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Paul Vrba

THE APPLICATION OF INDUSTRIAL ENGINEERING TO PETROLEUM REFINERY MAINTENANCE

22T

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THE APPLICATION OF INDUSTRIAL ENGINEERING TO PETROLEUM REFINERY MAINTENANCE

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PREFACE

This paper is the result of the author's firm conviction, based on two years' experience in the industry, that the application of the principles of industrial engineering has long been overdue in the petroleum refining industry generally and in the activities involved in the maintenance of refineries specifically.

The greater part of the material contained in Chapters II and III, dealing with the purpose and classification of maintenance, has been drawn from the Productivity Report on Plant Maintenance, published by the Anglo-American Council on Productivity: U. K. Section, in December 1952. The study of this publication is sincerely recommended to all interested in plant engineering. If some of the material in the two chapters appears to follow closely the wording of the Report, it will be only because the author found it difficult to improve upon the most excellent and clear phrasing of that publication.

The author wishes to acknowledge gratefully the valuable advice received by him from Professor W. N. Cox, Jr., Dr. J. J. Moder, and Dr. R. N. Lehrer of the School of Industrial Engineering, and from Dr. J. M. Dalla Valle of the School of Chemical Engineering, Georgia Institute of Technology. Thanks are also due to Professor Howard P. Emerson, Head of Industrial Engineering at the University of Tennessee, for his helpful suggestions.

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ABSTRACT

THE APPLICATION OF INDUSTRIAL ENGINEERING
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PAUL VRBA

The aim of this work was to investigate the existing maintenance procedures in oil refineries, to draw appropriate conclusions as to their effectiveness, and to investigate and make recommendations concerning the part which the application of the principles of industrial engineering can play in improving the many services which maintenance renders to the industry.

The first section of the work deals with the purpose, classification and evaluation of maintenance. Also included are the results of and conclusions drawn from a recently published survey of maintenance activities in fifteen major industries representing 12 per cent of all manufacturing plants in the United States with over five hundred employees.

The second section consists of a description and systematization of maintenance activities in the oil refining industry, a detailed analysis of the relevant applications of industrial engineering to refinery maintenance, and a consideration of the modifications in

specific industrial engineering techniques which are necessary as a result of the peculiar nature of such maintenance work.

The investigation has revealed the following facts:

(1) The importance of maintenance in an oil refinery is not generally appreciated within the industry. Only rarely is a refinery maintenance organization provided with the facilities and resources commensurate with the significant position which it occupies in relation to efficient production.

(2) Full preventive maintenance must be the ultimate objective of an oil refinery maintenance department. A high degree of planning, scheduling,and coordinating of maintenance activities is therefore necessary.

(3) Many of the activities connected with the successful establishment and operation of preventive maintenance consist essentially of the application of industrial engineering. Hence, the organizational structure of a maintenance department should make proper provision for an adequate industrial engineering section which must be placed in such a position within the department as to be able to fulfill all its functions.

(4) The most important function of industrial engineering in refinery maintenance is the measurement, evaluation and control of the effectiveness with which

maintenance is being or should be performed. Work measurement is recommended as a highly useful means to this end, and its various techniques are described and critically analyzed.

(5) Wage incentives for refinery maintenance work, based on properly established standards, are considered to be valuable motivating agents towards more satisfactory performance.

(6) It is concluded that in the oil refining industry, the numerous and complex activities of maintenance present a most rewarding field of endeavour to industrial engineering with its aims of reducing the expenditure of time, money, and effort to a minimum.

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SECTION ONE

CHAPTER I

INTRODUCTION

One of the dictionary definitions of the verb "to maintain" is "to hold or keep in a state of efficiency or validity; to support, sustain or uphold; to keep up".
It is these functions which maintenance in industry aims to perform with respect to the physical assets concerned in the efficient operation of an industrial undertaking. However modern and efficient the production facilities of a plant may be, their value will depend in the last analysis on their availability and proper functioning in accordance with a predetermined program. In turn, these factors will be achieved only by adequate and efficient maintenance. It is clear therefore that maintenance is not an end in itself but is a necessary means to the end of optimum economical production. The importance of maintenance in a particular industry, however, will vary according to the type of product and the conditions under which it is made.

