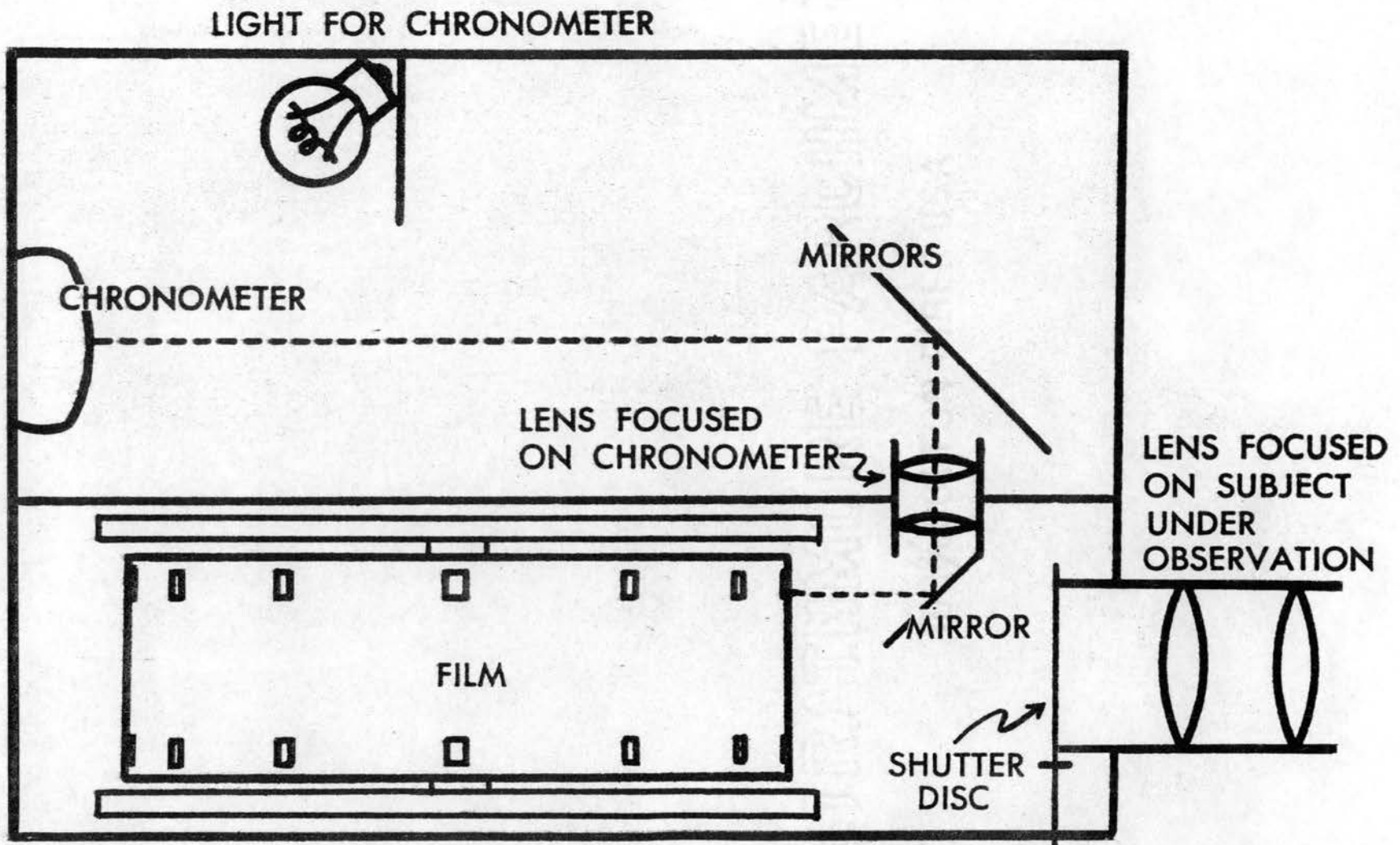


Figure 6. Schematic Diagram of the Memo-Activity Camera

that the memo-activity study uses less film than the memo-motion study.

A major saving occasioned by use of the memo-activity camera is in the labor cost of making films of work to be examined. The 100 foot roll is standard in the 16-mm film size. At the standard memomotion speed of 60 frames per minute, a 100 foot roll of film is exposed in 1.1 hours at which time a new roll of film must be loaded. Since many long cycle jobs last more than an hour, someone must be present to change film periodically. The frequency of trips to change film in memomotion camera is such that most such studies are made with a photographer in full-time attendance. Also, of some importance is the fact that the memomotion study must be interrupted while film is being changed.

With the memo-activity camera using a speed of two exposures per minute, 33.3 continuous hours of work may be recorded on one roll of film without service being required. Using a speed of 10 frames per minute, 6.67 hours of work may be recorded with an unattended memo-activity camera. Then, if a rough idea of the length of a job can be attained, the appropriate film speed for viewing the entire operation may be chosen. Since most turn-around tasks are considerably longer than one hour, the two or 10 frame per minute speed will usually be appropriate.

Another important feature of the memo-activity camera is that the duration of each individual exposure remains

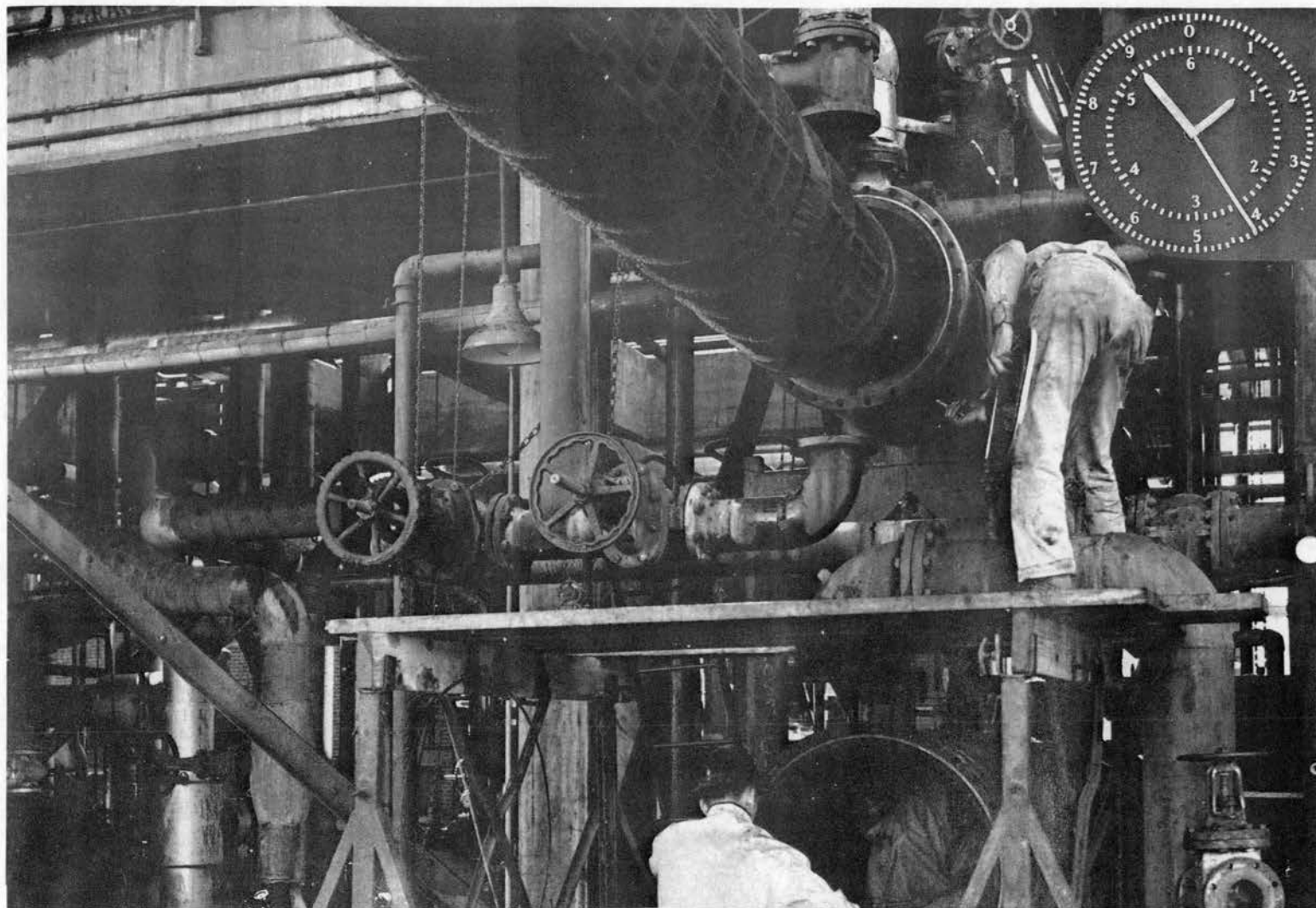
constant at one-thirtieth of one second regardless of the number of exposures being made per minute. Due to this factor, the camera's diaphragm opening need not be adjusted when the rate of exposure is changed. In addition, since the exposure duration of one-thirtieth second is the same as that employed by cameras exposing motion picture film at the normal rate of 960 frames per minute, film exposure ratings and other published data pertaining to the normal use of motion picture film apply equally well to the use of the same film in the memo-activity camera.

Savings on film costs, gained from slower rates of exposure, are less important than the considerable cost of labor required to operate the camera; but, theoretically, since film exposed at the slowest memo-activity rate is used at one-thirtieth the usual memomotion rate, film costs should be somewhat more than three per cent of the film cost of memomotion.

Plate V is a replica of one frame of memo-activity film. A replica is used to demonstrate the type of photograph produced by the memo-activity camera for two reasons. First, 16-mm film used for projection is developed as a positive rather than a negative image. Reproduction of a positive photograph from 16-mm film requires that a negative first be produced from the original film and then a positive print made from that negative. In this process much resolution of the photograph is lost.

Second, in enlarging the small 16-mm frame and in

Plate V. Shell and Tube Heat Exchanger Bundle Removed From Shell



further processing for reproduction, a great deal more resolution is lost so that the end product does not convey accurately the purposes to which memo-activity film may be put.

Plate V shows a very important piece of refinery equipment, the shell and tube heat exchanger. In the upper foreground, the tube bundle has been removed from the shell and is suspended by cables waiting until it can be lowered for removal to an area where it will be cleaned. The workman at the upper right is laying out measurements for the modification of the heat exchanger shell which, in operation, encloses the bundle.

In the lower foreground, two workmen are cleaning a heat exchanger shell from which the tube bundle has been removed.

Plate VI shows another stage in the process of turning around a similar type of shell and tube heat exchanger. In Plate VI, a crew of six is replacing one tube bundle in its shell. Occasionally, exceptionally large shell and tube heat exchangers are built with two or more tube bundles in order to facilitate construction, cleaning and repair. In this illustration, it can be seen that the bundle is suspended by cable slings and chains and electric hoists and is being pulled into its shell with a third hoist. Another interesting point which may be seen in Plate VI is the fact that the worker to the extreme right is violating an important safety rule by not wearing the mandatory "hard hat."

Plate VI. Replacing Shell and Tube Heat Exchanger
Bundle in Shell

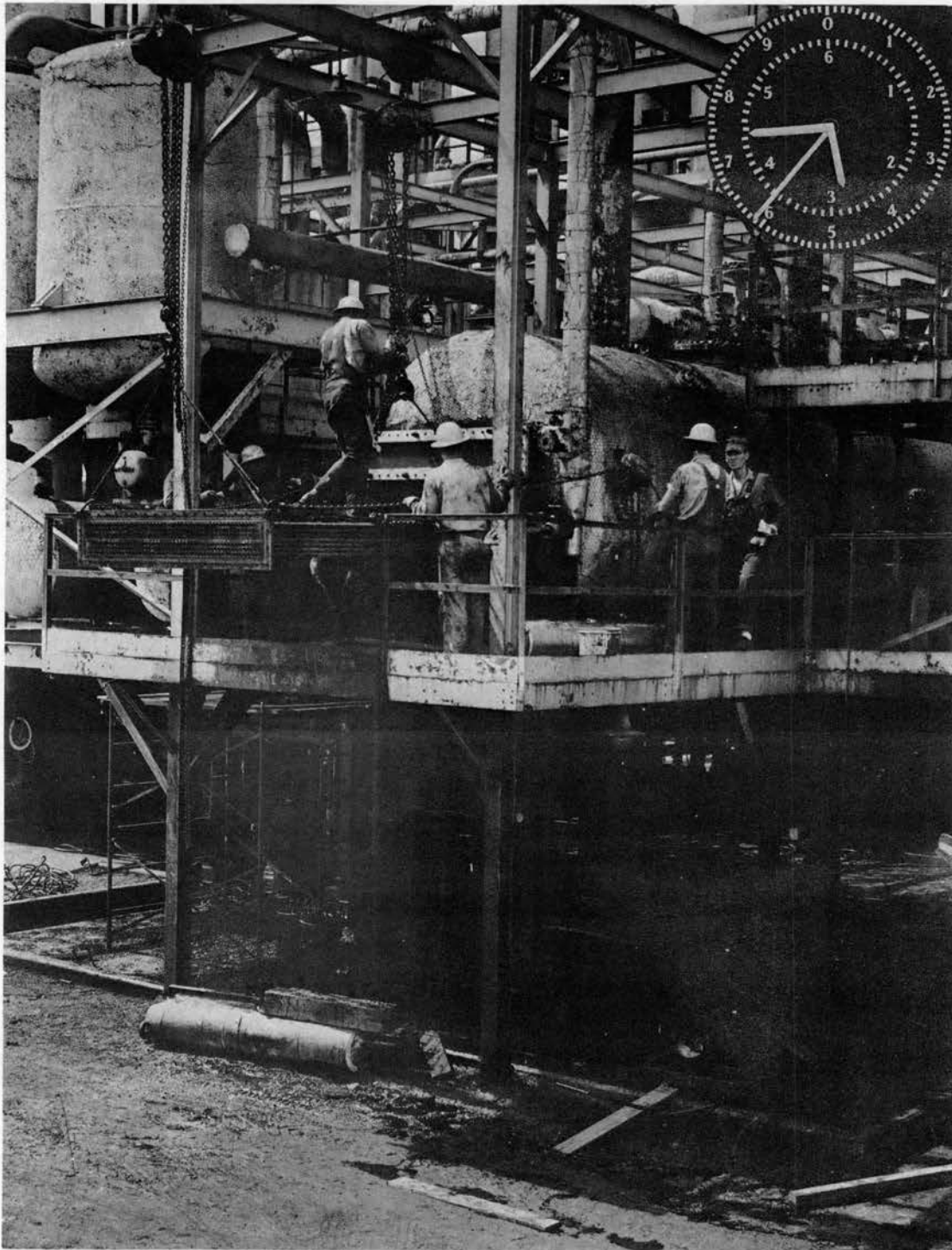


Plate VII shows one method used for removing a large gate valve from a pipe line for cleaning and repair.

In each of these photographs, the exact time is shown by the watch in the upper right corner of the frame. For example, the time at which Plate VII was made is permanently recorded as 6:57:04.

Plate VII. Removing a Gate Valve



CHAPTER VI

WORK SAMPLING

In Work Sampling, the first text published on this subject in the United States, the author, Barnes (38), writes:

Work sampling is based on the laws of probability. A sample taken at random from a large group tends to have the same pattern of distribution as the large group or universe. If the sample is large enough, the characteristics of the sample will differ but little from the characteristics of the group. Sample is the term used for this small number, and population or universe is the term for the large group. Obtaining and analyzing only a part of the universe is known as sampling.

A further short description of work sampling is given by Davidson (39):

In brief, these techniques employ a sample of instantaneous observations on the "activity state" of a man, a machine or a process to estimate the percentage of time that is spent in various states.

Since this dissertation is not based upon work sampling theory, no further explanation of the theory will be given herein. For a complete discussion of work sampling, see Barnes (38), Heiland and Richardson (40) and Hansen (41).

Conway (43) describes the use of work sampling in this way:

The technique is characterized by the use of intermittent sampling over a protracted interval of time (as opposed to conventional time study which is of a continuous nature over a relatively short period of time), and by the use of qualitative observations. An observation consists of a description of the state of activity concerned at a particular instant of time. No quantitative measure (e.g., stopwatch timing) is required.

Most of the applications of work sampling can be classified as either the estimation of the proportion of time in which an activity is in a particular state, or the study of the activity of a team of men, or machines. The estimation of the proportion of machine down-time was the problem that led to the origination of work sampling and much of its application since has been to similar problems. In fact, the technique is often called "ratio-delay" study although by now its use is considerably broader than that name would imply.

Gambrell (42) continues in a similar vein:

The major application of work sampling in the field of industrial engineering has been in the use of ratio delay studies designed to determine the per cent allowances for unavoidable delays. However, identically the same methodology can be used to determine the amount of time devoted to various activities in a job that is cyclic in nature, such as clerical procedures in a payroll department, preventive maintenance programs, etc.

Krick (4) provides "typical applications" of work sampling as follows:

1. Estimation of unavoidable delay time as a basis for establishing a delay allowance.
2. Estimation of the per cent of utilization of machine tools in a tool room, of cranes in a heavy machine shop, or of fork trucks in a warehouse.
3. Estimation of the per cent of time consumed by various job activities on the part of shop supervisors, engineers, repairmen, inspectors, nurses, school teachers, office personnel, etc.

4. Estimation of a time standard by combining rating with work sampling. For example, if a work sampling study shows that 20 per cent of a work week was consumed by avoidable delays; if each time a work-sampling observation was made the operator was also rated and the average of such ratings was 110 per cent; and if 1000 units were produced by the operator in that 40-hour period; the standard time would be

$$\frac{40 \text{ hrs.} \times 0.80 \times 1.10}{1000 \text{ units}}$$

or 0.32 hour/unit x 1.10

or 0.35 hour per unit.

Therefore, it can be seen that most essential and most important element of the performance evaluation standard, the standard time, may be obtained by using the work sampling technique.

Work sampling, in addition to the making of random, instantaneous observations of the work studied and the classification of the observations into categories, requires that three measurements be made. The first of these is a count of the number of units produced. This, in the class of work examined by this dissertation, is relatively easy in most cases to determine. Since "a job" in nearly all cases in the type of work to be examined and treated herein consists of repairing and/or cleaning a single piece of equipment, the number of units "produced" on a job is usually one. In some cases, however, the determination of the number of units produced requires that an accounting system be provided.

The second measurement which must be made is

considerably more difficult to determine. "Rating" the operator, in fact, could probably be said to be the most controversial factor in the practice of work measurement and the establishment of performance evaluation standards. Rating is discussed and defined by Barnes (3) as follows:

Perhaps the most important and the most difficult part of time study is to evaluate the speed¹ or the tempo at which the person is working while the study is being made. The time study analyst must judge the operator's speed while he is making the time study. This is called rating.

Rating is that process during which the time study analyst compares the performance (speed or tempo) of the operator under observation with the observer's own concept of normal performance. Later this rating factor will be applied to the time value to obtain the normal time for the job.

Rating is a matter of judgement on the part of the time study analyst, and unfortunately there is no way to establish a time standard for an operation without having the judgement of the analyst enter into the process.