Modern petroleum refining is a continuous process industry, in which the production facilities represent very high capital investments. Any idleness of processing plant is an extremely expensive occurrence and must therefore be kept to a minimum. Under such conditions, the great significance of proper maintenance is beyond doubt. Moreover, owing to the high degree of automatic control in oil refining processes, the maintenance labor force in a refinery represents a very high proportion of the total personnel employed and will therefore play an exceptionally important role in the overall costs of conversion of raw material to finished product.

Briefly, it is the purpose of industrial engineering to analyze and improve all the aspects of the performance of work with a view to reducing its overall costs consistent with the required standards of quality, safety and economy. Consequently, it is understandable that the practical applications of industrial engineering have been largely confined to the field of production activities in the past. The true importance of the maintenance function and its close relation to production have only recently become generally appreciated, and it is in the continuous process industries that recognition of the possible advantages accruing from the proper practice of industrial engineering principles in maintenance activities will be most fruitful.

This paper attempts to present a picture of existing maintenance procedures in oil refineries, to draw appropriate conclusions as to their effectiveness, and to make recommendations concerning the part which the principles of industrial engineering can play in improving the many services which maintenance renders to the industry.

CHAPTER II

THE PURPOSE OF MAINTENANCE

Since the terms "maintenance" and "repair" are usually associated with each other, the belief has grown that there is a similarity in their meaning. However, maintenance and repairs represent two distinct (and sometimes even opposed) approaches to the service which maintenance is called upon to give to the production departments of an industrial undertaking. There was a time when the job of the maintenance section was limited to getting the plant back into production after it had broken down, and to doing this with more accent on speed than on permanence and effectiveness of repair. Maintenance staffs did what they could in the time allotted to them and, for the servicing of machinery and equipment they had to employ to the maximum those periods of plant idleness which lack of sales or the production-shift labor system might make available. Such periods of servicing were not, however, within the control of the maintenance engineer whose pattern of work was largely determined for him by production policy, and they seldom took account of his difficulties or of his facilities. As a result, a great deal of maintenance work was done out of normal working hours with consequent increased labor cost and inadequate supervision. Under such conditions, production management tended to regard maintenance as the friction in the wheels of industry, rather than as the lubricant which keeps them turning. Modern industry, however, has begun to recognize the advantages to be gained from treating maintenance as an equal partner with production and raising it to the status of a planned operation. (1)

The purposes and aims of maintenance are, broadly speaking, as follows:

1. To keep plant and equipment--production and service--in a condition to perform continuously the function for which they were designed;
2. To keep total production costs to a minimum;
3. To determine and increase the efficiency of the actual performance of maintenance work while it is being done, and in that way to increase the availability of plant for production: this means not only reduction of time taken to perform individual maintenance items, but also the use of improved methods so that the necessity for performing such items will recur less frequently;
4. To improve the operation of the plant while in production;
5. To improve working conditions in the plant and vicinity for all employees;
6. To provide for optimum safety and health of all employees consistent with the efficient performance of their work.

The purpose of maintenance is directed, in the long run, towards the safeguarding of an investment; hence, maintenance work must be regarded as a continuous and not an intermittent function. Furthermore, there are no short cuts to the achievement of any of these aims and purposes of maintenance. Each situation must be investigated and treated on its individual merits. The degree of technical knowledge as such is far less significant in the performance of maintenance than is the method of application of that knowledge to any specific problem. The above statement is probably more true in maintenance than in any other activity.

CHAPTER III

THE CLASSIFICATION OF MAINTENANCE [2]

Before any discussion on maintenance problems and activities can commence, it is necessary to differentiate between the types of maintenance that are in existence, their uses, and their advantages and disadvantages. The detailed stages of the maintenance policies discussed below do not fall within clear-cut limits; on the contrary, much overlapping exists between them; therefore, the headings under which maintenance has been classified here do not have an absolute significance but are intended rather to describe existing conditions.

Breakdown Maintenance.--This type of maintenance is a system which is designed to deal with troubles only if and when they occur. Such maintenance may or may not be organized as a separate department, but in either case it is regarded merely as a service to be called upon by the production or operating departments when mechanical, structural, or other failures impede, limit, or prevent the desired rate of production. It is obvious that this is the most primitive form of maintenance and one which has a strictly limited application.

Such maintenance may be suitable where:

(a) there is temporary urgency for a limited and definable period;

(b) plant capacity exceeds the current market demand;

(c) storage capacity for the final product is large;

(d) the process is obsolescent and more modern equipment is under consideration. However, in this case there must also be available space to erect new plant while the equipment that is being replaced remains in production;

(e) many standardized and interchangeable individual units are concerned, a short life of equipment is economically justified and replacement is easy, as for example in industrial transportation vehicles.

Breakdown maintenance is unsuitable where:

(a) there is a well-established market which can and does absorb the full production capacity or more;

(b) the limited size of storage capacity for the final products necessitates a smooth continuity of production;

(c) the recognized improvements in process and equipment are not sufficiently significant to justify great capital expenditures;

(d) available plant space is restricted;

(e) large quantities of material being processed cannot be recovered if production breaks down.

The advantages of this system of maintenance, where it is applicable, are the virtual absence of clerical or paper work, no necessity for the employment of highly qualified staff in maintenance engineering and possibly the lower initial capital cost of plant and equipment if the system is combined with a suitable capital replacement policy.

The disadvantages are heavy costs of depreciation and of plant spares, the necessity for installed spare equipment, low availability and utilization of both equipment and labor, erratic nature of demands on maintenance personnel, unreliability of production schedules and forecasts, wide fluctuations in cost of maintenance, poor working conditions for maintenance and operating personnel as a result of unreliability and possible hazards of plant, and unduly high losses of material in production due to lack of warning of equipment failure.

It is concluded that generally maintenance of this type involves the acceptance of a lower equipment efficiency resulting in lower production than could be achieved from identical machinery and plant if the latter were maintained at a higher level by other methods available.

Scheduled Maintenance.--Scheduled maintenance is that which is carried out to a definite program, usually drawn up for one calendar year in advance and added to as required.

The maintenance staff is responsible for producing an inventory of all major items of plant equipment and suggesting to management where and when maintenance work will be advisable. Generally, production schedules will determine the exact availability of units or equipment for maintenance activity, but often other considerations will affect this, as for example legal or safety requirements for periodic inspection of boilers, pressure vessels and similar equipment.

Scheduled maintenance is the natural system to use where plant is not required to run continuously for twenty-four hours per day, seven days per week, or where periods of idleness due to such factors as re-tooling, revision of layout for new product, or seasonal decrease in demand are customary and foreseeable.

The system is unsuitable in industries where demand is in excess of capacity of continuously operating plant, or when there is no general annual holiday or other customary break in production.

The advantages of this method are:

(a) it is possible for maintenance departments to make valid long-term forecasts of labor requirements and hence to estimate at least some of its costs with reasonable accuracy;

(b) a large measure of flexibility in programming maintenance work is retained untilat least near the actual scheduled date for any specific task;

(c) the ordering and purchasing of required replacements becomes much more predictable, thus eliminating the accumulation of excessive stores and inventory.

The disadvantages are:

(a) the scheduled periods of production idleness may not be adequate for all the work to be carried out;

(b) a certain amount of clerical work will be necessary in preparing records and following up the program.

It is concluded that scheduled maintenance should generally be the first step, both in time and principle, towards full preventive maintenance. It is thus a means to an end, rather than an end in itself. Where the enforced periodic idle time of plant is of such duration as to permit the carrying out of all necessary maintenance work, scheduling will greatly increase the efficient utilization of such idle time as well as enable the maintenance department to use its labor to better advantage.

Planned Maintenance.--This system carries maintenance scheduling several steps further in as much as the latter forms the framework of a more detailed analysis leading to the planning of specific methods by which maintenance work is performed. Planned maintenance endeavours to determine what work is required and by whom as well as how it is to be accomplished. From records and conditions found and from work previously done under scheduled maintenance, tentative estimates can be made of the work content of the jobs involved and materials and labor are accordingly allocated and in advance.

Planned maintenance is most suitable for situations where scheduled maintenance was considered inadequate, namely where demand is in excess of producing capacity of a continuously operating plant, or where there is no customary periodic break in production. The system may well be uneconomical and unnecessary where these conditions do not exist.

Its advantages include:

(a) maintenance labor and facilities are more fully utilized;

(b) production becomes more reliable and consistent during normal operating periods;

(c) equipment records are reinforced by extensive data which give a means of comparing maintenance performance on different production programs.