Krick (4) explains the reasons why rating is necessary as follows:

For the rating process to succeed and a useable standard to be established, the following three requirements must reasonably be satisfied:

1. The company must establish what it means by normal work rate, the level

¹The terms speed, effort, tempo, and pace all refer to the rate of speed of the operator's motions. Speed and effort are terms commonly used by time study analysts, and the term tempo is gaining in favor. In this volume these terms will be used synonymously, and they will all have but a single meaning -- speed of movement.

of performance it wishes its time standards to represent, and express this in some form that can be communicated.

2. A reasonable approximation of this concept of normal performance must be instilled in the mind of each rater.

3. The rater must develop the ability to apply this concept to various operations and produce reasonable numerical rating factors.

Unfortunately, the current available means of accomplishing these three essential steps are relatively crude and leave much to be desired. The field does not possess objective means of deciding on, expressing, or applying a concept of normal performance

Just how a given company arrived at their particular concept of normal rate of work is a very mysterious matter and difficult to trace in most instances. The reason for this is that rarely has normal performance been established by an initial, carefully deliberated and specified decision. Rather, it is probably a matter of initially arriving at a vague and roughly specified notion of what the company wants normal performance to be, then letting the time study personnel determine through experience over a period of time the level at which normal will fall within these broad limits. In other words, if a general idea is given of what level is desired, after a period of time a certain concept of normal "evolves." To be sure the level that does evolve is probably affected by the general level of worker performance that prevailed in the plant before standards were installed as well as by wage matters.

In summary of the subject of rating, it could be said that if a standard is to be established for all persons doing a particular job, then some judgement of the pace or speed of the operator(s) being observed must be made in order to determine whether this operator(s) is working faster or slower or at the speed or pace management

expects the operator(s) to maintain. Naturally, this normal pace or speed which the operator is expected to maintain varies from analyst to analyst within an organization and from organization to organization.

It has been explained by Krick above and many other authors in the field that although rating is subjective and "unscientific," it remains a necessary part of the process of determining time standards. For criticism of the rating procedure, see Davidson (34) and Gombérg (44).

In the simple example given by Krick above, he neglects to take into account the third measurement which must be considered in formulating a standard time from the data obtained from a work sampling study. This third measurement is the determination of the amount of time given to the operator for allowances. Barnes (3) explains the meaning of the word allowances in this manner:

The normal time for an operation does not contain any allowances. It is merely the time that a qualified operator would need to perform the job if he worked at a normal tempo. However, it is not expected that a person will work all day without some interruptions. The operator may take time out for his personal needs, for rest and for reasons beyond his control. Allowances for such interruptions to production may be classified as follows: (1) personal allowance, (2) fatigue allowance, or (3) delay allowance.

The standard time must include time for all the elements in the operation, and in addition it must contain time for all necessary allowances. Standard time is equal to normal time plus the allowances. Allowances are not a part of the rating factor and best results are obtained if they are applied separately.

In other words, to the normal time for an operation which has been obtained through the processing of work sampling observations, rating and a production count, allowances in terms of time are added for personal needs, fatigue and delays beyond the control of the operator. The resulting time period is the standard time.

Allowances are customarily added to normal times in the form of a certain percentage of the amount of time in the normal working day. In one company referred to by Barnes (3), allowances ranged from eight per cent of an eight hour day or 38.4 minutes per day for a person making telephone calls to 30 per cent or 144 minutes per day for a person lifting "70-pound containers from skid waist-high to shoulder-high stack." The difference in the amount of time given for allowances is largely a function of the fatigue induced by the various jobs.

The application of allowances, too, has received considerable criticism as being subjective and inexact. Like rating, however, consideration of allowances is vital to work measurement and no acceptable alternative has yet been developed. The application of allowances in work sampling presents a somewhat peculiar situation. Work sampling is recommended by each of the authors on the subject who have been listed above, as an appropriate tool for measuring allowances, i.e., for measuring the amount of time various operators spend not working while attending to personal needs, resting to overcome fatigue or

being delayed by factors outside their control. This information in terms of a certain percentage of time is used to determine proper allowances.

On the other hand, in a work sampling study conducted for the purpose of determining a standard time, only the portion of the time the operator is working is used to determine the normal time and to this normal time allowances which may vary from those measured on the particular job, may be used to determine the time standard. This is to say that the information gained from the study which shows how long the operator actually takes for allowances may not be accepted as the desirable amount of time for these allowances. The amount of time chosen for allowances is likely to be chosen from a time study manual or a scale of bench-mark jobs for which allowances have been determined through work sampling studies.

In summary, the method of determining time standards by work sampling can be shown by the formula:

$$\text{Standard time per piece} = \frac{\left(\begin{array}{l} \text{Total elapsed} \\ \text{time per shift} \\ \text{in minutes} \end{array} \right) \times \left(\begin{array}{l} \text{Actual working} \\ \text{time per shift} \\ \text{in per cent} \end{array} \right) \times \left(\begin{array}{l} \text{Performance} \\ \text{index in} \\ \text{per cent} \end{array} \right)}{\text{Total number of pieces produced}}$$

+ Allowances.

The Use of the Motion Picture Camera in Work Sampling

The motion picture camera has long been a favorite analytical tool of the industrial engineer. Frank B.

Gilbreth just after 1900, began filming work for the purpose of improving methods. Consequently, it is not surprising that many photographic work-study techniques have been evolved by industrial engineers and others interested in the study of work. Since work sampling normally requires an instantaneous observation of a worker, crew, machine, etc., it is quite natural that the camera be used to replace this observer wherever the phenomena to be observed are capable of being covered by the camera's field of view. Barnes (3) describes such a work sampling camera in his text Motion and Time Study. He says:

The electric motor-driven timer operates the synchronous motor, which drives the camera at 1000 frames per minute. A separate device on the timer permits the camera "run time" to be set for intervals of 2 to 30 seconds each. The camera run time, or the length of the observation time, would be preset on the timer and maintained throughout the study. Since pictures are taken at a speed of 1000 frames per minute, when the film is projected at this same speed a performance rating of the operator can be made from the film.

Gambrell and Barany (42) experimented with a "16-mm motion picture camera with a constant speed drive and an automatic timer device used to actuate the camera at random intervals during the study period." A study of the duties of the librarian at a "small departmental library" was made and the authors concluded that the camera could effectively and economically replace a human observer.

The Engineering and Industrial Experiment Station at the University of Florida has recently designed a camera which solves at least one of the problems inherent in

previous work sampling cameras. (45). This camera is designed to move "automatically over a preset pattern" controlled by a punched tape. Quoting from the research

Bulletin:

The camera can be moved horizontally through a 360-degree circle and vertically through a 90-degree arc. This provides a field of view which is the major portion of a sphere. There are 216 possible picture-taking positions within this zone of coverage for which the camera can be adjusted. In the vast majority of actual studies, a much smaller area and fewer positions would be used, but the large number is available if desired.

A work sampling camera designed for utilization studies is described by Niebel (46).

Although work sampling by human observer and by camera have extended the area of work which is susceptible to examination by industrial engineers, there remain other areas of work which are not yet feasible to examine. Work sampling is designed primarily as an information-getting tool; its function as a standards-setting instrument is secondary. For the following reasons, work sampling is not the final solution in the field of formulating performance evaluation standards:

1. If the number of observations made in a work sampling study is not to be large, in order to achieve statistical significance, the number of categories into which activities on a job are to be divided must be relatively small. For example, if a job is divided into

five classifications, each requiring 20 per cent of the operator's time, 1600 observations must be made to achieve ± 10 per cent relative accuracy on the 95 per cent confidence level. To achieve the 95 per cent confidence level and the same ± 10 per cent relative accuracy on a part of a job which required only 10 per cent of the job's total elapsed time would require 3600 observations. This number of observations, even if made by a motion picture camera requires an analyst to rate each observation. This rating, subsequent classification and further processing are relatively expensive and, thus, remove some areas of work from that which may be economically examined and measured.

The higher the number of categories into which the work involved in a particular job is divided, the better the description of the job. But, on the other hand, a time standard may be obtained by dividing work sampling observations into only two categories -- "working" and "idle or absent." If the first of these two divisions, "working," is found to constitute 70 per cent of the total elapsed time, then the relative accuracy and

confidence levels specified above may be achieved with only 170 work sampling observations for the "working" segment of time.

This reduction in the number of observations required provides an important saving, but a total of 170 observations is highly unlikely to provide sufficient information on the method used to perform the work. By definition, a performance evaluation standard must carefully define the method to be used in performing a job. On jobs longer in duration, such as those encountered in the petroleum-refinery, 170 observations may be entirely inadequate to describe the method used to do the job. Take, for example, a relatively short job which it is expected will require about eight hours to complete. Making 170 observations on this job gives an average time interval between work sampling observations of:

$$\frac{8 \text{ hours} \times 60 \text{ minutes/hour}}{170 \text{ observations}} = 2.82 \text{ minutes/observation}$$

or an average time of nearly three minutes between observations.

But the exact 2.82 minute interval is rarely encountered because work sampling

requires in order that it be a true random sampling of time, that every instant of the eight-hour time period have an equal chance to be chosen as that instant when an observation will be made. Therefore, since times for observation are chosen at random, intervals between observations will also be random in length. Because the frequency of times chosen for observation within a particular increment of time is bounded by zero and infinity and because the continuous function of time must be made discrete in order that sampling times might be chosen, the binomial or Poisson distributions should best represent the frequency distribution of sampling. The Poisson has been chosen because of its simplicity. If then, the Poisson distribution represents the frequency of sampling, the exponential distribution should represent the interval distribution between samples in terms of elapsed time. See Morse (47). From Morse, page 11:

$$S(t) = \frac{1}{T} e^{-\frac{t}{T}}$$

where $S(t)$ = probability of a particular time interval between work sampling observations.

T = mean time between observations.

t = an arbitrary time interval.

Then to calculate the probability of experiencing a 10-minute interval between observations, let $t = 10$ and:

$$S(t) = \frac{1}{2.82} e^{-\frac{10}{2.82}} = \frac{1}{2.82} e^{-3.54} = \frac{0.0290}{2.84}$$

$$= 0.0103 = 1.03\%.$$

That is, in the long run, 1.03 out of each 100 intervals between work sampling observations will be between 9.5 and 10.5 minutes in duration. Putting this alternately, over many such studies, one interval in each 97 such intervals could be expected to last between $9\frac{1}{2}$ and $10\frac{1}{2}$ minutes since discrete increments of time of one minute are being dealt with here. Then by accumulating the probabilities of intervals between observations of 10 minutes or greater (actually all intervals greater than $9\frac{1}{2}$ minutes), the total is 0.0325. This means that 3.25 per cent of the increments in the long run can be expected to last longer than $9\frac{1}{2}$ minutes.

It is the contention of this writer that samples of work so far separated in time make this particular work sampling study unsuited

for the purpose of establishing a performance evaluation standard. The occurrence of these relatively lengthy period of time between observations leaves the method by which the work was accomplished inadequately described. It is again the writer's contention that work should be observed no less often than once each half-minute if the method used is to be adequately described.

If the writer's contention is accepted, then it is obvious that samples would have to be made on the average much more often than once each half-minute if the work is to be sampled at least each half-minute. In fact, sampling would have to be continuous if there were to be no probability of any 30-second interval not being sampled. This amounts to continuous filming which has been shown to be uneconomical for the analysis of maintenance work.

But, if as a compromise between cost and accuracy, it were decided that intervals between samples could be set at an average of 15-seconds each, and if the two-second minimum exposure time specified by Barnes as the minimum amount necessary for rating were chosen,

then the amount of film consumed would be:²

1000 frames/minute x 4 samples/minute

$$\times \frac{2 \text{ seconds/sample}}{60 \text{ seconds/minute}}$$

$$= 133.3 \text{ frames/minute.}$$

At this speed of exposure, a 100 foot roll of 16-mm film which contains about 4000 frames of film would last:

$$\frac{4000 \text{ frames/100 foot roll}}{133.3 \text{ frames/minute}} = 30 \text{ minutes/100 foot roll.}$$

It can be seen then that in order to provide adequate information from which a performance evaluation standard could be established, the film must be changed each half-hour or, with a special 200 foot magazine, each hour. This film-changing time plus travel time necessary for the photographer makes it nearly as economical for the photographer to attend the camera full-time. These costs plus the considerable costs of film and analysis entailed in work sampling by camera, preclude the economical examination of many areas of work.

²Most 16-mm cameras used in industrial engineering work expose film at a rate of either 960 or 1000 frames per minute.

2. Another criticism of work sampling by camera has recently been advanced by Davidson (39) who wrote:

Techniques patterned after Tippett's application [work sampling] have proven extremely useful in manpower and equipment utilization studies, in the collection of data for analysis of queueing problems, and in other kinds of investigation. However, the randomizing of observation times has been both a nuisance and a source of inefficiency in the utilization of observers. To avoid these disadvantages some investigators have employed motion picture cameras arranged for time-lapse photography and actuated by random interval timing devices. While photographic records must still be interpreted by analysts, the method does permit efficient programming of the analysts' time which is not the case in the instance of randomized direct observation.

In spite of the advantages that may pertain to use of the camera instead of the human as an instrument for randomly spaced observations, this approach to the problem seems rather like attempting to remodel a new horse to fit an old saddle. The camera is particularly suited to economical fixed interval observation, and it is difficult to believe that there is any real necessity of complicating the instrumentation with additional equipment to secure random intervals. Moreover, in studying processes one is frequently interested in discovering not only the relative frequency of certain states but also their time of occurrence and approximate duration (since they are not often truly 'random'). A fixed interval observation scheme is superior for this purpose to a set of random observations.

It should be pointed out that where Davidson says that photographic work sampling "does permit efficient programming of the analysts'

time" he is speaking specifically of "man-power and equipment utilization studies" and "the collection of data for analysis of queueing problems." In this type of problem only the "activity state" need be recorded and rating is not necessary. If rating is not necessary, then only one frame of film need be exposed for each "sample;" but, if the purpose of the study is to establish a performance evaluation standard then the method of performing the work must be adequately described and rating is necessary. Thus, film must be exposed at normal speeds for some time period and the consumption of film is much higher. Therefore, it is quite likely that the use of the work sampling camera for determining performance evaluation standards would not allow "efficient programming of the analyst's time." A search of the literature revealed no reference to a work sampling camera designed for the gathering of information from which performance evaluation standards could be directly determined.

In a more recent article Davidson (48) continues his discussion of "systematic" or non-random sampling as follows:

Suppose we make the interval between our regularly spaced observations sufficiently small that whenever a particular category of activity occurs we will detect that occurrence in at least one observation. Or let us at least make the interval small enough so that the exceptions to this condition are negligibly few for practical purposes. Now we will know that if a particular activity is identified in exactly five consecutive observations, the duration of that occurrence must have been greater than four times the interval between observations but less than six times the interval. Our uncertainty is due to the fact that we do not know the position of the beginning point of activity occurrence in the interval between the last observation showing the preceding activity and the first observation showing the activity whose duration we are attempting to estimate; and to a similar lack of knowledge about the position of the end point. We can make a strong conjecture however that the probability of the beginning point being at any particular position on the interval is for all practical purposes the same for all positions on the interval; and likewise for the end point.

Although Davidson is advocating the use of fixed-interval studies in those areas he mentions and which are more typical applications for work sampling, this dissertation will investigate the extension of this technique to the determining of performance evaluation standards for even less repetitive types of work. The same reasoning Davidson gives on the occurrence of the beginning and ending of the elements or parts of the type of work he describes should apply equally well to the

elements of less-repetitive or seldom-repetitive jobs. Moreover, if the interval between filmed observations remains constant and the duration of that which is being measured becomes greater, then the inaccuracy due to not knowing exactly where within the interval the element or job started or stopped becomes less significant. For example, in measuring a two-hour job with no interruptions experienced and with a 30-second interval between observations, the maximum inaccuracy that could occur would be one minute or $1/119$ or 0.00840 or 0.84%.

Because two articles by Davidson are pertinent to this dissertation, portions of these articles are included as Appendix A.

3. The purpose of sampling work at random intervals is to avoid bias occurring by observation of a cyclic activity at regular intervals; but where the activity observed is not cyclic no such bias occurs and regular or fixed interval studies would as well describe the activity. The traditional work measurement tools, including work sampling, are designed for operation upon cyclic or repetitive operations. Partially due to this factor, the seldom-repetitive task is seldom measured and

standardized. One need of industry is for a work measurement tool primarily designed to treat the less-often performed task.

CHAPTER VII

DELINEATION OF SPECIFIC PROPOSAL TO BE EXAMINED

Generally speaking, this dissertaion will examine a broad classification of work often termed "non-repetitive" but which could better be described as "seldom-repetitive." That is, work which is seldom (and in some cases, never) repeated using the same tools, materials, methods, crew size, etc. The usually-annual shutdown or turn-around in the petroleum refinery has been chosen as an excellent example of a concentration of seldom-repetitive tasks which, up to the present, have resisted work measurement because of the economic factors involved. The petroleum refinery can be considered as a typical example of the continuous process industries and valid results from this study should then be applicable to periodic maintenance shutdowns in other continuous process industries such as steel, glass, and chemical manufacture.

Specifically, this dissertation will examine the following:

1. The hypothesis that a substantial part of the work necessary during a petroleum refinery turn-around is subject to determination previous to the opening of units for inspection

and repair. If this hypothesis is correct, the application of performance evaluation standards to this portion of work would unquestionably be of value.

The method of study proposed for the determination of conclusions with reference to this objective is the observation of actual petroleum refinery turn-around work and the use of work sampling studies during turn-arounds. These work sampling studies will permit the calculation of confidence limits for conclusions pertaining to the portion of the work which is capable of being specified and planned prior to the opening of refinery equipment.

2. To investigate the applicability of known industrial engineering techniques such as stop watch time study, synthetic basic motion times and work sampling in determining performance evaluation standards for petroleum refinery maintenance tasks.
3. To develop a new approach to the problem of determining and applying performance evaluation standards applicable to the general type of work represented by turn-arounds in the petroleum refining industry. A prime consideration in the development of new methods will

be the economic aspect. It is believed that the use of the memo-activity camera will allow performance evaluation standards to be determined for types of work on which studies by other methods are not economical.

The advantage in analysis of having the absolute time recorded directly on the memo-activity film will also be investigated.

4. To examine the hypothesis that performance evaluation standards, with standard times being the essential criteria, are for many petroleum refinery tasks, capable of being determined with sufficient statistical reliability to be of use to refinery management in the planning, scheduling and control of work. Where a sufficient number of identical tasks under similar conditions are capable of being observed and timed, statistical confidence limits will be calculated to determine the degree of variability in time required to perform the task.
5. To describe, where sufficient information is not available for statistical analysis, the methods, equipment, number of workers assigned, conditions encountered and time required to perform other turn-around tasks. Although no confidence limits may be calculated for this

information, the description of these job factors should be of value to petroleum refinery management in comparison with their own methods, equipment, typical time requirements, etc.