Some of the possible disadvantages are:

(a) last-minute alterations to planned shut-downs are expensive, hence there is a certain loss of flexibility in production;

(b) there is a marked increase in the clerical work connected with maintenance;

(c) it is necessary to have well-qualified inspection and maintenance supervision in order that the full benefits of the system may be obtained.

The conclusion may be drawn that planned maintenance is economically justified mainly in continuously operating process industries with high rates of plant throughput. Under such conditions, the analysis of maintenance performance and its comparison with advance estimates, and a strict application of experience gained, will lead to reductions in both maintenance and production costs.

Preventive Maintenance.--This system comprises a philosophy and approach to maintenance in which detailed inspection and study of existing equipment and work procedures result in effective economies through improvement in design, alteration in the frequencies of scheduled work and the development of new maintenance techniques, methods, and materials of construction. Preventive maintenance is a development of planned and scheduled maintenance, the prior establishment of which it presumes; it is based on the requirement that persons in charge of maintenance must possess an intimate knowledge of the condition of their equipment at all times. Hence, the prerequisites of preventive maintenance are extensive inspection and records. All the work under preventive maintenance, namely inspection, maintenance, replacement or modification, as well as the clerical work involved, is ideally broken down into elements which are studied to improve methods and to obtain more accurate work contents. Preventive maintenance attempts to relate the performance of work to some more suitable and absolute standard than past experience; good methods study and work measurement procedures are aids in this objective. Furthermore, at this level, the emphasis of maintenance is on upkeep, modification, and replacement of equipment to the exclusion of mere repairs.

Since preventive maintenance is an extension of planned maintenance, it follows that it will be suitable under somewhat similar conditions; these include the cases where:

(a) continuity of production is essential because of inadequate storage for or the nature of the finished products;

(b) space for expansion of plant is restricted or too costly;

(c) shortage of suitable labor exists;

(d) capital expenditure is strictly limited;

(e) the total cost of maintenance is high compared with production costs.

The advantages of preventive maintenance are numerous, both direct and indirect. They include the flexibility arising from accurate and advance knowledge which permits reliable forecasts of production to be made, very low actual depreciation of plant and equipment, an absolute minimum of installed spares and stores inventory, better working conditions for operating and maintenance personnel, and the lowest overall maintenance costs consistent with the highest quality of equipment condition.

The disadvantages are firstly, the necessity for fairly comprehensive record keeping and attendant clerical work involved, and secondly, the possible reluctance to replace technically obsolete equipment because of the satisfactory condition of the existing plant.

It is concluded that there is no universally applicable formula for preventive maintenance, since the latter represents an approach to the problems of maintenance which depends to a great extent on the efforts of an efficient maintenance staff applied to specific conditions. The administration of preventive maintenance must be on a sufficiently high level to ensure integration with production policy. Technical methods for production and maintenance must be under constant and related review. The allocation of function and responsibility must be clearly defined. The application of preventive maintenance is most suitable in processes where maintenance costs represent a major part of the overall cost of conversion of raw material to finished product. The installation of preventive maintenance may often involve a review of the organizational structure of a plant, and hence it requires the whole-hearted cooperation and acceptance by all staff concerned.

CHAPTER IV

A SURVEY OF MAINTENANCE PRACTICES IN INDUSTRY

Recently a survey was made of maintenance practices in fifteen major industries by the McGraw-Hill Research Department.[3] The 542 plants reporting in the survey represented 12 per cent of all manufacturing plants with over 500 employees in the United States. These companies employed a total of 1,116,374 plant employees, of whom 93,451 were engaged in maintenance activities; the plants had a connected motor load of 5.8 million HP, 597 million square feet of manufacturing area, and 8.4 million square feet of centralized maintenance shop area.

As can be seen in Table 1, the ratio of maintenance to total plant employees is almost three times as high in petroleum and coal plants as it is in any other industry, while in most of the other industries surveyed the ratio is between one-quarter and one-twelfth of that in the petroleum industry. Furthermore, the latter has only 71 square feet of centralized maintenance shop area per craftsman. This is explained partly by the fact that in petroleum refineries, the maintenance shop is very often organized and functions as a specialty production shop. A great deal of the maintenance work is scheduled, hence little space is wasted on occasionally-used equipment, most of it being fully utilized. It should also be noted that, although the space devoted to maintenance shops in petroleum refineries appears inadequate when compared with other types of industry quoted, the actual average size of the shops in the fifteen reporting plants was in excess of 55,000 square feet, while the next highest average was for the primary metals industry which had an average maintenance shop size of 29,000 square feet.

Some other interesting facts were uncovered by the survey concerning maintenance practices in the 542 plants in various industries:

(a) About 58 per cent of the companies regularly scheduled overtime for maintenance and construction craftsmen, and nine out of every ten of these claimed that overtime maintenance was required because of production schedules.

(b) Only 30 per cent of the companies had a formal training program for maintenance craftsmen, and 28 per cent had one for maintenance supervisors. It was evident, that even among the leading companies, not enough progress had been made in this field, although spot-checks had revealed that the level of maintenance performance was higher in those plants in which such training programs existed.

(c) In 86 per cent of the plants, maintenance craftsmen were organized in unions, most of them (about 88 per cent) being in plant-wide unions rather than in craft unions. It was generally thought that plant-wide unions were to be preferred because they minimized the jurisdictional problems, necessitated less duplication of personnel, and facilitated

TABLE 1. RATIOS OF MAINTENANCE EMPLOYEES TO CERTAIN CHARACTERISTICS IN INDUSTRY

Type of Major Industry	Ratio of One Maintenance Craftsman to Number of:				Units Reporting	
	Total Plant Employees	HP of Conn. Motor Load	Ft^2 of Plant Mfg. area	Ft^2 of Centralized Maint. Shop Area	No. of Plants	Total Plant Employees
Petroleum & coal products	3	41	*	71	15	36,362
Chemical processing	8	59	7,727	148	52	74,775
Primary metals	9	133	10,439	186	44	95,522
Pulp and paper	10	180	4,773	128	25	30,780
Stone, clay & glass	10	65	3,793	128	20	31,961
Food processing	12	56	5,995	162	35	48,303
Rubber and rubber products	13	94	5,114	83	23	67,096
Fabricated metal products	18	81	7,197	140	27	29,385
Transportation equipment	18	73	5,744	77	45	201,797
Textile mill products	20	68	7,744	218	41	51,586
Furniture	23	69	9,366	148	10	10,481
Electrical machinery	27	105	7,089	138	33	105,846
Other machinery	28	92	7,953	137	104	237,766
Printing and publishing	32	52	6,890	175	22	20,628

TABLE 1. RATIOS OF MAINTENANCE EMPLOYEES TO CERTAIN CHARACTERISTICS IN INDUSTRY (Cont'd)

Type of Major Industry	Ratio of One Maintenance Craftsman to Number of:				Units Reporting	
	Total Plant Employees	HP of Conn. Motor Load	Ft^2 of Plant Mfg. area	Ft^2 of Centralized Maint. Shop Area	No. of Plants	Total Plant Employees
Instruments	37	60	5,294	97	16	39,559
All other Manufacturing	13	47	5,545	142	30	34,527

*Many of the plants in this category were petroleum refineries which are usually spread over very large areas. Hence, the term "manufacturing area" does not have the same meaning in this industry as it does in the others where it denotes area under roof.

better cooperation in the operation of work-order systems, preventive maintenance and scheduling programs.

(d) Most plants, about 88 per cent, had a formal written maintenance work-order system of some sort or another, but the survey revealed that the scheduling of work orders was more of a cost accounting device in most plants than a reality, since 30 per cent of the plants scheduled less than 25 per cent of their maintenance work-orders.

(e) About 80 per cent of the plants kept plant equipment records in the maintenance department, and of these seven out of ten kept track of maintenance costs on such records.

(f) The situation existing as regards progress reports made by maintenance departments to top management was revealing. About 80 per cent of the maintenance departments reported progress either weekly or monthly, while the remainder did so annually, occasionally, on request, or not at all (5 per cent). In spite of this apparently fair situation, the survey revealed a widespread failure of maintenance men to capitalize fully on the opportunities offered by progress reports. Less than two in five plants reported on the backlog of their workload. Only one plant in three reported machine-downtime caused by breakdowns of equipment. Unless such items as these are reported to top management, it is impossible for the latter to realize the price of its failure to provide adequate maintenance facilities. Most of the reports overemphasized big, immediate cash outlays on major projects and overtime, while excluding items which have often proved to be sources of even greater, though less obvious, routine expenditures.