6. To investigate methods of applying predetermined performance evaluation standards to the cleaning and repair of petroleum refinery equipment which is not capable of being inspected internally before the equipment is shut down for inspection and/or maintenance; and also to determine the potential advantages and disadvantages of determining and applying such standards.
7. To determine whether it is possible with the memo-activity camera to formulate suggested improvements in the manner in which various jobs are done. These improvements would be in terms of equipment, tools, crew sizes, methods, etc. The objective of such improvements would, of course, be to reduce the cost of performing these tasks.
8. To develop, by the methods described, a usable body of performance evaluation standards for turn-around tasks which are capable of broad application in the petroleum refining industry.
9. To use the study proposed to continue the

development of the memo-activity camera in order to increase its utility as a work measurement tool.

CHAPTER VIII

A WORK SAMPLING STUDY OF THE TURN-AROUND

Inquiry among petroleum refinery personnel, chemical manufacturing management and industrial engineering consultants and a search of the literature revealed no evidence that a systematic study of manpower utilization and application during a turn-around has been made through the use of industrial engineering techniques for analyzing and synthesizing work. That is, although work is planned, scheduled and controlled before, during and after the turn-around and accounts are kept of expenditures for materials and labor for integrated production units and a few individual pieces of major equipment, no evidence could be found that a careful study of the utilization of manpower during the turn-around has been made with work measurement techniques designed to develop and standardize more economical methods of doing work. In most refineries, little or no effort is exerted toward determining exactly how the maintenance labor force spends its time, how much unavoidable delay is experienced, how much voluntary idleness is found, the amount of materials and labor applied to various classifications of equipment, the amounts and types of skills or crafts necessary, the best known method of

performing work, the amount of work which may be accurately predetermined before the turn-around or repair is begun, and most important, how much time should be budgeted for the accomplishment of specific tasks.

The primary reason for studying the utilization of manpower during the turn-around was to attempt to refute the contention by petroleum refinery management that performance evaluation standards are not economical to establish for maintenance and turn-around work because of the high degree of variation in conditions encountered and because closed units may not be visually inspected before they are shut down and opened.

The work sampling technique is well-known for its ability to quickly and economically ascertain the degree of utilization of men and machines with known statistical reliability. Consequently, this technique was chosen to determine how workmen spent their time during the turn-around.

The particular turn-around during which much of the data for this dissertation was obtained lasted for a period of six weeks. However, the majority of the work done was accomplished during the first two and one-half weeks of the turn-around period when an outside contractor was employed to assist regularly employed maintenance and operating personnel. During the first week of the turn-around, an average of 125 men was employed on the first shift and 68 men on the second shift. During the second

week an average of 132 men was employed on the first shift and 73 on the second. The majority of the contract personnel left at the end of the second week so that during the first three days of the third week an average of 57 men worked the first shift and 22 worked the second. Work then continued for the remaining three and one-half weeks with eight to 10 welders and helpers as the only contract labor.

The first shift began at 7:00 A. M. and ended at 3:30 P. M.; the second shift began at 3:30 P. M. and ended at 12:00 A. M. Occasionally, work was done after 12:00 A. M. so that work for the full crew would not be delayed the following day. This work after 12:00 A. M. was excluded from this study.

It was determined that three work sampling inspection trips per day would adequately determine the utilization of manpower. Accordingly, random times were chosen from a table of random numbers and those times between 12:00 A. M. and 7:00 A. M. were discarded. It can be seen from the total number of observations in Table I that for the first four consecutive days, the random times chosen fell during the first shift twice and the second shift once.

As a result of a preliminary sampling inspection trip, a majority of the categories shown in Table I were chosen as a logical and descriptive breakdown of turn-around activities. Since not all types of work were observed during the preliminary study, other categories,

TABLE I
SUMMARY OF WORK SAMPLING STUDY

CLASSIFICATION OF ACTIVITY	WORK SAMPLING TRIP NUMBER																																							TOTAL NUMBER OF OBSERVATIONS	p(%)*	s**								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39											
1 Welding	22	24	8	24	24	10	20	20	8	24	22	9	21	23	10	22	9	8	21	22	10	22	21	22	10	9	10	20	22	8	4							8	8	525	15.20	.082								
2 Opening manways	5	6	5	8	6	3		4	2	3	2	2	3	3	2	4	1		1	1	1																						65	1.88	.245					
3 Closing manways											1	2	1			2	2	3	3	1	2	2	4	4	3	4	3	4		3	2	1	1	1		1	3	2	2			57	1.65	.242						
4 Unbolting flanges	5		5	7	8	6	1	1	4	2	3	1	5	3	3	4	3	3	4	4	3	3	3	2	5	1	4	2	1	2	1					1							100	2.90	.200					
5 Bolting flanges											2	2	1	2	1	1	4	1	4	2	4	4	5	6	3	3	5	6	8	2	4	2	2				1		4	1			80	2.32	.224					
6 Opening heat exchangers	26	15	10	15	16	10	15	16	10	14	15	9	11	11	10	10	11	10	9	10	6	4	4	3	3	1	3	1	2				2	1									283	8.20	.113					
7 Pulling bundles	6	18	7	15	14	10	20	20	11	15	15	10	16	16	11	18	10	9	10	10	6	11	5	10	6	5	6	6	6							2	1							328	9.50	.105				
8 Cleaning bundles							6	6		5	6		6	6		5			6	6		5	5	5					6	6		5											84	2.43	.214					
9 Clean heat exch. shells										2	2	2	1	2	2	3	3	3	2	4	2	3	4	4	3	3	3	2	4		1													55	1.59	.270				
10 Replace heat exch. bundles																			5	6	2	15	15	9	6	6	6	16	17	10				11	6	6	6	6	5	10	11	6		180	5.21	.148				
11 Remove reboiler heater tubes	5	5		6	5																																								21	.61	.435			
12 Clean reboiler heater tubes							4	4		4	3			4					5	5	4																								36	1.04	.336			
13 Replace reboiler heater tubes																				5		5	5		5	5	4	4																	33	.96	.344			
14 Internal repair, cleaning of vessels	8	10	4	11	11	3	8	7	8	8	9	5	6	7	5	8	5	6	4	6	3	3	6	2	2	6	5	1	3	3	1														174	5.04	.149			
15 Washing down vessels	4		2	2	2		2		2	2	1		2	2	1	0	3			3	4	4	2				5	1	2																	44	1.27	.299		
16 Pipe fitting	5	8	3	9	10	4	3	6	3	3	4	4	5	6	4	6	4	4	6	3	4	6	3	6	10	10	10	11	10	4	2								1	1	4				183	5.30	.143			
17 Air compressor overhaul	3	3		3	2																																									11	.32	—		
18 Electrical repairs (misc)	2	2		2	2		2	2		1	2		2	2		2	1	2	2						3	3			1																33	.96	.344			
19 Winch operation	4	4	1	4	4	1	5	4	1	4	4	1	4	4	1	4	2	2	4	3	1	5	5	4	2	2	2	4	4	1	2	1	1	1	1	1	1							98	2.84	.194				
20 Pump repair	2	2		2	2			2	3							2									1																					16	.46	—		
21 Cleaning storage tanks							4	4		4	3		4	3		4		4	5		4	4	4						2	3																52	1.50	.280		
22 Digging for underground pipe		1		2	2		4	3		2	2	1		2																																19	.55	—		
23 Repair valves							2	2		1			1			1			2	2																											11	.32	—	
24 Repair electric motors																																															7	.20	—	
25 Erect and remove scaffolding					2					4	5		5	6		3																									2	1					28	.81	.434	
26 Insulate pipe																3					3	3		3	3	3																					18	.52	—	
27 Hauling (truck)			3	2	4	4	2	10	10	4	8	9	4	8	8	4	4	4	3	6	7	4	7	6	7	3	1	3	4	5	2	2	2	2			2	2	4	2	2				164	4.75	.156			
28 Drilling coke																4	4		3	4		5	5	4				6	6																		41	1.19	.277	
29 Loading vessels																												4	4	4	4	2	2	2	2	2	2	4	2									32	.93	.356
30 Unloading vessels			2	2	2		4			3	2		3	4	2	1	2	2	2	1	1																										33	.96	.344	
31 Pull tubestill tubes																												5	6		5																	16	.46	—
32 Clean tubestill tubes																												3	2	3	3	2	3	2	1	2												21	.61	.435
33 Replace tubestill tubes																																									5	6						11	.32	—
34 Clean up grounds	8	4	2	6	6	2	4	4	3	5	3	2		2		9	2	2	5	5	3	4	1			1	2			3	2	2	2						1	2	2	4	4			107	3.10	.194		
35 Unavoidable delay	4	1	4	1	3	3	5	2	5	2	3	6	6	1	2	6	5	6	4	6	5	3	8	1	2	3	6	4	5	3																123	3.56	.180		
36 Avoidable delay	3	5	4	2	1	5	3	4	4	1	3	4	5	2	3	5	4	3	5	8	5	6	7	7	1	5	2	5	6	7	1	1						4	3		5	6			145	4.20	.167			
37 Couldn't find and Misc.	7	8	9	4	3	7	5	6	5	8	6	5	7	7	6	2	3	5	10	3	6	5	10	14	4	5	2	8	9	7	3	3	2	3	2	3	2	3	5	6	6				219	6.34	.132			
Total number men assigned (Total number of observations per work sampling trip)	119	119	68	129	129	66	127	127	68	128	128	68	125	125	68	134	73	73	132	132	73	130	129	129	73	73	131	131	73	58	21	21	22	22	22	56	56	22				3453	100.00							

*p = Percentage of the total number of observations in each category.

**s = Standard error of the percentage on 95% confidence level.

e.g., "Insulate pipe" and "cleaning storage tanks" were later added where the addition would not interfere with previous classification of observations. Conferences were held with foremen and refinery management to determine the adequacy of the classification and some revision was made in the form before the study was begun.

Sampling error was reduced by making a large number of observations. Bias was reduced by randomizing observation times and routes. Although it has been explained that turn-around work is essentially non-cyclical, nevertheless, there are several jobs involved (some are described above) which contain repetitive tasks and it was desired to reduce any bias which might have resulted from sampling these jobs at regular intervals. It is felt that there was little bias in the study due to changes in behavior of those observed since the purpose of the study had been adequately explained to all personnel previous to any observation. There was little bias due to preconceived notions of the observer, but on the basis of the relatively low portion of time classified as avoidable and unavoidable delays, it is probable that workers were sometimes classified as doing constructive work when at the time of observation they should have been classified as delayed. This bias is due partially to the tendency of the observer to classify those first, in a crew of men, who are busy, leaving those idle to be classified last, at which time they may have resumed work. An attempt was made to reduce

bias by contacting the foreman in charge of each area on each sampling trip to determine the number of men working under his direction and their location. This accounts for the relatively low percentage of men that could not be found. No sampling was done during scheduled lunch periods.

A third type of error inherent within work sampling which was considered in the design of the study could be termed "nonrepresentativeness." This is the error due to the fact that a future event never happens in all its characteristics in the same way that the event has happened in the past. This error was reduced by subjecting as much of the turn-around work as possible to an equal chance of being sampled. The greatest error through nonrepresentativeness occurs in this study because not all refinery units were "turned-around" during the two and one-half week duration of the study. An attempt was made to reduce this error by choosing the categories into which observations were classified to be as general as possible and which could be expected to occur in "turning-around" any major unit in a petroleum refinery.

Further error through nonrepresentativeness undoubtedly occurred because the process as a whole was not cyclic. In other words, the population was different each time it was sampled because of the progressive nature of the work. This factor is a second reason for randomizing observations and routes. Here the universe or population

must be considered to be the whole of the work done within a two and one-half week period.

The terminology used to denote the categories in Table I (page 99) is indigenous to the petroleum refining industry. Appendix B is a glossary of terms used in this dissertation and will explain and define word usage.

In Table I, the number of observations classified in each category is shown under "Total." The total number of observations made was 3453. Under "p" is the total number of observations under each category divided by the total number of observations. Therefore, p is the estimate of the proportion of time spent in each activity (shown in percentage form). For example, the estimate of the portion of man-hours devoted to welding during the study is 15.20%. The column headed "S" in Table I is the standard error of the percentage, or defined somewhat less exactly, the relative accuracy of the estimate, on the 95% confidence level. It can alternately be stated that one can be 95% confident that $15.20\% \pm 0.082$ (15.20%) represents the number of man-hours expended on welding during this particular period of time. Still another way of expressing the same concept is to state that in the long run one can expect to determine that "welding" constitutes between 14.0 and 16.4% of the total number of man-hours expended 95% of the time if one could repetitively measure the same period of time over which the study was conducted. It should be pointed out here that because of the statistics involved in

determining the standard error of the percentage that this figure is lowest for the "welding" category, i.e., the estimate for this category is capable of being stated within the smallest relative limits of any of the 37 categories. On the other hand, activity number 11, "Remove reboiler heater tubes," has a standard error of the percentage of 43.5%. Therefore, it can only be said that one is 95% confident that this activity required $0.61\% \pm .435$ (0.61%) of the total man-hours expended or between 0.35 and 0.87% of these man-hours. Since the confidence limits for lesser figures vary more widely and, hence, are less reliable, no confidence limits were calculated for categories 17, 20, 22, 23, 24, 26, 31 and 33.

Under activity number 1, "Welding," is included all observations of welders and helpers observed working outside closed vessels, but some of this work included parts that had been removed from these closed vessels. Some portion of this latter work could not have been predetermined. Therefore, in order to make a conservative estimate of the portion of work which is capable of being predetermined with accuracy, three-fourths of the welding activity will be added to that work which is classified as being capable of accurate predetermination.

It can be seen then, that although the times required to perform the various activities on individual units may vary more widely than the times for repetitive, routine, manual tasks performed indoors, the times required to

perform certain activities in Table I are capable of predetermination. As will be shown below, this predetermination of task times may be made within usefully narrow limits. Tentatively chosen as those categories or activities which may not be accurately predetermined in Table I are 8, 9, 12, 14, 15, 17, 18, 20, 21, 23, 24, 28, and 32. It can be seen that these activities are concerned with the cleaning and repair of closed production units and accessory equipment; the total effort devoted to these "unpredictable" activities as estimated by the work sampling study during the period specified, is 16.93%. Adding one-fourth of the welding percentage brings this figure to 20.73%. The statistical validity of the statement that 20.73% of the man-hours during the particular turn-around observed is much reduced by the necessity to allot a portion of the welding activity to those internal parts which cannot be examined previous to the shutdown. The decision was made to classify welding external to vessels in one category because of the delay to both observer and welder, possibility of endangering welders and work and possible mis-information involved in asking welders what part they were working on. If the conservative estimate of one-fourth of the welding activity or 3.80% of the total activity is accepted as fact, then it can be stated that on the 95% confidence level the activities classified above as not being capable of predetermination constitute between 19.35 and 22.11% of the total number of man-hours expended

during the turn-around observed. If it can be assumed that this study was unbiased and representative, it can then be said that work on refinery equipment which is not susceptible to examination and prediction based on that examination prior to initiating work on the particular equipment, constitutes about 20% of the man-hours expended during the turn-around. It should be added as a qualification that certain tasks for certain activities included within this 20% are definitely capable of accurate prediction. For example, categories 17, "Air compressor overhaul"; 18, "Electrical repairs"; 20, "Pump repair"; 23, "Repair valves"; and 24, "Repair electric motors" each contain several tasks which are scheduled previous to the turn-around and, hence, are capable of being measured for use in a performance evaluation standard. One last qualification should be mentioned. In nearly every case, it was not possible to observe men working inside closed vessels because of the cramped working conditions and disruption of work involved. Accordingly, the foreman of each area was contacted to determine the number of men working inside each vessel. This number was recorded as given by the foreman. Thus, there is the possibility that the foreman could have given inaccurate information. Due to this same condition, avoidable and unavoidable delays for men working inside vessels and tanks were not recorded.

One other estimate by refinery management may be

examined by the information gained from the work sampling study. In interviewing management personnel from refineries, an attempt was made to determine if there were any areas or types of equipment upon which efforts could be concentrated in order to reduce the costs of the turn-around through the establishing of performance evaluation standards. In response to questions concerning the number of man-hours expended and costs incurred in turning-around various units, the unanimous reply was that heat exchangers in their various forms¹ accounted for an estimated 25-30% of the cost of the average turn-around. An estimate of the cost was necessary because few, if any refineries keep individual accounts for equipment as small as an individual heat exchanger. Accounts are usually kept for integrated processing units containing many pieces of equipment and occasionally for major individual items such as a catalytic cracker. To illustrate what is meant by an integrated unit, a plan view of a Polymerization Unit is shown in Figure 7. Totaling the percentages for categories 6 through 13 in Table I (page 99) gives a total of 29.54%. Therefore, it can be said that on the 95% confidence level, the amount of time spent in opening, cleaning and closing

¹Heat Exchangers in their various forms and uses are called coolers, condensers, waste heat boilers, tubular reactors, reflux sections, catalyst coolers, gas coolers, reboiler steam generators, preheaters and heaters among other terms.

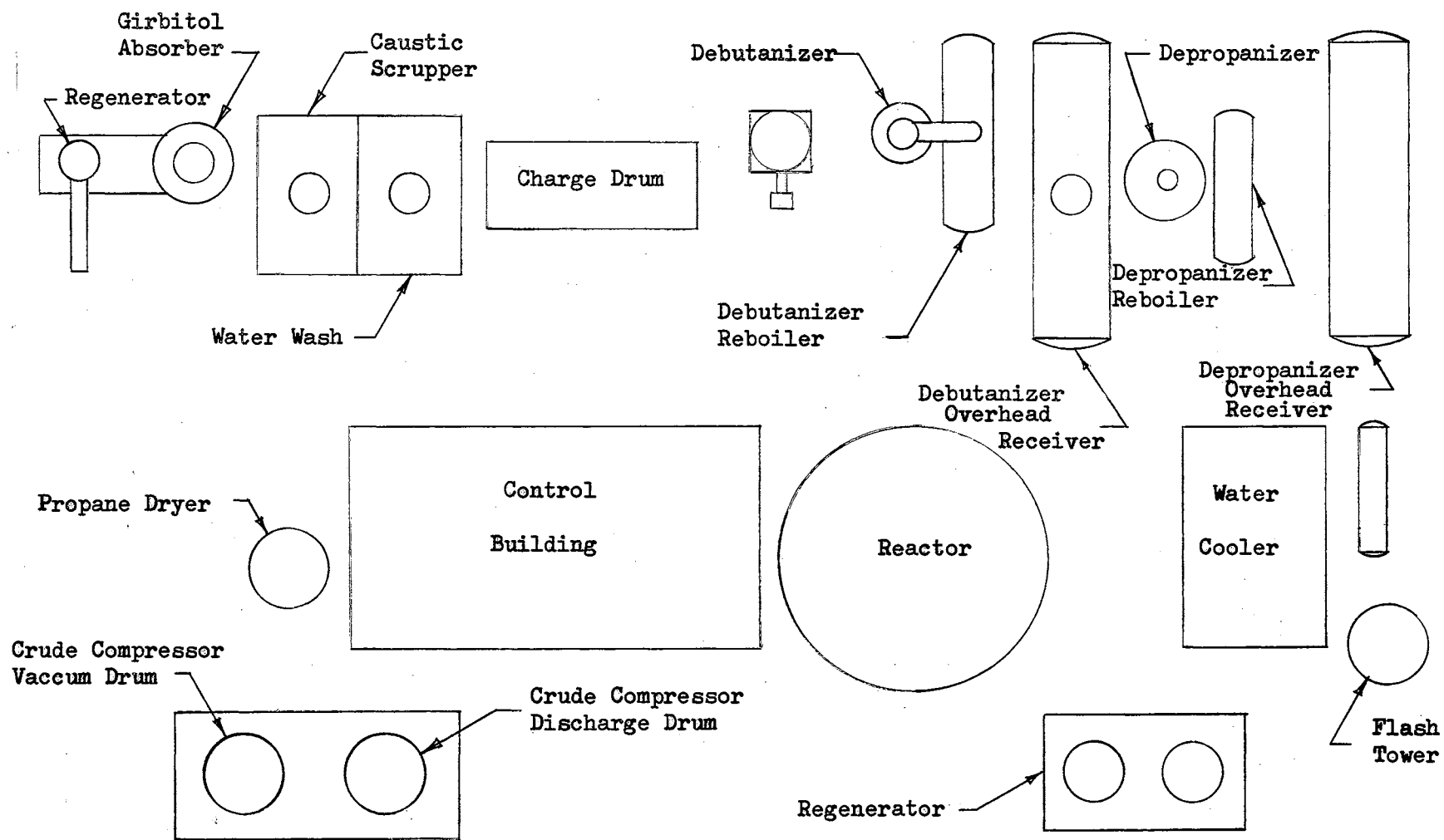


Figure 7. Plan View of Polymerization Unit

heat exchangers is between 27.89% and 31.19%. It can be seen then that if cost is directly proportional to man-hours expended, management personnel are substantially correct in their estimate that heat exchangers account for 25-30% of the cost of the average turn-around. Since the large majority of heat exchangers in the petroleum refinery are of the "shell and tube" type shown in Figure 5 (page 34), effort should be concentrated toward improving and standardizing methods of repairing and cleaning this type heat exchanger and establishing performance evaluation standards for the various tasks involved.

CHAPTER IX

APPLICATION OF EXISTING WORK MEASUREMENT TECHNIQUES TO THE TURN-AROUND

Several tasks were found during the turn-around which were susceptible to measurement by time study. One problem that is encountered in making time studies of maintenance operations arises from the long-standing custom with most petroleum refineries of assigning two or more men to each maintenance task. The difficulty of making time studies usually rises in proportion to the number of men in the crew being timed.

As evidence of the fact that one-man jobs are relatively scarce during a turn-around, few such jobs were found even though such jobs were sought as good examples of how time study might be used to measure turn-around work. A time study observation sheet for one of these jobs is shown in Figure 8. This job consisted of using a steam lance to clean the tubes of a heat exchanger which had been opened but not removed from the shell. (This latter occurrence was observed but once during the turn-around.) The worker was timed for 30 repetitions and the selected cycle time was 0.330 minutes/tube. One of the problems encountered in the use of time study for the setting of

TIME STUDY OBSERVATION SHEET

PROPOSED METHOD

PRESENT METHOD

DEPARTMENT TCC Unit

OPERATION Clean out $\frac{5}{8}$ " tubes in HE M106
with steam lance; 1 man

OBSERVER D. G. Gates

DATE 4/11

Study Started A. M. P. M.	Study Finished A. M. P. M.	Overall Time	Pieces Produced
---------------------------------	----------------------------------	--------------	-----------------

No.	Element	1	2	3	4	5	6	7	8	9	10	Select. Time	Effort Rate	Normal Time
		.20	.20	.29										
		.20	.33	7.21								.330	115	.380
		.30	.37	.19										
		.50	4.70	7.40										
		.65	.22	.32										
		1.15	4.92	7.72										
		.35	.38	.38										
		1.50	5.30	8.10										
		.60	.18	.51										
		2.10	5.48	8.61										
		.25	.24	.26										
		2.35	5.72	8.87										
		.65	.29	.25										
		3.00	6.01	9.12										
		.25	.29	.31										
		3.25	6.30	9.43										
		.18	.21	.27										
		3.48	6.51	9.70										
		.65	.41	.24										
		4.13	6.92	9.94										

INTERRUPTIONS OR DELAYS

Sym.	Explanation Or Remarks	Start	Stop	Interval	Allowed

OPERATOR _____ PAY RATE _____ CHECKED BY _____

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Figure 8. Time Study Observation Sheet

time standards for turn-around tasks is illustrated by this short time study. Namely, the problem is the amount of variation in cycle times encountered. Because of the range of cycle times measured, 0.18 minutes to 0.65 minutes, a relatively low confidence level is achieved with only 30 cycles being timed. The probability is 95% that the average selected time per cycle for this task falls between 0.284 minutes and 0.376 minutes.¹ This rather wide confidence interval precludes establishing a precise standard for the job until more cycles are timed.

When "two-man" tasks are considered, the number of tasks appropriate for measurement by time study, i.e., those where a cyclic process is involved, becomes much greater. One of the most frequently encountered cyclic jobs was the loosening or tightening of nuts. Referring to Table I (page 99), it can be seen that categories 2-6 are almost entirely concerned with this activity and the opening and closing of heat exchangers requires the loosening and tightening of many nuts. Figures 9 and 10 are time studies of the removal of the nuts holding the channel covers on heat exchangers. Figure 9 shows the times required for one man to remove 38 nuts with a hammer and hammer wrench. (The hammer wrench resembles an open-end wrench but has a thick solid shank that may be struck with a hammer to

¹See Barnes (4) page 353 for the method of calculation of confidence limits.

TIME STUDY OBSERVATION SHEET

PROPOSED METHOD

PRESENT METHOD

DEPARTMENT Crude Unit

OPERATION Unbolt 7/8" nuts with hammer

wrench. On M109, 38 nuts; 1 man

OBSERVER D. G. Gates

DATE 4/4

Study Started A. M. P. M.	Study Finished A. M. P. M.	Overall Time 58.82	Pieces Produced 38
---------------------------------	----------------------------------	-----------------------	-----------------------

No.	Element											Select. Time	Effort Rate	Normal Time
		1	2	3	4	5	6	7	8	9	10			
		1.21	1.36	1.58	2.61									
		1.21	1.55	3.39	6.50	2.8						1.52	95	1.44
		1.18	1.48	1.62	1.32									
		2.39	1.20	3.55	5.16									
		1.30	1.49	1.50	1.29									
		3.69	1.85	3.70	5.28									
		1.25	1.61	1.52	1.29									
		4.94	2.01	3.61	4.18									
		1.46	1.53	1.54	1.23									
		6.40	2.12	4.01	5.54									
		1.32	4.13	1.53	1.21									
		2.75	2.27	4.16	5.62									
		1.45	1.57	1.49	1.09									
		9.20	2.73	4.51	7.71									
		1.36	1.69	1.48	1.11									
		1.56	2.90	4.46	5.82									
		1.20	1.61	1.55										
		2.76	2.05	4.16										
		1.41	1.24	1.49										
		14.17	3.28	4.76										

INTERRUPTIONS OR DELAYS

Sym.	Explanation Or Remarks	Start	Stop	Interval	Allowed
4.13	"Frozen" nut	21.64	25.77	4.13	x
2.61	"Frozen" nut	47.67	50.28	2.61	x

OPERATOR _____ PAY RATE _____ CHECKED BY _____

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Figure 9. Time Study Observation Sheet

TIME STUDY OBSERVATION SHEET

PROPOSED METHOD

PRESENT METHOD

DEPARTMENT Crude Unit - Heat Exchanger M108

OPERATION Remove 28 - 7/8" nuts with
pneumatic torque wrench; 2 men

OBSERVER D. G. Gates

DATE 4/4

Study Started A.M. P.M.	Study Finished A.M. P.M.	Overall Time 13:05	Pieces Produced 28
-------------------------------	--------------------------------	-----------------------	-----------------------

No.	Element											Select. Time	Effort Rate	Normal Time
		1	2	3	4	5	6	7	8	9	10			
		.34	.39	(.51)										
		.34	.472	.997								.466	105	.489
		.36	.45	.50										
		.70	.517	1.047										
		.41	.44	.45										
		1.11	1.561	1.092										
		.39	.48	.38										
		1.50	1.609	1.30										
		.97	.40	.46										
		2.21	1.649	1.176										
		.37	.36	.44										
		2.58	1.685	1.220										
		.44	.40	.43										
		3.02	1.726	1.269										
		.51	.40	.36										
		3.53	1.666	1.305										
		.42	.43											
		3.95	1.609											
		.38	.37											
		4.33	1.46											

INTERRUPTIONS OR DELAYS

Sym.	Explanation Or Remarks	Start	Stop	Interval	Allowed
.71	Operators change jobs	1.50	2.21	.71	x
1.51	"Frozen" nut	8.46	9.97	1.51	x

OPERATOR _____ PAY RATE _____ CHECKED BY _____

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Figure 10. Time Study Observation Sheet

provide the necessary torque to remove the nut.) It can be seen from this continuous time study that nearly one hour was required to remove 38 nuts. In contrast, Figure 10 shows a time study of a crew of two men removing the same size nuts with a pneumatic torque wrench. These two time studies not only provide the basis on which performance evaluation standards may be established, but also point out specifically the need for methods improvement, provide data necessary in order to make an economic analysis in this situation, and provide information for the development of standard data.

Figure 11 is a record of a time study made on another turn-around task. The job consisted of removing 17 sets of pipe from the main pipestill in the refinery's Crude Unit, the unit where the original separation of crude oil is effected. The job consists of passing a cable sling around a "header" with two tubes attached, using a truck equipped with an "A frame" to pull the header and tubes out four to five feet and cutting off each tube with an acetylene torch. Each tube is then separately removed by use of a cable from the truck and with the use of bars by the crew and is lowered to the ground where subsequent operations take place. The tubes are $3\frac{7}{16}$ inches inside diameter, 4 inches outside diameter by 21 feet long and the average distance they were lowered was 52 inches.

The time to record the time values on Figure 11 was approximately 3 hours, 20 minutes. Two 20-minute cycles

TIME STUDY OBSERVATION SHEET

PROPOSED METHOD

PRESENT METHOD

OBSERVER D. G. Gates

DATE 4/9

DEPARTMENT Crude Heater (Pipestill)

OPERATION Pull, remove and lower tubes
in crude heater, 5 man crew, truck;
tubes 3 7/16" ID, 4" OD x 21' long

Study Started	Study Finished	Overall Time	Pieces Produced
A. M. P. M.	A. M. P. M.		

No.	Element											Select. Time	Effort Rate	Normal Time
		1	2	3	4	5	6	7	8	9	10			
1	Rig sling	1.51	1.07	1.24	1.28	1.00	1.77	1.29	1.04	1.84	1.36	1.34	85	1.14
2	Pull header (two tubes att.)	3.12	2.09	3.62	2.98	3.53	2.97	2.75	3.30	2.16	5.34	3.69	100	3.69
3	Cut off header (acetylene torch)	6.91	7.50	7.19	7.04	7.13	6.98	7.10	6.84	6.80	6.44	6.99	110	7.69
4	Pull first tube	8.44	1.91	2.11	1.86	2.65	2.14	5.10	3.33	2.27	1.86	3.17	100	3.17
5	Lower first tube*	.69	.63	.92	.49	.56	.47	.82	.62	.64	.76	.66	100	.66
6	Pull second tube	3.38	4.12	2.55	2.53	4.71	2.86	2.93	3.63	2.90	3.04	3.26	100	3.26
7	Lower second tube*	.61	.44	.45	.59	.81	.67	.61	.57	.68	.59	.60	100	.60
8	Remove sling	.60	.47	.49	.71	.62	M	.58	.53	.48	.49	.56	85	.48
	TOTAL TIME	25.36	23.20	18.57	17.48	21.01	—	21.18	19.91	17.27	19.88			20.69

INTERRUPTIONS OR DELAYS

Sym.	Explanation Or Remarks	Start	Stop	Interval	Allowed

OPERATOR _____ PAY RATE _____ CHECKED BY _____

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*Avg. dist. 52"

Figure 11. Time Study Observation Sheet

had to be observed before the elements of the job were determined. Therefore, the total time consumed in recording data was approximately 4 hours. The confidence limits, as could be expected with only 10 timings of the cycle, are wide. On the 95% confidence level, element number one, for example, is measured with a precision of $\pm 16.5\%$. At this confidence level then, the average time required for element number one in the long run will be between 1.18 minutes and 1.50 minutes. For element number four, a greater variation in time is evident and on the same confidence level one can expect the average time for this element to be between 1.83 and 4.51 minutes. Further processing of the time study data including the above check on the precision attained required about 55 minutes. Thus, the total time required to complete the time study was approximately 5 hours.

Application of Synthetic Basic Motion Times to Turn-Around Work

The terms "synthetic basic motion times," "motion time data," "predetermined-elemental time standards," and variations of these terms all refer to another system of work measurement which Krick (4) defines as follows:

A predetermined motion time is the expected performance time for a basic subdivision of manual activity, obtained by averaging the times required by many persons to perform the given motion. A predetermined motion time system is a set of these predetermined motion times from which it is possible to synthesize performance times for a large variety of manual operations.

.... Different manual operations appear to be different combinations and permutations of only a limited number of unique body member movements, such as move hand to object, grasp object, move object, release object, and so forth. Because each of these small subdivisions is common to a large number of manual operations, it becomes technically and economically feasible to carefully derive an expected performance time for each. Using these basic subdivisions, usually referred to simply as motions, and their associated performance time values it becomes possible to:

- a. designate the various motions required by a given method;
- b. consult tables of time values to obtain the expected performance time for each of these motions;
- c. sum these times to obtain a total expected performance time for that method.

Synthetic basic motion times may be used to determine a time standard for a job without the analyst's ever having seen the job if he is furnished with an adequate description of the movements of the worker. This technique would seem applicable to those turn-around tasks which are seldom repeated, since the analyst could, theoretically, synthesize a standard before the turn-around began. However, there are several difficulties in applying these synthetic basic motion times to turn-around tasks. Foremost among these problems is the fact that these times, being both "basic" and designed for application to repetitive factory work are very short in duration. Taking the most commonly used system, MTM (Methods-Time Measurement), for example, the average time given for the basic motion "Reach" is about 13 TMU's (13 Time Measurement Units) or

0.00013 hours. This is for a reach to an object 10 inches away from the hand with the object likely to be in a slightly variable position from time to time. This amount of time for a wide variety of basic motions appears to be about average. To synthesize a one-hour job if the MTM basic motions indeed averaged 0.00013 hours in length and no repetition took place, would require a minimum of 7,700 basic motions to be recorded, times for motions determined, the times to be totaled and allowances to be applied before the standard could be synthesized. (This also assumes the worker is working with only one hand since the motions of the other hand complicate calculations.)

Obviously, for turn-around work, synthesis of MTM and similar basic motion time data is not economically feasible, but one system based on MTM has been evolved which it is claimed "applies to virtually any long cycle work..." This system is called Master Standard Data or MSD and consists of frequently-used combinations of MTM basic motions.

Many problems were found when the MSD system was applied to turn-around work. First, it was found that because the motion patterns had to be known before MSD could be applied, an analyst not experienced in methods used in turn-around work was required to watch the actual job to determine the motions required or to be furnished with a detailed description of these motions in order to synthesize a standard time. The alternative would be to assign a person experienced in turn-around work to make the

analysis himself. Second, it was found that MSD simplified MTM by classifying motions in fewer, simpler categories rather than providing fewer, longer-duration basic motions. The average MSD basic motion time is about twice as long as an MTM basic motion time. Third, crew activities, where usually the work of individuals is coordinated, complicated the analysis still further. For these reasons, the use of synthetic basic motion times in their present state of development was rejected as a valid work measurement tool for turn-around work.

A Work Sampling Study to Determine the Standard Time for a Turn-Around Task

In order to provide a comparison between time study and work sampling as methods for determining performance evaluation standards during turn-arounds, a work sampling study was made of a job which was also time-studied. The "tube-pulling" job described above and summarized in Figure 11 (page 115) was chosen as the job for which this comparison would be made. It should be noted before proceeding, however, that this job is not one which would normally be chosen as a typical turn-around task. The very fact that the job in question was chosen to be time-studied illustrates that it is a relatively cyclic or repetitive job. This repetition is due to the similarity of the components which were being processed, i.e., the pipe being removed. A somewhat similar repetition is often

experienced during the turn-around but is usually on a larger scale. For example, in many respects operations on heat exchangers are quite similar but the performance evaluation standards set on each may vary considerably because of the location, usage, physical characteristics, period of time since last cleaning, etc. Then, of course, there are a large number of jobs such as welding, catalyst removal and replacement and new construction which are virtually non-repetitive. Being repetitive then, the task in question, "pulling tubes," is somewhat better suited to study by work sampling than are many other turn-around tasks. Where there are several cycles or several pieces produced, time study or work sampling may measure the average time experienced rather than measuring only one repetition. Thus, more confidence may be placed in the average time for repetitious work.

The work sampling study was designed to achieve $\pm 10\%$ precision on the 95% confidence level. It was estimated that delays or absences of crew members would amount to 15% of the elapsed time. The duration of the job was estimated by the foreman in charge of the particular area to be about "six to eight hours." Based on 85% working time, if working time were to be measured with $\pm 10\%$ precision, 71 observations would have to be made during the job. Therefore, in order to be sure of achieving the desired confidence level, 110 observation times over a nine-hour period were drawn from a random number table. The largest

interval between these observation times was 19 minutes. Observation times were chosen to the nearest minute and the average interval between observations was 4.91 minutes. Because crews tended to take relief or "break" times as a group, it was thought necessary to observe crew members individually in order to avoid a large bias in the study. Each worker was rated at each observation and the average pace for the study was calculated to be 101.3%. During the 378 minutes or six hours, 18 minutes required by the job exclusive of "set-up" and "take-down" time, the five crew members were observed working 65 times and were idle or absent seven times in 72 observations.¹ Thus, working time was estimated as:

$$\frac{65}{72} = 0.9028 = 90.28\%.$$

The standard time for the job may be calculated by the expression previously given as:

$$\text{Standard Time/Piece} = \frac{378 \text{ minutes} \times 0.9028 \times 1.013}{17 \text{ pieces}}$$

$$+ \text{ Allowances} = 20.34 \text{ minutes/piece}$$

$$+ \text{ Allowances.}$$

Since work sampling for the purpose of deriving time

¹No observations were made during the scheduled lunch period.

standards considers only that time which the worker spends actually engaged in work, it is customary to add some amount of time to allow the worker to rest and attend to his personal needs and to compensate for delays beyond his control. These three amounts of time and occasionally others, totaled are called "allowances" and are usually added to the total elapsed working time in order to arrive at the time standard. Without allowances being added, the time figure derived for this total elapsed working time is termed "normal time" and in the case in point, is 20.34 minutes. This figure is directly comparable to the summation of element times for the time study of the same job since allowances were not added to the time study and since time study also considers only that time when the crew is working. These comparable figures for the normal time per piece on the same job at nearly the same time were 20.69 minutes as measured by time study and 20.34 minutes as determined by work sampling. Thus, the difference in normal times if these two studies were to be used to predict the time to accomplish the complete job would be approximately six minutes. For the work sampling study, the confidence interval on the 95% confidence level of the "working" category is 18.71 to 21.91 minutes, whereas, the confidence interval for the average cycle time of the time study on the 95% confidence level is 18.51 to 22.31. It should be noted that both of these studies depend upon the rating process and, thus, are directly dependent upon the

observer's judgment of the pace of the worker or workers observed.