(g) Only 42 per cent of the companies reported that they made a definite periodical review of the costs of maintenance of all equipment as part of a regular equipment replacement program. This was rather a surprising revelation, particularly so considering that for companies of the size covered by the survey, one would have expected a recognition of the important influence that maintenance cost has on the replacement of equipment.

(h) Over one-half of the companies used outside contractors for the maintenance of roofs, and for window cleaning, while 13 per cent did not use them at all. Less than two plants in five availed themselves regularly of the services of outside consultants on special plant engineering and maintenance problems. It appeared that there was a widespread reluctance on the part of plant managements or heads of maintenance departments to do so, probably because of an imagined implication or admission of inability to perform the jobs in question. However, modern plant engineering is so complex and specialized that there should be no such reluctance to accept expert outside advice even in the largest plants.

(i) Most plants (84 per cent) had a separate maintenance shop, and generally they sent less than 10 per cent of the maintenance-shop work to be done outside the company.

Similarly, almost 90 per cent of the plants had separate maintenance stock-rooms and an equal percentage of companies allowed the maintenance department head to determine the size of maintenance stock inventory.

(j) The survey revealed that top management keeps a tight rein on all types of maintenance expenses in a good majority of the plants; in less than a majority did the maintenance department have any say whatsoever in authorizing maintenance expenditure. In a large number of plants, production departments were responsible for authorizing maintenance expenditure on production equipment. The inference was that production departments could tell the maintenance men how much maintenance should be done. Such a situation is inherently unsatisfactory, especially where repair costs are included in maintenance budgets, since it is advisable that responsibility and costs should go hand in hand with authority to effect repairs at the optimum time and cost from the long-term economic point of view.

(k) A majority of the plants used budgeting based on historical data for the allocation of costs for new facilities, repairs, and routine maintenance. However, often funds were allocated by individual projects wherever exceptionally large amounts of money were involved. Three out of every four plants broke down their major maintenance costs by operating departments; most of the cost breakdowns showed insufficient detail, although it appeared that companies were trying to rectify the position.

(l) As regards lubrication of equipment, over 90 per cent of the companies reported the existence of a planned and scheduled lubrication program, although the responsibility for it appeared to be divided in almost one-fifth of the plants questioned. It was gratifying and significant that over 22 per cent of the plants had automatic centralized lubrication equipment in general practice; the usefulness of such installations appeared to be gaining recognition, at least among the larger enterprises.

(m) There was little agreement on the standards of work measurement used to check the efficiency of maintenance workers. Time values based on standard data were used by only 8 per cent of the plants surveyed while over 40 per cent based theirs on estimates, and over 20 per cent related them to the amount of down-time of equipment. Even the small number using standard data for measuring maintenance performance indicated the future possibilities of the method. Amount of down-time might be a good measure of the effectiveness of a maintenance program, but it does not necessarily bear any relation to the efficiency of individual maintenance workers.

Only 7 per cent of the companies surveyed had wage incentive plans for maintenance workers. This may have been due primarily to the general difficulty of establishing adequate standards for maintenance work on which such plans would have to be based. While the number of plants that reported the existence of incentives for maintenance work was insufficient to give statistical accuracy, the following trends were apparent: about one-third included supervisors in their plans; two-fifths figured payments on an individual basis; the remainder using group incentives. In one-third of the cases less than 30 per cent of all maintenance work was on incentive, while a similar number had over 95 per cent covered; one-half had been operating their incentive plans for longer than five years; and finally, 90 per cent reported that incentive plans had increased the productivity of their maintenance workers, although in most cases the increase had been 20 per cent or less of previous performance.

(n) Over 90 per cent of the plants reported the existence of preventive maintenance in one form or another, and most of these were using it for such items as motors, production equipment, controls, and materials handling equipment. Seventy per cent of the plants using preventive maintenance had a system of check-lists for guiding preventive maintenance work. However, the respondents were about evenly divided in the methods used for ordering preventive maintenance work by individual items of equipment, by type of equipment or department, or by one order for the whole plant on an annual schedule basis. Another factor which was important in any evaluation of how seriously companies regarded preventive maintenance was the ratio of full-time and part-time preventive maintenance personnel.