Bias was undoubtedly induced into this work sampling study because this study was carried out during the time the observer was conducting a time study. In a few instances the necessary observations and ratings had to be postponed for short periods until one of the time study elements could be recorded.

The cost of making a work sampling study of this job is difficult to determine since it depends directly upon how the observer is able to utilize his time otherwise. Nevertheless, for comparison purposes, an attempt to determine these costs will be made. Since several intervals between observation times chosen were less than three minutes and none larger than 19 minutes, it was assumed that the observer could utilize his time best by making a second work sampling study on another job. Based upon this insupportable premise, the observer would have spent one-half of the 378 minutes required to accomplish the task in observing and rating the crew members. Approximately one hour was required to design the study and process the results. The total of these two estimates is 249 minutes or about four hours, a saving of roughly one hour over the time required for the time study. Probably, in some cases, three work sampling studies could be carried out simultaneously. If so, the estimated time for actual work sampling would be approximately 126 minutes if it were

assumed the observer divided his time equally between the three jobs he observed concurrently. Assuming the same time is necessary to design the study and process the results, the total time estimated to be devoted to the study is 186 minutes or slightly over three hours. Some small error could be induced in sampling turn-around work, which is usually non-repetitive, because of the absolute beginning and ending points of work of this nature. That is, if the job is to be measured purely by sampling, then the exact number of minutes to process a certain number of units may not be known because sampling trips will probably not coincide with the exact beginning and ending of the job.

It should also be pointed out that time study as a work measurement tool allows the compilation of standard data from its results where work sampling is not well suited for this purpose. Time study also allows the variation of element times to be examined where work sampling does not.

In addition, the establishing of a time standard by classifying work sampling observations into the categories "working" and "not working" is somewhat of a misnomer since Nadler (1), Mundel (2), Barnes (3), et.al., specify that a time standard includes a description of the methods used. Where only a few or possibly only one cycle of the work is performed, work sampling may not be a desirable measurement tool. Krick (4) writes:

Note, however, that work sampling is more competitive with and probably superior to ordinary stopwatch procedures only in instances where a more aggregative picture is sufficient.

CHAPTER X

USE OF THE MEMO-ACTIVITY CAMERA TO DETERMINE PERFORMANCE EVALUATION STANDARDS

The primary criterion in the selection of work measurement methods for the determination of performance evaluation standards is economic. The benefit derived from establishing these standards must be greater than the costs involved. The memo-activity camera, designed and built by the School of Industrial Engineering and Management at Oklahoma State University for work analysis, is potentially a tool which may be used for the gathering of work data at a relatively low cost. This inexpensive method of establishing standards, if proven practical, should allow standards with their numerous benefits to be set for certain types of work where performance evaluation standards, in terms of the expected time to perform a task in a given manner, are not now economically feasible. In order to determine the validity of the memo-activity camera, the camera was extensively used to photograph turn-around work as the first step toward the development of performance evaluation standards for this work.

As a direct comparison with other work measurement systems, the memo-activity camera was set up to photograph

the "tube pulling" operation on the Crude Heater during the same time period in which the work sampling study and the time study were being performed. The camera, since it is designed to operate automatically, required no attention. The camera was placed and started one-half hour before the job was begun on the Crude Heater and ran approximately 15 minutes after the job was finished. Thus, the camera was in operation for about 423 minutes and at a rate of exposure of two frames per minute, some 846 frames of film were exposed. At current costs of 16-mm film and development, the cost of this amount of film ready for analysis is \$1.25 or alternately put, \$0.003665 per minute or \$0.21990 per hour of usage. During the examination of this film, the analyst required approximately six minutes to locate the beginning of the job, the beginning and end of the lunch period and the end of the job, read the clock in the film frame at each of these four times and subtract to determine the total elapsed working time. An additional nine minutes was required to rewind the film, project it at slow speed in order to count the number of tubes removed, and note that there were no excessive delays or absences beyond one regular 10 minute "break." The elapsed working time including rest periods was measured by subtracting successive clock readings to be $376\frac{1}{2}$ minutes. Therefore, a standard of:

$$\frac{376.5 \text{ minutes}}{17 \text{ tubes}} = 22.15 \text{ minutes/tube}$$

could be set for this operation. The cost of this standard is approximately \$1.25 for film plus 15 minutes of the analyst's labor plus an estimated additional time of 15 minutes to place the camera before the job and return for it at the end of the job.

It has been found that it is relatively easy to develop data derived by use of the memo-activity camera into performance evaluation standards since the crew sizes, equipment used, physical environment and methods employed are quite graphically described on film. Occasionally, however, the material used in certain jobs is not readily apparent from the film and must be determined otherwise.

At least two problems arise in using memo-activity film to determine performance evaluation standards. The first has to do with allowances. The cycle time for the job described above was determined to be 20.69 minutes by time study, 20.34 minutes by work sampling and 22.15 minutes by film analysis. The first two cycle times as explained previously are normal times, i.e., no time has been allowed the worker for rest, personal needs or unavoidable delays. The final step in calculating the standard time by each of the first two methods is to add a certain percentage of time to allow for these non-productive, but necessary delays. Customarily, there is a company policy which specifies a certain allowance for certain classes of labor and which is based primarily on the amount of physical exertion required by the work. In this case,

if 10% was the figure specified for allowances, the standard time derived by work sampling would be 20.34 minutes +0.10 (20.34) minutes or 22.37 minutes and the standard time determined by time study would be 20.69 minutes +0.10 (20.69) minutes or 22.76 minutes. Both of these figures compare quite favorably with the memo-activity time standard of 22.15 minutes/piece.

The memo-activity standard time of course included allowances since it measured the elapsed working time including the collective rest periods and excluded the lunch period which occurred during the latter part of the study.

The standard time could have been determined from the memo-activity study by excluding from working time the amount of time spent by crew members on those activities usually defined as constituting allowances, then adding to the normal time thus developed, a standard percentage of time for allowances. However, it seemed much simpler and less time consuming to inspect the films to determine whether excessive time had been spent away from the job and if not, to apply as allowances, the time the workers actually took for personal needs, rest and unavoidable delays. However, there may be cases where the analyst is convinced that the workers observed are taking more or less time away from work than is specified. In this case, the actual non-working time taken may economically be estimated by sampling a number of film frames. Ordinarily, it can be assumed that supervision will maintain the working

versus non-working time within the bounds it considers proper.

The second problem or aspect in which the memo-activity standard differs with respect to presently used standards is that of rating, the observer's judgment of the worker's speed, pace, rate or tempo. Obviously, all workers cannot be expected to work at the rate of the fastest worker or be tolerated to work at the speed of the slowest worker. Therefore, it is customary to "rate" the worker observed when a work measurement study is made in order to determine how his effort should be compared with that expected from the average employee.

One factor that somewhat reduces the extremes experienced in rating where crews or teams are rated, is the likelihood of a fast or slow worker being controlled by the pace set by other crew members. Too, if crews of four to seven men are used, as is customary in turn-around work, the pace for the team is the average of individual paces and thus would have a central tendency. It was found in the turn-around which is the subject of this dissertation and one other turn-around which was used as a check study that the majority of crews, as a whole, maintain a pace judged by the writer to be within the range of 95 to 100% of "normal pace".

There are several methods by which the memo-activity data could be rated. Since time studies are often made with only one rating for the whole study, memo-activity

studies should also be considered valid with one rating of pace. This rating could be accomplished by having an observer rate the crew at some time during the study. Probably a more economical method rating would be to incorporate a short burst of film taken at normal speed sometime during the study so that the film, projected at normal speed, could be used to rate the crew's pace. This would make for economy because the person who sets up and collects the camera would not have to be a trained rater and could as well be a lower paid person. Accordingly, one of the suggestions for the development of the memo-activity camera and also a suggestion for future research will be the incorporation into the design of the memo-activity camera the ability to expose film at normal exposure rates for short periods of time and the use of this feature in rating the pace of individuals or crews.

Another economical method of rating would be measuring the crew's performance over a standard segment of work. Often, there are similar elements of work in different jobs. A carefully established standard on a few common elements should provide a tool for measuring the pace on any task which contains one (or more) of these common elements.

In rating as in the amount of time given for allowances, supervision may be counted on to exert persuasion toward the maintenance of normal pace. That is, there is a fairly well understood concept of the acceptable rate of

work between management and labor and a departure from this rate usually initiates some pressure toward equilibrium.

In addition, it is not unreasonable to expect that workers who know that the photographs being taken are subject to examination for excessive idle time and who know that their pace is also being determined will not allow their effort to fall much below normal, especially when their performance is recorded on film. Neither can their performance be expected to be far above average or normal if the men know that the film is to be used as a standard for future work. This validity of this premise should also be a subject for future research.

Because accuracy of measurement is polemic with the cost of production, it may prove economic with less often used standards to subject only selected films to audit for pace and for allowances, and accept the remainder as filmed.

Comparing the exact costs of determining time standards by time study, by work sampling and by memo-activity study requires several assumptions, but in order to provide a cost comparison the following information is submitted assuming a labor cost for the analyst of \$3.00 per hour (Table II).

TABLE II

A COMPARISON OF THE COST OF DETERMINING PERFORMANCE
EVALUATION STANDARDS BY USE OF TIME STUDY,
WORK SAMPLING AND MEMO-ACTIVITY STUDY

	Time Study	Work Sampling	Memo- Activity
Standard error of the Estimate or Accuracy	± 9.3%	± 7.7%	- 0.40%
Hours of Labor Required	5	3	1
Labor Cost	\$15.	\$9.	\$3.
Film Cost	<u> </u>	<u> </u>	<u>\$1.25</u>
Total Cost of Standard	\$15.	\$9	\$4.25

The assumptions necessary to make this calculation are:

1. The conservative estimate of the time necessary for the work sampling study was taken. That is, it was assumed that two other work sampling studies could be made simultaneously with the study in question and that the analyst's time could be equally prorated between the three jobs.
2. The times experienced by the writer for designing studies, recording data and processing data recorded are typical of the theoretical analyst performing these functions and may be used as a basis for calculation.

3. The memo-activity analyst spends 10 minutes in rating the crew and calculating the average rating. This 10 minutes may be divided into one or more ratings depending upon the time required for the analyst to travel to and from the place where the job in question is being done.
4. The memo-activity film is random-sampled to determine working time versus idle or absent time. This can effectively be done by following a table of random times and stopping the projector when the watch in the film frame shows one of the sampling times has arrived. The worker sampled may be chosen by allowing the last digit in the random time to designate which worker is to be observed. This can be done and a percentage calculated from the results in about 20 minutes for most jobs since the number of samples will presumably be constant and few in number.

It is hoped, however, that "working" versus "idle or absent time" will be controlled by other factors so that only an occasional check need be made to determine the relative proportions of these classifications. If this were assumed to be the case and assuming the previous estimated times held true, determining time standard for

this job would require 40 minutes of the analyst's time at a cost of \$2.00. Adding the film cost of \$1.25 would bring the total cost of determining the time standard to \$3.25.

5. The analyst sets up and takes down the camera himself instead of using lower cost labor.
6. The relative amount of inaccuracy is calculated for the memo-activity camera on the basis that the duration of working time as measured by film analysis was one and one-half minutes less than the same time measured by visual observation. A general figure for the accuracy attainable cannot be based on one sample. Therefore, the accuracy stated for the memo-activity camera standard is for comparison purposes only. The Standard Error of the Average for the time study and for the work sampling study is based on sampling theory.
7. Further data needed to establish a performance evaluation standard (e.g., methods, tools and equipment, materials used, crew sizes) are determined in the same manner for each type of study and thus, the cost of doing so may be equally excluded from the cost of the standard derived by each means. This is not strictly true because the methods and often the equipment

and materials used are quickly summarized by viewing the memo-activity film but at least one repetition of the job must be viewed and information recorded in order to describe methods, equipment, and materials if standards are to be established by work sampling. Information supplemental to the element descriptions may or may not be necessary in describing methods in performance evaluation standards established by time study.

8. The cost of the memo-activity camera is not included in the cost of developing standards by the memo-activity technique because the camera is still in the developmental stage. However, it is estimated that if the camera was fully utilized over a period of a few years, the amortized camera cost per hour of operation would be negligible. For the same reason, the cost of a special projector for frame-by-frame memo-activity analysis is omitted. However, the projector used for frame-by-frame analysis may also be used for the regular projection of any 16-mm film.

It can, therefore, be seen that a large number of assumptions as to the characteristics of the job being measured are necessary before a statement can be made concerning the relative costs of developing standards by the three techniques compared. On the basis of his experience with

the three types of work measurement, the writer believes it conservative to state that in the majority of seldom-repetitive jobs, the memo-activity technique is capable of determining performance evaluation standards with an accuracy exceeding that of work sampling for a cost of less than one-half that of work sampling.

In addition to giving promise as a low cost method of standards determination, the memo-activity technique has been found through field usage to have other important characteristics. Barnes (3) suggested one of these characteristics when he wrote:

Some complicated manual operations can be recorded best by motion pictures. In fact, it may be more economical in certain cases to make the record in this manner than to rely entirely on a written description of the job. On important operations, "before" and "after" motion pictures are frequently made for other purposes and may also serve, of course, as a supplement to the written standard practice. However, few companies as yet have seen fit to use motion pictures for standard-practice records in a general way.

The excellent record of events and conditions provided by the memo-activity camera has evoked considerable interest in the camera as not only a work measurement tool but as a method of permanently recording methods, equipment and crew size utilized and the conditions under which the work was performed. This record is especially valuable for refinery turn-around and similar types of work in which variables such as weather, height of work, and variation in the physical arrangement of units processed complicate the process of providing written standard practice instructions for jobs.

Although they have not yet been used as such, memo-activity films should provide a valuable supplement to other records in planning operations. For jobs which are performed only occasionally as are many turn-around tasks, those responsible for planning undoubtedly forget some of the details of the job from one turn-around to the next. The viewing of films of previous operations should allow planners to recall more pertinent information with a resultant increase in planning efficiency.

Memo-activity film should also be of use when contract labor is used during a turn-around or other types of work. Films of jobs may be sent to the contractor who may be unfamiliar with the conditions and the specific type of equipment his crews will be expected to repair and maintain. The contractor with the aid of these films will be better able to anticipate the skills and equipment needed. Too, contractors may be "rated" by their performance on jobs previously done by "captive" maintenance.

In a similar sense, memo-activity films may be shown to the men who actually do the work. This can be a valuable supplement to the memory for seldom-performed tasks or a training device for inexperienced or new workers.

Memo-activity films should also be of value in explaining maintenance, construction or other common refinery tasks to non-technical members of management and those who lack refinery experience.

Time standards are indispensable in scheduling

refinery work. Because of the lack of valid time standards, scheduling in some refineries is rudimentary. Poor scheduling means that tools and equipment may not be efficiently utilized, work may be delayed because men with certain skills are detained elsewhere or that these men may have to wait for others to finish before they can begin. Modern cost-saving techniques such as critical path planning may not be used without a reasonably accurate concept of the time it should take for a certain job to be finished. The use of the memo-activity technique, on the basis of its observed performance, should provide an economical method of establishing these time standards.

Through the use of memo-activity films not only is the total elapsed time to perform a task capable of being economically determined but intermediate stages in the progress of the job toward its completion may also be determined and timed. Thus, if a job falls behind its schedule for the completion of intermediate stages, then management will be able to apply remedial action before the schedule is further disrupted.

The inclusion of the clock face on the film frame in memo-activity film decreases the cost of analysis by providing a more rapid calculation of the elapsed time between two points on the film. The projector which is used to analyze memo-activity film is equipped with a frame counter, a dial which shows the number of frames which have passed through the projector; but delays are encountered

in subtracting one number from another to determine the number of frames consumed by some activity and in keeping track of the number of revolutions of the frame counting dial. The clock in the memo-activity film frame shows absolute time and this feature, it was found in the analysis of film, allowed the analyst to anticipate lunch periods and relief "breaks" so that less film had to be rewound in order to determine the frame of film on which activity stopped and started. Absolute time being recorded on the film also made possible the detection of late starting and early quitting.

One other potential advantage could possibly accrue from the use of the memo-activity camera. It was observed that the crews of which memo-activity films were made took a somewhat unexpectedly small amount of time away from the job, were seldom idle and maintained on the average, a pace quite near normal. It is not unreasonable to assume that part of this effect was due to the fact that the crews knew they were being filmed. If this assumption is correct, some use might be made of the camera for supervisory purposes. There would undoubtedly be a great amount of objection from the Unions if a practice of partially supervising by camera were adopted, but the very low cost of doing so (\$0.22 per hour) could possibly interest management regardless of labor's protests.

There seems to be no theoretical objection to work sampling memo-activity film to gain certain types of

information. Observation times for visual sampling are normally chosen in increments of one minute or even five minutes. The watch image in the frame of the film allows the analyst to make observations at random times accurate to within one-half or one-tenth minute with the speeds of exposure made in this study. According to some recently developed theory (Davidson, 39, 48), sampling at fixed intervals may accurately describe repetitive tasks. Thus, it is possible that if sampling of memo-activity film were done on a large scale, a projector might be equipped so that it would advance a certain fixed or scheduled, random number of frames upon a signal from the analyst. The time for finding the specific frame to be sampled could be greatly reduced in this manner. The use for which work sampling is ideal, the utilization study, has been found to be quite practical and economical to accomplish by the analysis of single film frames.

One other expected use for memo-activity film was found to be impractical for the type of work chosen to be analyzed. It was expected that memo-activity film exposed at the rate of two or 10 frames per minute and projected at the standard projection rate of 960 frames per minute would provide the analyst trained in motion study techniques with a condensed concept of the motions required by each member of a crew to accomplish a task. From the pattern of motions, better methods of work might be evolved. For example, the condensed version of a job could be

expected to give a concept of the division of work between crew members and lead to more effective utilization of efforts.

Analysis of film exposed at memo-activity speeds and projected at normal speeds showed the progress of the work quite well, but problems were encountered in precisely determining the motions of individual workers. The interval between exposures precluded a close examination of the workers' hands and arms. Using the exposure rate of 10 frames per minute gave a good concept of the gross body movements of workers, but the lack of continuity of the film left much to be desired in showing exactly what the worker was doing.

It was found that the variation in the location and physical arrangement of the equipment worked upon caused variations in patterns of motion. For example, in "pulling" a heat exchanger "bundle," different methods were used for heat exchangers located off the ground than for those located at ground level. In performing this task at an elevated location even the gross body movements were restricted.