Table 2 shows these values as well as the number of men engaged in such work as compared with the total maintenance labor force. It will be seen that there exists a considerable variation in the significance attached to preventive maintenance by managements in various industries. The percentage of craftsmen assigned to preventive maintenance in the petroleum industry appears to be one of the lowest of those shown, although this fact may be partly explained by the large number of employees usually employed in the maintenance departments of oil refineries. Nevertheless, it is revealing that less than 10 per cent of the craftsmen employed in the petroleum industry are engaged in preventive maintenance on approximately a full-time basis.

From the point of view of this paper, probably the most significant fact exposed by the survey is the extremely high proportion of maintenance employees to others in an oil refinery. This high figure can be explained partly by the characteristic of low process labor requirements of the petroleum industry, in which automatic control of operations has been more fully developed than in any other type of industry. Over the years, as refining processes have progressed from the batch or semi-continuous types to fully continuous operations, a comparable advance has taken place in the development of instruments for indicating, recording, and controlling such functions as temperature, pressure, flow rate, and liquid levels. By means of remote transmission systems it has become possible to centralize practically all instruments in one control room, even though the plant unit itself may spread over a considerable area. Such centralization has simplified operating problems in many ways, one of the latter being the low operating labor requirement of modern refinery processes. However, this same tendency and the ever-increasing complexity of refining processes have multiplied similar problems of maintenance manifold.

Nevertheless, the above-mentioned situation is not the only reason for the high maintenance/total employees ratio. Most of the processing units in an oil refinery represent extremely high capital investments. As a result, it is essential to keep them in continuous on-stream operation for long periods of time. Scheduled shut-downs for overhaul and repair must be kept to a minimum, while emergency shut-downs must be prevented. The amount and quality of maintenance demanded by these economic considerations is necessarily much greater than in other industries.

The scope and diversity of the activities involved in a modern oil refinery are so extensive that the maintenance force must include most of the known skilled crafts in existence. Furthermore, such labor will command relatively high wages, and thus the significance of maintenance is further increased by the financial considerations involved.

TABLE 2. ALLOCATION OF LABOR TO PREVENTIVE MAINTENANCE

Type of Industry	Percentage of Craftsmen Assigned to Preventive Maintenance	Percentage of Craftsmen on Preventive Maintenance Devoting to it: 100% of their time	More than 50% of their time	Less than 50% of their time
Petroleum & Coal Products	12.0	60.5	32.5	7.0
Chemical Processing	14.0	64.5	16.5	19.0
Primary Metal Industries	42.0	37.5	48.5	14.0
Pulp & Paper	20.0	18.0	31.5	50.5
Stone, Clay & Glass	19.5	18.0	8.0	74.0
Food Processing	23.5	35.0	15.0	50.0
Rubber & Rubber Products	14.5	27.0	14.5	58.5
Fabricated Metal Products	20.0	52.0	34.5	13.5
Transportation Equipment	18.5	68.0	14.0	18.0
Textile Mill Products	19.0	44.5	18.5	37.0
Furniture	21.5	20.5	71.5	8.0
Electrical Machinery	15.5	27.5	11.5	61.0
Machinery (except Electrical)	16.0	37.0	20.0	43.0
Printing & Publishing	31.0	44.5	15.0	40.5

TABLE 2. ALLOCATION OF LABOR TO PREVENTIVE MAINTENANCE (Cont'd)

Type of Industry	Percentage of Craftsmen Assigned to Preventive Maintenance	Percentage of Craftsmen on Preventive Maintenance Devoting to it: 100% of their time	More than 50% of their time	Less than 50% of their time
Instruments	11.0	27.0	6.5	66.5
All other Industries	10.0	43.0	10.0	47.0

All figures are given to the nearest 0.5 per cent.

CHAPTER V

MEASURING THE EFFECTIVENESS OF MAINTENANCE

The foregoing are some of the reasons for the great importance which must be attached to maintenance activities in an oil refinery. It follows that any improvement achieved in the performance of maintenance under such conditions will be reflected significantly in the overall economics of the industry.