This same lack of exact detail hampered the frame-by-frame examination of memo-activity film for the purpose of constructing gang process or man-machine charts. (These charts are used in methods improvement work.) However, as it has previously been stated, high accuracy is not usually compatible with economy of production. Therefore, it might

be expected that a measurement tool designed for economy might lack the detail or accuracy provided by more expensive tools. The memo-activity technique was designed to set standards on work where standards had previously been thought to be uneconomical, to long-cycle, seldom-repetitive jobs; it could be expected to lack the detail necessary for the examination of work with different characteristics and for the use of techniques designed for the examination of work with different characteristics. Although exposure rates faster than 10 frames per minute were not used, the memo-activity camera is capable of exposing film at the rate of 200 frames per minute or about one-fifth the normal rate of exposure for a 16-mm moving picture camera. It is quite possible that this speed may provide the detail necessary for the construction of various process and activity charts and, at the same time, provide important economies in the cost of film.

CHAPTER XI

PERFORMANCE EVALUATION STANDARDS DETERMINED BY ANALYSIS OF MEMO-ACTIVITY FILM

Although the memo-activity technique is designed primarily for the analysis of long-cycle seldom-repetitive work, several jobs were filmed which were sufficiently alike to group together in order that they might be treated statistically. An attempt was made to find a correlation between one or more of the physical characteristics of the type of equipment being worked upon and the standard time¹ for performing the work. The method used to determine this correlation was the calculation of a linear regression line by the method of least squares. Eight performance evaluation standards have been compiled in this manner and are included herein in Appendix C. These performance evaluation standards describe the task, crew size and equipment to be used and show a formula recommended for the prediction of the time which will be required to perform a given

¹The times shown in the performance evaluation standards may be considered standard times since a predicted time for accomplishing the job is specified, a performance rating for the individual or the crew was determined and applied and the elapsed time of the job was sampled to determine the presence of excess idle or absent time.

task. This prediction is based on one or more specified physical characteristics of the work. The confidence level and standard error of the estimate for each performance evaluation standard are given.

All of the performance evaluation standards with the exception of those for bolting and unbolting flanges pertain to the opening, cleaning and reassembly of shell and tube heat exchangers of various sizes; and in addition, there are always at least two flanges which must be bolted and unbolted for each heat exchanger disassembled. Therefore, all of the performance evaluation standards for which confidence limits have been calculated are directly applicable to the processing of one general type of heat exchanger. The fact that all of these standards are for one type of equipment is not due to accident. The processing of these heat exchangers has been found in corroboration of management's opinion, to be the most common major turn-around job. Consequently, it was attempted to provide as accurate as possible a description of the processing of these units along with the time requirements for various stages of work. Certain of the tasks required for a complete description of the entire process were photographed an inadequate number of times for any statistical analysis to be made. Several of these tasks will be described below so that by combining the times experienced with the various steps of the process, an estimate may be made of the duration of the entire job.

The confidence levels on the tasks described in Appendix C were not so high as it had been hoped they would be. It was found necessary for some of these standards, to specify a confidence level for the amount of time required as \pm one σ or about 68% in order to provide a usefully small confidence interval. On the other hand, the units which were combined in order to treat them statistically were somewhat diverse in their characteristics. For example, jobs combined into one category were performed at various heights above the ground. This has, of course, some effect upon the speed at which the worker performs his duties. It is felt by the writer that a larger number of memo-activity films of turn-around tasks would allow a more homogeneous grouping of tasks with a resultant improvement in the confidence level or confidence interval for the times required. It would seem ideal if a memo-activity film could be made of each major unit each time it is "turned-around" to provide a more individual record and a better prediction of the time required to perform tasks on that particular unit. If the cost of making and analyzing these films is, as has been calculated, less than \$0.25 per hour, repetitive filming of the same job should prove feasible.

With reference to the relatively low confidence level of the performance evaluation standards, it should be noted that the tasks described were relatively short; few were longer than one hour and some required but five to six

minutes. Applied to the longer duration, more comprehensive tasks upon which the memo-activity technique is primarily designed to operate, there is a good chance that variation in the times to perform sub-tasks will compensate for one another, that one "frozen" nut to be removed will be matched by one which may easily be removed. Then the time for the complete job "remove, clean and reassemble heat exchanger" should be somewhat more predictable than the individual time requirements for the components of the job.

It should also be recognized that chance plays a considerable part in determining the confidence levels and corresponding confidence limits for these standards. That is, an occasional high or low value may be recorded which greatly increases the range of values. With a small amount of data, the effect of one incongruous value can be expected to be large. Then the inclusion or exclusion of relatively high or low values by chance has an inordinate effect when the amount of data is small.

For the above reasons, it can be seen that there is a favorable probability of improving the reliability of information gained from the analysis of memo-activity film.

It will be noted that information is included in the performance evaluation standards in Appendix C which was not obtained from the memo-activity film. For example, the diameter and length and in some cases the number of tubes and the volume of shell and tube heat exchanger tube

bundles were measured and used in the attempt to find a close correlation between these characteristics and the time required to perform various operations. An exact determination of these characteristics was not possible from the memo-activity film. However, nearly all refineries have this specific information recorded and filed where it may be located with less effort and expense than that required by the analyst to measure characteristics of the equipment himself.

The performance evaluation standards in Appendix C are arranged in their chronological order as the work of processing heat exchangers proceeds and the work involved should be fairly well understood even by those unfamiliar with the refinery. The exception is the standard for the task "Hydroblasting." This is the trade name of the Dowell Corporation for cleaning heat exchanger bundles with a high-velocity water jet. In this recently developed process, a nozzle is mechanically moved parallel to the longitudinal axis of the heat exchanger bundle. The water blast from this nozzle loosens the petroleum sediment or "coke" from between the tubes and flushes it away. Meanwhile, an operator manually uses a high-pressure water hose to clean the inside of the tubes. For a more detailed description of the Hydroblast technique, see Ramsey (49). The best guess of the workers who were operating the Hydroblast machine was that it required "about an hour to clean an average-size bundle."

In conclusion then, it can be seen that the majority of the performance evaluation standards formulated demonstrate sufficient statistical reliability to be of considerable use to refinery management in the planning, scheduling and control of work.

Performance Evaluation Standards for Which Confidence Limits are not Calculated

For a large group of operations, no confidence limits were calculated because too few repetitions of identical or similar operations were filmed for statistical analyses to be made. These, however, constitute the more important part of the study since it is the seldom-repeated task for which the memo-activity technique is designed. Performance evaluation standards in terms of the task to be performed, the equipment and crew sizes required and the standard time for 32 jobs are shown in Appendix D. Although unimposing in appearance, the first two of these standards are probably more important.

Raschig rings are a type of packing. Packings in the refinery can be defined as loose pieces of solid material that fill columns except for short spaces at the top and bottom. By providing the surface over which the down-flowing liquid distributes itself, they increase the area of contact between liquid and vapor and thus promote the transfer of materials between the two streams. Raschig rings are small, hollow cylinders open at both ends, with

length equal to diameter. Although Raschig rings are made of different materials, those observed were made of graphite and were one and one-half inches in length and outside diameter. It is necessary, periodically, to remove these rings for cleaning and this is done through a small port at the bottom of the vessel. The port is opened and a worker pulls the rings through the port with a three-pronged hook which he holds in one hand. The rings fall onto a chute and a second worker pushes them along the chute and into a hopper. It can be seen that this is the type of job for which there has been no standard set because the expense of work measurement has been greater than the benefit to be derived from the performance evaluation standard. Here though, a performance evaluation standard may be set at a very low cost by use of the memo-activity camera.

The second standard under the heading "Raschig rings" is for the filling of another vessel with these rings after they have been cleaned. From these two measurements, an adequate time standard may be evolved for similar jobs.

Several of the jobs described in Appendix C were observed more than once. When this occurred, the times for the job were averaged and both the individual times and the average times are shown. The generic terms used are defined in the Glossary of Terms, Appendix B.

CHAPTER XII

THE APPLICATION OF PERFORMANCE EVALUATION STANDARDS TO CLOSED REFINERY EQUIPMENT

One of the reasons often cited by petroleum refinery management for the lack of performance evaluation standards applicable to turn-around work is the fact that closed refinery units are not capable of being inspected internally so that an accurate prediction of the work necessary cannot be made.

Work on these closed refinery units can nearly always be classified as either cleaning or repair. It has been found that the amount of cleaning can be predicted fairly accurately. For example, the "charge heater" for the Dubbs thermal "cracking" unit is shut down each one to four months for cleaning. The decision as to when to shut this unit down is made on the basis of the thermal efficiency of the unit. The thermal efficiency as well as the flow rate of the charge stock through the heater's tubes indicates directly the amount of "coke" or hardened petroleum sediment in the tubes. On this basis, a reasonably accurate estimate can be (and is) made of the time required to clean the "coke" out of the Dubb's unit tubes. This is not to say that the turn-around time, as a whole,

is accurately predictable. After the tubes are cleaned, they are inspected for corrosion and wall thickness and those not passing inspection are "pulled" and replaced. This replacement time is not so predictable as cleaning time, but records kept of the previous inspection allow a fair prediction of the number of tubes which will have to be replaced.

As a second example of the ability to predict cleaning time for closed refinery units, consider the predictability of cleaning shell and tube heat exchanger bundles. Although the times for cleaning the bundles as determined by memo-activity study could have fallen by chance into a fortuitous relationship with their physical characteristics, nonetheless the confidence limits on the 68% confidence level were only ± 2.69 minutes and the average cleaning time was somewhat over one hour. Therefore, the cleaning of this "unpredictable" piece of equipment was, in fact, one of the most predictable jobs measured.

Repairing these uninspectable pieces of equipment is a somewhat different proposition. The repairs to equipment not capable of inspection before shut-down may be divided into three categories which will be termed:

- (1) Predicted
- (2) Scheduled
- (3) As necessary.

It has been seen that the amount of cleaning necessary to closed refinery units may often be predicted with

accuracy. So it is with repairs in some cases. Experienced operators and engineers are often able to diagnose the ills of a particular piece of refinery equipment and prescribe treatment at the subsequent turn-around. This is evidenced by the fact that a "work list" of jobs to be performed at the turn-around usually contains instructions for specific internal repairs to be made. If these repairs may be prescribed, they may also be pre-planned in which case performance evaluation standards are feasible. It has previously been mentioned that advanced inspection techniques such as the use of sound waves to measure pipe or vessel thickness are available to predict the need for repairs. Records of the characteristics of internal components are kept by many refineries for the purpose of directing the attention of the inspector to those components which are likely to fail. These records could also be used to predict failure and to calculate an economic replacement date before failure.

Some internal components give no warning of failure. Where these components are relatively inexpensive it is economic to replace them whenever the unit is opened during the turn-around. The replacement time of these components, too, is quite predictable.

The third category of internal repairs, called here "as necessary" is not so predictable. This portion of turn-around work is termed "as necessary" because the work lists prepared for the various production units before the

turn-around usually include the statement "clean and repair as necessary." In Chapter VIII of this dissertation, it was estimated from the work sampling study conducted that 20.73% of the work during one particular turn-around was devoted to work on closed equipment. Some unknown portion of this amount of work was devoted to jobs which were definitely predictable and some portion of this work was that which could be predicted with some accuracy. For example, there is some evidence to the fact that the portion of the total turn-around effort directed toward cleaning bundles is predictable. If this is taken as evidence that "cleaning" in general is relatively predictable, then the total amount of effort remaining to be classified as "unpredictable" after those categories principally consisting of cleaning are excluded is reduced to 11.10%. (Activities 8, 9, 12, 15, 21, 28, and 32 are considered predictable within usable limits.) Of this remaining 11.10%, the two important constituents are "welding" and "internal repair and cleaning of vessels." Since some portion of this remaining amount of work is also predictable, the remaining "unpredictable" or "as necessary" work hardly constitutes a justification for the lack of performance evaluation standards for turn-around work.

Neither is the assertion that no time can be spared for planning and scheduling after the unit is opened a particularly valid one. It has been amply demonstrated that planning and scheduling reduce the time and expense

associated with doing work. Otherwise, there would be no valid excuse for these functions. For any type of work which can be classified as other than minor repairs, planning and scheduling help assure that efficient methods and crew sizes are used, that proper crafts, materials and tools are available when needed and allow management to control the work by providing a standard against which actual performance may be measured. Neither is management precluded from measuring the more common unpredictable repairs for future application without delay.

Although the possibility of using the memo-activity camera to measure internal cleaning and repair was investigated, no such film was exposed. The limiting factor was not the use of the camera but the presence of the writer which was felt necessary to protect the camera from damage. The presence of the camera itself in some cases would not have hampered the efforts of workers but the presence of another person in confined quarters would have reduced the efficiency of crews and would have resulted in an inaccurate standard. There seems no reason why a memo-activity camera, adequately protected from damage, could not be utilized to examine the activities of workers inside normally-closed equipment. Films exposed at night with normal illumination for work were capable of analysis so that where there is enough illumination for work, there should be enough illumination to photograph the work.

One method of indirectly measuring work inside closed

vessels was found. Where the "decks" or "trays" were being removed from a tower called a Propanizer, the trays were being unbolted inside the tower and removed through a manway at the top of the tower. By focusing the memo-activity camera at the manway and exposing film at the rate of 10 frames per minute, the time required to remove the trays could have been determined. But, since it was not possible to observe the workers directly and thus determine their pace or working time, no attempt was made here to determine a standard.

CHAPTER XIII

THE USE OF THE MEMO-ACTIVITY CAMERA FOR METHODS IMPROVEMENT

Although the memo-activity technique abstracts certain factors pertaining to the manner in which jobs are performed, it also affords the observer a novel view of the work. Thus, it has been found that the memo-activity technique may supplement visual observation and charting as a methods improvement technique. As it has been stated previously, the films exposed by this technique do not provide an adequate source of information for the construction of charts because of the doubt concerning the starting and ending points of many motions and the simultaneity of others.

From the examination of films made, it appears that the memo-activity technique would have good potential as a methods improvement tool wherever alternate methods of performing the work have been filmed. For example, it was determined from the analysis of film that it required a two man crew equipped with a pneumatic torque wrench 11.5 minutes to remove 20 three-fourth inch nuts from a manway. This amounts to 0.575 minutes per nut. (Standard D4.) On a quite comparable job, unbolting flanges (Standard C1),

it required two men equipped with hammer wrenches an average of 1.320 minutes to remove three-fourth inch nuts on five jobs. The extra time per nut for removal of a three-fourth inch nut when using a hammer wrench is 1.320 - 0.575 minutes or 0.745 minutes. At a cost of \$3.50 per man per hour, or \$7.00 per hour for the crew, the extra cost of using the hammer wrench is:

$$\frac{\$7.00/\text{hour}}{60 \text{ minutes/hour}} \times 0.745 \text{ minutes/nut}$$

$$= \$0.0869/\text{nut}$$

or an extra cost of nearly nine cents per nut or put in other terms, using the pneumatic wrench is over twice as fast as the hammer wrench and \$1.74 was saved on this one job by using the pneumatic torque wrench. It can be seen from this example that the memo-activity camera is a valuable tool for the inexpensive comparison of alternate methods and would allow extended comparison of these methods in the more leisurely period of time following the turn-around. The technique should also encourage the trial of new methods and provide a more concrete basis for conclusions concerning the alternatives.

A second example is furnished by the standard for re-installing heat exchanger bundles. Although the crew size varied for several similar jobs, there was no apparent correlation between the size of the crew and the time required to perform the task. This indicates that an

excessive number of men is used in certain cases.

A traditional problem with maintenance in most industries has been the supposed need of the maintenance man for a helper. Many maintenance managers feel that the helper is more often a companion than an aide. The memo-activity technique would seem well-suited to investigating the activities of helpers and, as well, the activities of the members of larger crews. It is possible, for example, when performance evaluation standards are established for maintenance jobs, for a helper to be scheduled to report to the maintenance man at the time when he is needed. Thus, in some cases, two or more maintenance men could share a helper without a reduction in efficiency.

Memo-activity films also provide a stimulus to the memory when one wishes to recall the details of a job for the purpose of improving it. Photographs present, visually and concurrently, many more pertinent factors than could be combined mentally or even sketched on paper. Memo-activity films furnish an abundance of such photographs in chronological sequence each with the absolute time a part of the photograph.

There are many distractions present when viewing jobs during the actual turn-around for the purpose of devising methods improvements. The writer found that viewing the memo-activity film of the job in a quiet room allows concentration upon the job without these distractions.

Many turn-around jobs are performed but once per year

and the person who wishes to improve the methods used on such a job may watch it through only once. With a memo-activity film, the analyst may view the job as many times as he wishes.

Foremen and other supervisors, who have a great deal to do with determining the work methods to be used during the turn-around, are nearly always much too busy with other duties to observe methods with the intent of improving them. Such improvements could easily be formulated during the period following the turn-around when the need for routine maintenance can be expected to be less than normal. These memo-activity films would also serve as a valuable subject of discussion in departmental meetings as to the methods which should be used.

Projecting memo-activity film at normal projection speeds as an aid to the formulation of better methods as suggested by Mundel (2) was found to have no evident value for this purpose. Although a condensed version of the job may be conceived by the rapid viewing of memomotion films, the longer interval between exposures of memo-activity films gave a decidedly inadequate concept of the work when shown at normal projection speed. The memo-activity film was found to have value primarily when considered and used as a sequence or series of individual still photographs.

CHAPTER XIV

SUGGESTIONS FOR THE FURTHER DEVELOPMENT OF THE MEMO-ACTIVITY CAMERA

It was found that the memo-activity camera quite adequately performed its intended function during the period of time it was in use. The problems encountered in its use were minor and consequently, so are the revisions suggested.

Two aspects of the use of the camera could be termed problems. The first was the interference with photography by the sun. The camera in some cases was set up in such a position that at times during the day the sun or reflected glare somewhat reduced the value of photographs. It was found that this problem could be partially overcome by placing the camera generally to the south of the job being photographed. In several cases, however, this appeared not to be easily accomplished because of various obstructions. For those cases where the sun is expected to interfere with photography, a polaroid filter should be used to reduce glare.

Second, because of various obstacles, placement of the camera is not always at an advantageous spot. Thus, either the field of view may be inadequate or conversely,

the amount of detail which may be recorded from the camera's position may be inadequate. To alleviate considerable of these problems, it is suggested that a turret containing a telephoto and a wide-angle lens, as well as the normal lens, be installed on the memo-activity camera. It is expected that the wide-angle, short focal length lens will not only allow wider coverage of area from a fixed position but will also provide a greater depth of focus. This latter characteristic becomes increasingly important as the diaphragm is set at wider openings.

Because of the apparent success of work sampling memo-activity film, it does not appear worthwhile to develop a facility for random operation of the camera for one or more frames. However, since it is occasionally desirable to pace rate workers or crews during the memo-activity study, the incorporation of the ability to photograph at a normal or a known, near-normal rate of exposure for not less than three to five seconds is recommended.

It appears possible to reduce the size of the clock image shown on the film frame. If this is done, more of the film frame would be available for the photography of the activity being observed. Also it would seem advisable to place the clock image at one of the lower corners of the film frame because usually, less activity is filmed in the lower portion of the frame than in the upper.

If it becomes desirable in the future to photograph very large areas or widely scattered activities, it is

recommended that provision be made to photograph the image of these activities in an inclined mirror or prism rotating about a vertical axis. This would allow coverage of a complete circle around the camera and would seem to be a more economical solution to the problem of photographing large areas or work lying in different directions around the camera and would be less subject to mechanical malfunction than would be the movement of the camera itself.

CHAPTER XV

A FURTHER APPLICATION OF MEMO-ACTIVITY STUDY

Since the memo-activity technique appeared to be a useful tool for the examination of petroleum refinery turn-around work, it was thought that the technique might be capable of extension to the analysis of other types of work which are seldom repetitive. As an exploratory study, several days' films were exposed of an executive at work. The study was aimed toward determining how an executive spends his time while in his office. From the analysis of such films, Table III was constructed. Table III is a simple classification of the executive's activities over a period of about 22 hours of elapsed time or about 18 hours of working time. From this study, one interesting observation is that this executive spent the great majority of the time in his office communicating with people. Another interesting aspect of this study is the amount of time this executive spends in telephone conversation.

This brief study shows that the memo-activity technique is an inexpensive method for gathering information on the functions of executives. Such information could be checked against existing theories of the executive

TABLE III
ANALYSIS OF AN EXECUTIVE'S ACTIVITIES

	Total Minutes	Percentage of Total Time	Percentage of Time Spent in Office
Conversing with visitors to office	177.5	15.4	33.8
Reading corres- pondence and writing	173.5	15.1	33.0
Telephone conversation	119.0	10.3	22.7
Dictation	37.0	3.2	7.0
Thinking	7.5	0.7	1.4
Conversing with employees of his office	6.0	0.5	1.1
Absent from office	625.0	54.3	-
Miscellaneous	4.5	0.4	0.9
Total	1150.0	99.9	99.9

processes in order to further the understanding of this vital function. Certainly much information is lacking by the use of photographs only, but various means could be used to improve the amount of information gained. For example, locating the camera close behind the executive might allow the analyst of the resulting films to identify those persons visiting the executive's office and to determine the content of written correspondence both from and read by the executive. For the executive whose activities are shown in Table III, investigation of these two categories of activity would deal with more than two-thirds of the executive's work during this two and one-half day period.

Filming the activities of executives could supplement or be supplemented by a sound recording device on a continuous or sampling basis in order to determine the content and character of verbal communication.

The study of work has made a valuable contribution to the productivity of the direct laborer, is beginning to improve indirect labor activities and in the future, may allow the executive and administrative functions to be performed at a lower cost.

CHAPTER XVI

SUMMARY AND CONCLUSIONS

The problem investigated in this dissertation can be stated generally as an inquiry into possible methods of economically establishing and applying performance evaluation standards to seldom-repetitive, indirect labor tasks. The usually annual shut-down for repair or "turn-around" in the petroleum refinery was chosen for research as being a concentration of this type of work.

Specifically, the investigation proposed:

1. To examine the hypothesis that a substantial part of the work done during the turn-around is subject to predetermination and, hence, the application of performance evaluation standards.
2. To investigate the applicability of known industrial engineering techniques such as stop watch time study, synthetic basic motion times and work sampling in determining performance evaluation standards for petroleum refinery turn-around tasks.
3. To develop a new approach to the problem of determining and applying performance

evaluation standards applicable to the general type of work represented by the petroleum-refinery turn-around.

4. To examine the hypothesis that performance evaluation standards for many petroleum-refinery turn-around tasks are capable of being determined with sufficient statistical reliability to be of use to refinery management in the planning, scheduling and control of work.
5. To describe, where insufficient information is available for statistical analysis, the methods, equipment, number of workers assigned, conditions encountered and time required to perform other turn-around tasks.
6. To investigate methods of applying predetermined performance evaluation standards to the cleaning and repair of petroleum-refinery equipment which is not capable of being inspected internally before the equipment is shut down for maintenance.
7. To determine whether it is possible with the memo-activity camera to formulate suggested improvements in the manner in which various jobs are done.
8. To develop by the methods described, a usable body of performance evaluation standards for

turn-around tasks which are capable of broad application in the petroleum refining industry.

9. To use the study proposed to continue the development of the memo-activity camera in order to increase its utility as a work measurement tool.

The more important findings of this investigation may be summarized as follows:

1. A work sampling study of turn-around labor utilization showed that 79 per cent of the labor expended was applied to work which was capable of predetermination. The remaining 21 per cent of turn-around labor was devoted to the cleaning and repair of closed refinery units which may not be visually inspected internally until the unit is shut down.
2. About 30 per cent of the number of man-hours during the period observed were used in the opening, cleaning and closing of heat exchangers.
3. Several repetitive or semi-repetitive tasks were found during the turn-around. This type of work is that which is usually considered to be appropriate for measurement by the traditional work measurement tools, the time

study and the work sampling study.

4. Synthetic basic motion time systems were found to be uneconomical for the formulation of performance evaluation standards for petroleum-refinery turn-around tasks.
5. It was found possible to develop data from memo-activity films into performance evaluation standards with statistical confidence limits.
6. The application of time study, work sampling and memo-activity study to the same activity at approximately the same time showed that with the necessary assumptions, the cost to establish a performance evaluation standard for the activity by work sampling was approximately one-half that incurred by time study. Further results indicated that the cost of establishing a performance evaluation standard by memo-activity study was somewhat less than one-half the cost of establishing the same standard by work sampling.
7. It was found possible to develop improved methods of performing tasks from memo-activity films, especially where alternate methods are available for comparison.
8. Memo-activity studies were found to have a general application to the examination and

measurement of work through a further study of the activities of an executive.

The conclusions drawn by the writer from the results of the investigation are these:

1. In addition to the 79 per cent of the labor effort applied to refinery units which is capable of predetermination, planning and scheduling before the turn-around begins, it appears that no less than an additional 10 per cent of total labor hours is predictable enough through historical records, economic replacement calculations, routine maintenance and prediction through operating characteristics, that work thus predicted may be scheduled. This scheduling makes desirable the availability and the application of performance evaluation standards to some 90% of the work involved during the turn-around. Work involving the remaining 10 per cent of the total effort probably could be accomplished more economically even considering down-time costs if time were taken after units were shut down and visually inspected, to plan and schedule the work found necessary. Therefore, the development and use of performance evaluation standards for the majority of turn-around tasks would prove economical.

2. Performance evaluation standards may be economically determined for many turn-around tasks by presently used work measurement techniques, e.g., time studies, production studies, work sampling. Many refinery turn-around tasks were observed which are repetitive or semi-repetitive which makes them susceptible to economical measurement by these techniques.
3. The memo-activity camera was found to be well suited for measuring long-cycle repetitive operations and determining standards for these operations at about one-half the cost of arriving at a standard by use of visual work sampling under average conditions, i.e., the observer must travel some distance to make his observation. No cost comparison between memo-activity study and work sampling by camera has been made because no work sampling camera was available, but it has been shown that random-sampling either visually or by camera leaves the method and possibly the equipment and materials inadequately described for the formulation of a valid performance evaluation standard.

The memo-activity camera increases its advantage over other work measurement tools as

the job being studied grows longer and less repetitive. For many of these jobs, memo-activity appears to be the only technique which may be used to determine accurate standards without the cost of deriving the standard exceeding the potential benefit accruing from the application of the standard. Therefore, the memo-activity technique should allow new areas of work to be studied economically with a resultant decrease in the cost of performing this work.

The consistency of the times experienced in measuring turn-around tasks was not so great as it had been expected. Yet it should be recognized that final conclusions cannot be reached from a relatively small amount of data and that compilation and examination of further data (which can be gained inexpensively by the memo-activity camera) should allow more accurate predictions of performance times to be made.

It should be recognized, too, that in work where a greater number of variables are present, a greater fluctuation in times to perform that work can be expected. Nevertheless, the tasks for which confidence limits were calculated for the most part, exhibit

sufficient regularity for their predicted times to be used as a basis for planning, scheduling and control.

And, even if these tasks had shown much less regularity, then only a secondary objective of memo-activity would have been affected. Memo-activity study was designed primarily to measure, examine and record the very long-cycle, seldom-repetitive job for which several years of data may have to be gathered in order to make even the simplest statistical analysis. This means, in effect, that performance evaluation standards for these jobs may not be based on any statistical correlation, but rather upon one or two similar jobs in the past. Again, this procedure is dictated by the economics of accuracy of measurement versus the benefit to be derived from this accuracy. As Krick (4) was quoted as saying in Chapter I, "... a grosser standard or set of standards ... is what should be sought for highly variable indirect labor tasks."

In addition to its use as a work measurement tool, memo-activity films furnish a permanent record of events and conditions. Some of the advantages and uses seen for

this permanent record are:

- a. As a record and a review of methods or procedure.
 - b. As a comparison between alternate methods.
 - c. As a method of control for work accomplished.
 - d. As a training device.
 - e. As a report to higher management.
 - f. As a basis for work sampling studies.
 - g. As a record of repair, modification or construction.
 - h. As a source of standard data.
4. From its performance the memo-activity camera has a larger potential application than those tasks upon which it was used in the petroleum refinery. The memo-activity study may be a partial solution to the need described by Krick (4) in speaking of indirect labor: "There is a dire need for the development of new descriptive and analytical techniques for application to this rather different type of activity."

Suggestions for Future Study

The following potential areas for investigation are suggested:

1. The continued use of the memo-activity camera

to measure turn-around tasks in the refinery in order that more data be available for analysis. It is believed that further data will provide the basis upon which more accurate predictions may be made.

2. Validation of the findings of this investigation by similar investigations in other petroleum refineries.
3. Further research to determine whether the pace maintained by workers photographed by the memo-activity camera tends toward normal pace and how pace varies between crews observed by memo-activity study and crews which believe they are unobserved.
4. Investigation to determine the manner in which the range of individual paces of crew members varies under observation of the memo-activity camera from the range of paces of those who believe they are unobserved.
5. Studies similar to Numbers Three and Four above to determine the amount of absence or idle time of individuals separately or as crews under the scrutiny of the memo-activity camera and believing themselves unobserved.
6. An attempt to discover if there are common elements of work present in specialized areas of indirect labor, e.g., maintenance. Common

elements would allow standard data developed for one industry to be applied in another industry and would allow ratings to be made on the basis of the times required to perform the common element or task.

7. Measurement with the memo-activity camera of the amount of delays, idleness, absence or other events in relation to the time of day. The results of such studies could provide a more effective utilization of supervisory manpower.
8. Measurement of delays, idleness, absence or other events over a period of time could show the results of greater or lesser amounts of planning, scheduling and control and allow the determination of the most economical application of these factors.
9. Investigation of the duties performed by helpers and how much of the time and for what lengths of time they are needed and what skills they are called upon to apply.
10. To investigate with the aid of the memo-activity camera the amount of supervision applied to particular jobs and how this supervision affects delays, idleness, etc.
11. To investigate the prospect of supervising workers with the memo-activity camera.

12. To investigate in a manner similar to this investigation of maintenance work during the turn-around, work during the periodic shut-down of other industries in order to determine how memo-activity studies might best be used in these other industries and to develop usable performance evaluation standards for these industries.
13. To study other types of indirect labor such as clerical, technical, sales, supervisory, construction and service personnel, with the objective of determining performance evaluation standards for portions (or all) of the work involved.
14. The extension of memo-activity analysis to the study of executive work. Some of the questions which could be investigated are:
 - a. How much of an executive's time is spent in communicating?
 - b. Is the amount of communication of an executive proportional to the number of subordinates he has?
 - c. By what media do executives communicate and how much is each medium used?
 - d. How do the functions of executives vary with rank or responsibility?

- e. Do staff executives communicate with others more or less than line executives?

These questions pertain to only one aspect of an executive's functions. There are many other questions which could be investigated where the low-cost data provided by the memo-activity camera are available.

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APPENDIXES

APPENDIX A

EXCERPTS FROM WORK SAMPLING ARTICLES

AN EXCERPT FROM
THE ERROR OF ESTIMATE IN SYSTEMATIC
ACTIVITY SAMPLING

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DISADVANTAGES OF RANDOM SAMPLING

Techniques patterned after Tippett's application have proven extremely useful in manpower and equipment utilization studies, in the collection of data for analysis of queueing problems, and in other kinds of investigations. However, the randomizing of observation times has been both a nuisance and a source of inefficiency in the utilization of observers. To avoid these disadvantages some investigators have employed motion picture cameras arranged for time-lapse photography and actuated by random interval timing devices. While photographic records must still be interpreted by analysts, the method does permit efficient programming of the analysts' time which is not the case in the instance of randomized direct observation.

In spite of the advantages that may pertain to use of the camera instead of the human as an instrument for randomly spaced observations, this approach to the problem seems rather like attempting to remodel a new horse to fit an old saddle. The camera is particularly suited to economical fixed interval observation, and it is difficult to believe that there is any real necessity of complicating the instrumentation with additional equipment to secure random intervals. Moreover, in studying processes one is frequently interested in discovering not only the relative frequency of certain states but also their time of occurrence and approximate duration (since they are not often truly "random"). A fixed interval observation scheme is superior for this purpose to a set of random observations. Finally, there are instances where with human observers a

fixed interval sampling schedule would have definite practical advantages over randomized sampling.

See Bibliography reference (39) for complete data of publication.

AN EXCERPT FROM

WORK SAMPLING - ELEVEN FALLACIES

by Harold O. Davidson
Vice President, Industrial Engineering,
Operations Research, Incorporated

11. Randomization of observation times is necessary to satisfy the assumptions of statistical theory used to calculate a confidence interval. This idea is subscribed to either explicitly or implicitly by a considerable number of writers on work sampling. Actually, the requirements of statistical theory are not nearly so specific. It will be sufficient if the error is a stochastic variable with a tractable distribution function. How we get the error to be this kind of variable is a matter of complete indifference to the statistical theory. We may attempt to do it by randomizing the observation times; but as we have just seen, this by no means guarantees the desired result. Indeed, it is entirely possible for systematic sampling to yield a "more random" error than "random" sampling.

To see why this may be so let's use the bowl-of-beads example once more. Let's suppose that there are 100 black beads and 400 white beads in the bowl and we are to draw a sample of five without replacement. Now the usual method of "random" sampling would be a thorough mixing followed by selection of the sample, without looking in the bowl. Presumably each of the 500 beads had the same chance of being the first in the sample, each of the 499 remaining beads had the same chance of being next in the sample, and so forth. But suppose that in fact some of the black beads had a slightly different texture from the other beads, a difference that did not impress itself clearly upon our consciousness but which nevertheless resulted in an unconscious discrimination. We would not in reality have a random sample.

Let's go about the sampling in a different manner. We construct a long trough that will accommodate all of the 500 beads in a single long row. We decide arbitrarily that with all the beads lined up in this trough we will choose the 100th, 200th, 300th, 400th and 500th beads to

constitute our sample. So we mix the beads up in the bowl and pour them into a single line in the trough. Now, each of the 500 beads has the same chance of being the 100th in this row, and each of the remaining has the same chance of being the 200th, and so forth. And so, with "systematic" sampling we end up with a random sampling error.

The important principle to be noted in this example is that systematic sampling of a population by position can provide random samples if the occupancy of those positions by members of the population is a random occurrence. Now let's try to extend this notion to systematic sampling of activities. Can we assume that different categories of activity occur randomly over time? It is extremely doubtful in most cases. For example, if we find an operator absent from his workplace on personal time at t_1 , there is a fairly high probability that at $t_1 + \Delta t$ he will still be absent for the same reason; whereas if a few minutes later at t_2 he has returned to productive activity it is quite unlikely that he will be absent again on personal time at $t_2 + \Delta t$. Since we cannot find too much encouragement for assuming random occupancy of position in the macroscopic realm let us turn to the microscopic.

Suppose that we make the interval between our regularly spaced observations sufficiently small that whenever a particular category of activity occurs we will detect that occurrence in at least one observation. Or, let us at least make the interval small enough so that the exceptions to this condition are negligibly few for practical purposes. Now we will know that if a particular activity is identified in exactly five consecutive observations, the duration of that occurrence must have been greater than four times the interval between observations but less than six times the interval. Our uncertainty is due to the fact that we do not know the position of the beginning point of the activity occurrence in the interval between the last observation showing the preceding activity and the first observation showing the activity whose duration we are attempting to estimate; and to a similar lack of knowledge about the position of the end point. We can make a strong conjecture however that the probability of the beginning point being at any particular position on the interval is for all practical purposes the same for all positions on the interval; and likewise for the end point.

What we are proposing, in other words, is that the location of beginning and end points of activity occurrences is a stochastic variable uniformly distributed on the interval between observations. And no matter how non-random activities may be with respect to duration of occurrences, time of day at which they occur, or sequence of

occurrence with respect to other activities, our error of estimate will be statistically "digestible" providing this one simple condition is fulfilled. The calculation of an estimate and confidence level under this condition are given by the following:

$$p_A = \frac{n_A}{n}; \text{ where } p_A \text{ is an unbiased estimation of the}$$

true proportion of time, p_A , consumed in activity state A; n_A is the number of observations showing activity state A; and n is the total number of observations in the study. The error of estimate at p_A is normally distributed with

zero mean and standard deviation $\frac{1}{n} \sqrt{\frac{N}{6}}$, where N is the number of separate occurrences of activity A during the study (i.e., the number of sequences of observation showing activity state A).

See Bibliography reference (48) for complete data of publication.

APPENDIX B

GLOSSARY OF TERMS USED IN PETROLEUM REFINING

GLOSSARY OF TERMS USED IN PETROLEUM REFINING (50)

absorption - The process by which one substance draws into itself another substance.

adsorption - The adhesion of the molecules of gasses or dissolved substances to the surfaces of solid bodies.

alkylation - Formation of complex saturated molecules by direct union of saturated and unsaturated molecules.

blind - A circular piece of sheet metal placed in pipe lines to prevent the flow of fluids.

boiling point - The temperature at which a substance begins to boil or to be converted into vapor.

bottoms - The liquid which collects in the bottom of a vessel, either during a fractionating process or during storage.

bubble cap - An inverted cup with notched or slotted periphery to disperse the vapor in small bubbles beneath the surface of a liquid on the bubbleplate in a distillation column.

bubble tray (plate) - A horizontal tray fitted to the inside of a fractionating tower; used to secure intimate contact between rising vapor and falling liquid in a tower.

butane - Inflammable, gaseous hydrocarbon, C_4H_{10} .

cat cracker - The apparatus in which the catalytic cracking process is carried out.

catalyst - A substance which hastens or retards a chemical action without necessarily undergoing a chemical change itself.

charge - A quantity of feed stock for a refinery processing unit.

coke - The generic term applied to the infusible, cellular, coherent solid material obtained from petroleum as a result of distillation or polymerization.

coke knocker - A mechanical device for breaking loose coke formations within vessels or tubes.

condensation - The act of changing from a vapor to a liquid.

condenser - The water cooled heat exchangers used for cooling and liquefying oil vapors.

cracking - A phenomenon by which large oil molecules are decomposed into smaller lower-boiling molecules.

crude petroleum - A naturally occurring mixture consisting predominantly of hydrocarbons.

crude still - A piece of refinery equipment designed to permit physical separation of crude oil by application of heat.

debutanization - The process of distillation in which the lighter components of a distillate are separated from the heavier components.

distillate - The product of distillation obtained by condensing the vapors from a still.

distillation - Vaporizing a liquid and subsequently condensing it in a different chamber.

flashing - Effecting a separation of products by releasing the pressure on a hot oil as it enters a vessel.

fractionation - The separation of a mixture by some process (such as distillation) into a series of fractions or portions of distillates having different boiling ranges than other fractions.

gasoline - A refined petroleum naphtha.

Girbotol process - A process for removing hydrogen sulphide, carbon dioxide and/or organic gasses from petroleum gasses and liquids.

hammer wrench - A special type of open end wrench with a heavy shank which is struck with a hammer or sledge to loosen or tighten nuts or bolts.

header - A common manifold in which a number of pipe lines are united.

heat exchanger - An apparatus for transferring heat from one fluid to another.

heater - The furnace and tube arrangement which furnishes the principal heating element in a processing unit.

hydrocarbon - A compound containing only hydrogen and carbon.

manways or manheads - Circular openings on or into structures large enough for a man to enter in order to clean or repair the interior.

petroleum - A material occurring naturally in the earth which is predominantly composed of mixtures of chemical components of carbon and hydrogen with or without other non-metallic elements such as sulphur, oxygen, nitrogen, etc.

pipe still - Still in which heat is applied to the oil while being pumped through a coil or pipe arranged in a suitable firebox.

polymerization - The process of combining two or more molecules to form a single molecule having the same elements in the same proportions as in the original molecules. Specifically, in the petroleum industry, the union of light olefins to form hydrocarbons of higher molecular weight.

propane - A heavy gaseous hydrocarbon.

pull - to remove, as one part from another.

raschig rings - Small cylindrical rings used in packed-type fractionating towers.

reactor - The vessel in which all, or at least the major part, of a reaction or conversion takes place.

reboiler - An auxiliary of a fractionating tower designed to supply additional heat to the lower portion. Liquid is usually withdrawn from the side or bottom of the tower; is reheated by means of heat exchange; and the vapors and residual liquid are reintroduced into the tower.

refining - The separation of crude petroleum into its component parts and the manufacture therefrom of products needed for the market.

reflux - In fractional distillation, the part of the distillate returned to the fractionating column to assist in making a more complete separation into the desired fractions.

regenerator - In a catalytic process, that part of the system having as its primary function the revivification or reactivation of the catalyst which is done by burning off coke deposits.

still - A closed chamber in which heat is applied to a substance to change it into a vapor.

stock - Any oil which is to receive further treatment.

stripper - Equipment in which the lightest fractions are removed from a mixture.

tower - An apparatus for increasing the degree of separation obtained during the distillation of oil in a still.

trays - Circular, perforated plates having the internal diameter of a tower, set at specified distances in a tower to collect the various fractions produced in fractional distillation.

tube bundle - A group of fixed parallel tubes, such as is used in a heat exchanger.

tube sheets - Flat plates in a heat exchanger with holes for the necessary number of tubes.

turn-around - Time necessary to clean and make necessary repairs on refinery equipment after a normal run.

vessel - Any closed container for storing or processing petroleum fractions or crude petroleum.

work list - A summary of the work planned to be accomplished during a turn-around.

APPENDIX C

STANDARD C1

TASK: Unbolting Flanges

CREW SIZE: 2

EQUIPMENT: Hammer Wrenches

<u>Nominal Pipe Diameter (inches)</u>	<u>Number of Bolts</u>	<u>Bolt Size (inches)</u>	<u>Time Required (minutes)</u>
1 ¹ / ₂	4	1/2	6.0
2	4	5/8	5.5
2	4	5/8	7.5
4	8	3/4	11.5
4	8	3/4	12.0
6	8	3/4	8.5
6	8	3/4	14.5
6	8	3/4	19.5
10	12	7/8	20.5

FORMULA: $y = 1.780x + 3.458$

where y = predicted number of minutes to perform task

x = nominal pipe diameter.

CONFIDENCE LEVEL: 68%

STANDARD ERROR OF THE ESTIMATE: ± 2.725 minutes.

STANDARD C2

TASK: Unbolt channel covers of shell and tube heat exchangers, remove channel cover and lower to ground with electric hoist.

CREW SIZE: 2

EQUIPMENT: Pneumatic impact wrench (1) and 2-ton capacity electric hoist, pry bars.

<u>Height off Ground (feet)</u>	<u>Number of Bolts</u>	<u>Bolt Size (inches)</u>	<u>Time Required (minutes)</u>
4	20	1 ³ / ₁₆	15
4	24	3/4	14
8	24	3/4	15
12	24	3/4	12
4	28	7/8	21
4	28	7/8	16
12	38	7/8	39

FORMULA: $y = 1.490x - 20.731$

where y = predicted number of minutes to perform task

x = number of bolts on channel cover.

CONFIDENCE LEVEL: 68%

STANDARD ERROR OF THE ESTIMATE: ± 3.32 minutes.

STANDARD C3

TASK: Unbolt, remove and lower shell and tube heat exchanger channel (header).

CREW SIZE: 2 men to unbolt, 3 men to remove and lower.

EQUIPMENT: Hammer wrenches, electric hoist or chain hoist.

<u>Height off Ground (feet)</u>	<u>Number of Bolts</u>	<u>Bolt Size (inches)</u>	<u>Time Required (minutes)</u>
4	20	3/4	26.5
8	20	3/4	32.0
4	20	1 3/16	32.5
4	24	3/4	33.0
8	24	3/4	35.0
8	24	3/4	40.5
4	28	7/8	35.5
8	28	1 3/16	38.0

FORMULA: $y = 0.853x + 14.090$

where y = predicted number of minutes to perform task

x = number of bolts holding on channel.

CONFIDENCE LEVEL: 68%

STANDARD ERROR OF THE ESTIMATE: ± 2.92 minutes.

STANDARD C4

TASK: Remove tube bundle from shell and tube heat exchanger by pulling bundle with cable stretched from truck. Bundle supported with cable slings on electric hoists as it emerges. Task begins when force is first applied and ends when bundle is free of shell.

CREW SIZE: As specified.

EQUIPMENT: Truck with "A" frame, cables, slings, electric hoists, pry bars.

<u>Height of Exchanger (feet)</u>	<u>Diameter of Bundle (inches)</u>	<u>Length of Bundle (inches)</u>	<u>Crew Size</u>	<u>Time Required (minutes)</u>
4	29 ¹ / ₁₆	195	5	32
4	15 ³ / ₁₆	225 ¹ / ₂	5	17.5
4	18 ¹ / ₁₆	220	5	19.5
8	20 ³ / ₈	228	5	19.0
4	41 ³ / ₁₆	211	5	46.5
40	17 ³ / ₈	189 ¹ / ₄	7	22.0

FORMULA: $y = 1.116x - 0.117$

where y = predicted number of minutes to perform task

x = diameter of heat exchanger bundle.

CONFIDENCE LEVEL: 68%

STANDARD ERROR OF THE ESTIMATE: ±1.62 minutes.

STANDARD C5

TASK: Clean shell and tube heat exchanger bundles by
Dowell "Hydroblast" technique (water spray).

CREW SIZE: 4 (contract labor)

EQUIPMENT: Special (Dowell patent)

<u>Diameter of Bundle (inches)</u>	<u>Length of Bundle (inches)</u>	<u>Volume of Bundle (ft³)</u>	<u>Number of Tubes</u>	<u>Time Required (minutes)</u>
16 ¹ / ₄	191 ³ / ₄	22.343	110	41.0
20 ⁵ / ₁₆	191 ³ / ₄	35.613	202	47.5
22 ⁷ / ₁₆	191 ³ / ₄	43.792	252	57.0
29	239 ³ / ₄	91.751	332	64.5
29	332	126.921	332	71.0
30 ¹ / ₄	233 ¹ / ₂	96.599	328	70.5
30 ¹ / ₄	239 ³ / ₄	99.501	332	75.0
30 ⁹ / ₁₆	239 ³ / ₄	101.611	450	76.0
38 ¹ / ₄	239	158.536	512	85.5

FORMULA: $y = 2.122x + 7.423$

where y = predicted number of minutes to perform task
 x = diameter of heat exchanger bundle.

CONFIDENCE LEVEL: 68%

STANDARD ERROR OF THE ESTIMATE: ± 2.69 minutes.

STANDARD C6

TASK: Re-install shell and tube heat exchanger bundles by lifting bundle with electric hoists and pulling bundle into shell with chain hoist. Task begins when slings are rigged to lift bundle and ends when bundle is in permanent position in shell.

CREW SIZE: As specified

EQUIPMENT: Electric hoists (2), Chain hoist (1), Pry bars.

<u>Height of Exchanger (feet)</u>	<u>Diameter of Bundle (inches)</u>	<u>Length of Bundle (inches)</u>	<u>Crew Size</u>	<u>Time Required (minutes)</u>
2 ¹ / ₂	19	168 ³ / ₈	5	24.5
2 ¹ / ₂	19	168 ³ / ₈	7	22.0
8	19	168 ³ / ₈	6	22.0
8	19	168 ³ / ₈	6	34.0
7	33	169 ¹ / ₈	6	60.5
4	34 ¹ / ₂	195	5	42.0

FORMULA: $y = 1.827x - 9.556$

where y = predicted number of minutes to perform task

x = diameter of heat exchanger bundle.

CONFIDENCE LEVEL: 68%

STANDARD ERROR OF THE ESTIMATE: ±7.32 minutes.

STANDARD C7

TASK: Re-assemble shell and tube heat exchanger channel (header) by lifting channel with hoist and re-bolting.

CREW SIZE: As specified

EQUIPMENT: Hammer wrench

<u>Height of Exchanger (feet)</u>	<u>Number of Bolts</u>	<u>Bolt Size (inches)</u>	<u>Crew Size</u>	<u>Time Required (minutes)</u>
4	20	3/4	2	27.0
8	20	3/4	2	42.0
4	24	3/4	3	31.5
8	24	3/4	2	39.0
4	28	7/8	2	53.5
22	38	7/8	3	68.0

FORMULA: $y = 2.005x - 8.048$

where y = predicted number of minutes to perform task

x = number of bolts.

CONFIDENCE LEVEL: 68%

STANDARD ERROR OF THE ESTIMATE: ± 6.43 minutes.

STANDARD C8

TASK: Bolting flanges

CREW SIZE: 2

EQUIPMENT: Hammer wrench

<u>Nominal Pipe Diameter (inches)</u>	<u>Number of Bolts</u>	<u>Bolt Size (inches)</u>	<u>Time Required (minutes)</u>
1 ¹ / ₂	4	1/2	7.0
2	4	5/8	6.0
3	4	5/8	7.5
3	4	5/8	8.5
4	8	5/8	14.5
4	8	5/8	16.0

FORMULA: $y = 2.844x - 5.250$ where y = predicted number of minutes to perform task x = number of bolts.

CONFIDENCE LEVEL: 68%

STANDARD ERROR OF THE ESTIMATE: ± 1.81 minutes.

APPENDIX D

RASCHIG RINGS

Standard D1

TASK: Remove 472 cubic feet of Raschig rings from vessel through 12 inch port.

EQUIPMENT: Hand rake

CREW SIZE: 2

TIME: 541 minutes

Standard D2

TASK: Refill vessel with Raschig rings. Vessel is filled through 18 inch port 10 feet high to a depth of about 10 feet. This port is closed and the vessel is filled to a depth of 20 feet through a port 22 feet high.

EQUIPMENT: Pulley, shovel, bucket (approx. 5 gallon)

CREW SIZE: 3 - 1 fills bucket with Raschig rings

1 hoists bucket

1 dumps rings through port

TIME: 126.0 minutes for first 125 ft³ (10 feet deep)

181.0 minutes for second 125 ft³ (20 feet deep)

Total Time 307 minutes or 5 hours, 7 minutes

OPEN MANWAYS

Standard D3

TASK: Open 24 inch manway (18 - $\frac{7}{8}$ inch bolts).

EQUIPMENT: Pneumatic torque wrench

CREW SIZE: 2

TIME: 12.0 minutes

Standard D4

TASK: Open 34 inch manway (20 - $\frac{3}{4}$ inch bolts).

EQUIPMENT: Pneumatic torque wrench

CREW SIZE: 2

TIME: 11.5 minutes

CLEAN FINTUBE HEAT EXCHANGERS

Standard D5

TASK: Open Fintube Header (12 - $\frac{3}{4}$ inch nuts).

EQUIPMENT: Pneumatic torque wrench

CREW SIZE: 2

TIME: 5.5, 6.5 minutes; average 6.0 minutes

Standard D6

TASK: Pull double Fintube.

EQUIPMENT: Chain hoist

CREW SIZE: 3

TIME: 12.0, 14.5 minutes; average, 13.25 minutes

Standard D7

TASK: Clean double Fintube.

EQUIPMENT: Wire brush

CREW SIZE: 1

TIME: 56.0, 63.5 minutes, average 59.75 minutes

Standard D8

TASK: Reseat double Fintube.

EQUIPMENT: None

CREW SIZE: 3

TIME: 5.5, 8.5 minutes; average: 7.0 minutes

Standard D9

TASK: Rebolt double Fintube header (12 - $\frac{3}{4}$ inch bolts).

EQUIPMENT: Pneumatic torque wrench

CREW SIZE: 2

TIME: 6.5, 6.5 minutes; average, 6.5 minutes

CLOSE 24 INCH MANWAY

Standard D10

TASK: Install chain hoist (2 ton capacity).

EQUIPMENT: Pulley

CREW SIZE: 3

TIME: 4.5 minutes

Standard D11

TASK: Rig cable.

EQUIPMENT: None

CREW SIZE: 3

TIME: 1.5 minutes

Standard D12

TASK: Hoist manway cover 8 feet.

EQUIPMENT: Chain hoist

CREW SIZE: 3

TIME: 4.0 minutes

Standard D13

TASK: Place manway cover and bolt (20 - 2 inch bolts).

EQUIPMENT: Pneumatic torque wrench

CREW SIZE: 2

TIME: 20.5 minutes

INSERT BLINDS

Standard D14

TASK: Blind 18 inch line.

EQUIPMENT: Blind, hammer wrenches

CREW SIZE: 2

TIME: (a) Remove 16 - $\frac{3}{4}$ inch nuts, 33.0 minutes

(b) Insert blind, 5.0 minutes

(c) Rebolt flange, 36.0 minutes

ACTIVITIES PREPARATORY TO REMOVING SHELL AND TUBE
HEAT EXCHANGER BUNDLES FROM SHELL

Standard D15

TASK: Install two screw eyes in fixed tube sheet and
attach cable.

EQUIPMENT: Adjustable wrench

CREW SIZE: 1

TIME: 14.0, 15.5 minutes; average: 14.75 minutes

Standard D16

TASK: Install and position electric hoists (2 hoists).

EQUIPMENT: Pulley

CREW SIZE: 2

TIME: 9.5, 12.0 minutes; average: 10.75 minutes

Standard D17

TASK: Attach bundle slings to hoists and position
hoists (2 slings).

EQUIPMENT: Pulley

CREW SIZE: 2

TIME: 10.5, 8.5 minutes, average: 9.5 minutes

ACTIVITIES SUBSEQUENT TO REMOVING SHELL AND TUBE
HEAT EXCHANGER BUNDLES FROM SHELL

Standard D18

TASK: Load shell and tube heat exchanger bundle on truck after bundle has been lowered to height of truck bed.

EQUIPMENT: Electric hoists, pry bars

CREW SIZE: 5

TIME: 9 minutes, 6 minutes; average: 7.5 minutes

Standard D19

TASK: Remove screw eyes and cable from shell and tube heat exchanger bundle and secure bundle to truck bed.

EQUIPMENT: Adjustable wrenches, chain hoists

CREW SIZE: Variable

TIME: 14.5, 16, 12 man-minutes; average: 14.2 minutes

REASSEMBLY OF SHELL AND TUBE HEAT EXCHANGER
FLOATING HEAD TO SHELL

Standard 20

TASK: Install electric hoist.

EQUIPMENT: Pulley

CREW SIZE: 3

TIME: 4.0 minutes

Standard D21

TASK: Hoist floating head (34 inch diameter) 22 feet.

EQUIPMENT: Electric hoist (4 ton capacity)

CREW SIZE: 3

TIME: 2.5 minutes

Standard D22

TASK: Clean tube sheet, floating head and install
gasket.

EQUIPMENT: Wire brushes

CREW SIZE: 3

TIME: 6.5 minutes

Standard D23

TASK: Bolt floating head to heat exchanger shell
40 - $\frac{5}{8}$ inch nuts.

EQUIPMENT: Hammer wrenches

CREW SIZE: 2

TIME: 71.5 minutes

REASSEMBLY OF SHELL AND TUBE HEAT EXCHANGER SHELL
COVER TO SHELL

Standard D24

TASK: Hoist shell cover ($43\frac{1}{2}$ inch diameter) 22 feet.

EQUIPMENT: Electric hoist (4 ton capacity)

CREW SIZE: 3

TIME: 3.5 minutes

Standard D25

TASK: Clean shell cover, shell, install gasket.

EQUIPMENT: Wire brushes

CREW SIZE: 3

TIME: 7.0 minutes

Standard D26

TASK: Bolt shell cover to heat exchanger shell 38 -
 $\frac{7}{8}$ inch bolts.

EQUIPMENT: Hammer wrenches

CREW SIZE: 2

TIME: $59\frac{1}{2}$ minutes

MISCELLANEOUS OPERATIONS

Standard D27

TASK: Remove valve from 4 inch line (16 - $\frac{5}{8}$ inch bolts).

EQUIPMENT: Hammer wrench

CREW SIZE: 2

TIME: 41 minutes

Standard D28

TASK: Remove floating head from shell and tube heat exchanger. (20 - $\frac{7}{8}$ inch bolts)

EQUIPMENT: Pneumatic torque wrench

CREW SIZE: 2

TIME: 11.5 minutes

DUBBS PROCESS TUBESTILL HEATER

Standard D29

TASK: Clean coke (oil residue) out of tubes $3\frac{9}{16}$ in-
side diameter x 21 feet long.

EQUIPMENT: Airetool (pneumatic drilling and cleaning
tool.)

CREW SIZE: 2

TIME REQUIRED: 11.0, 11.5, 12.5, 12.5, 11.5 minutes;
average: 11.8 minutes

Standard D30

TASK: Pull headers (two tubes attached to each header).

EQUIPMENT: Truck equipped with "A" frame, pry bars

CREW SIZE: 4

TIME REQUIRED: 6.0, 10.5, 10.0 minutes; average: 8.83
minutes

Standard D31

TASK: Clean Dubbs headers by burning out coke with
acetylene torch and wire brushing.

EQUIPMENT: Acetylene torch, wire brush

CREW SIZE: 1

TIME REQUIRED: 14.5, 14.0, 16.0 minutes; average:
14.83 minutes

DUBBS PROCESS TUBESTILL HEATER (Continued)

Standard D32

TASK: Remove and replace defective Dubbs Tube by unscrewing pipe from header and replacing with new tube.

EQUIPMENT: Pipe wrench

CREW SIZE: 2

TIME: 18.0, 25.5 minutes; average: 20.25 minutes

VITA

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