Great care should be exercised in the application of published maintenance cost data to any particular plant within a specific industry. It is rarely that maintenance cost statistics have been developed on an adequately comparable basis, and in any case little useful information can normally be gained from them as to the effectiveness of a maintenance department in any one specific plant. There are various reasons for this unreliability of published data, and they include the following: the definition of the functions of a maintenance department varies from plant to plant and from one industry to another. The type of product, age, and condition of plant and equipment, different kinds of operations and processes used, all these influence the scope and requirements of maintenance; moreover, management policy very often determines the costs of maintenance by its quality requirements.
The efficiency of the maintenance force depends to a great extent on proper organization, supervision, planning, tools, and equipment, while methods study, work measurement and

simplification all affect the proper utilization of the labor and material facilities of a maintenance department. Other variables which enter the picture are accounting standards and procedures used, and the local labor rates prevalent in the geographical area of location.

In order to measure the effectiveness of a maintenance program, certain criteria should be evaluated, these being the size of the maintenance job to be performed, the size of the maintenance forces to perform it, the efficiency of the maintenance force, the qulaity of the maintenance work required, and the level or amount of maintenance necessary. (4)

The size of the maintenance job may be determined by firstly making a complete inventory of all the physical assets of a plant, such as the structures, equipment, and services; sometimes referred to as "plant equipment records". Secondly, the various functions to be performed by the maintenance department on all these different physical assets must be determined and listed. Such a thorough analysis is not easy or speedy, but it will indicate with reasonable accuracy what the size of the maintenance task in a plant really is. Consequently, it will help management to ascertain the nature and the complexity of the functions of the plant maintenance department.

Having decided on the maintenance requirements, management will wish to ascertain the nature and size of the maintenance force required to perform them. This is best and most commonly done by the application of work-standards to the total work-load grouped according to man-hour requirements for the various crafts and services concerned. As has been stated, various forms of work-measurement standards are in use; however, the most scientific are undoubtedly those based on standard data or pre-determined time standards although not all maintenance jobs can be fixed in this manner. A widely used alternative is the estimation of man-hours and skills required for predictable jobs by experienced executives, supervisors and staff. Having applied work measurement standards to the various components of the total work-load, it remains only to match the job with an adequate labor force. It is always necessary to re-evaluate the maintenance man-power requirements at periodic intervals, since conditions that affect them are constantly changing.

The basic principle for measuring the efficiency of the maintenance force is to compare actual performance of a job with the standard time allowed for that job, assuming similar quality standards are being met. Just as in production work, time standards can be based on work factor estimates, on past experience, or on the more scientific methods of work measurement such as elementary time values.

The quality of maintenance is best measured by a combination of inspection and performance tests. The most important part of the former is satisfactory supervisory control and inspection while the job is actually being performed. Performance data which give a good insight into the quality of maintenance work performed include production department quality reports, mechanical downtime reports, frequency of repairs, reasons for repairs, and safety reports. However, such information must be carefully investigated and evaluated before any conclusions as to quality of maintenance work can be made.

The amount of maintenance which a plant should have is a function of the previously mentioned factors. It is not always easy to decide whether management is over-maintaining or under-maintaining a plant, but if it is well informed concerning the other yardsticks of effective maintenance, management can usually get any further necessary details from its maintenance departments and production departments which will enable it to decide the matter.
It must be noted that the amount or intensity of maintenance is purely a management decision, which is bound to be affected by a great number of extraneous circumstances and economic considerations.

SECTION TWO

CHAPTER VI

APPLICATION OF INDUSTRIAL ENGINEERING TO PETROLEUM REFINERY MAINTENANCE

The detailed procedures of industrial engineering which have been evolved from study and trial-and-error practices in other major industries cannot be applied directly in the petroleum refinery. The discovery of this fact by oil refinery managements has led to a certain reluctance on their part to utilize the valuable tools offered by personnel qualified in industrial engineering. In common with many other industries, petroleum refining also suffered from the nefarious activities of so-called "efficiency experts" when industrial engineering was in its infancy; and, owing to the peculiar nature of the industry, it has usually taken longer for the sound philosophy of industrial engineering to get established in petroleum refining than in other manufacturing industries.

While the broad principles of industrial engineering are equally applicable to petroleum refining as to other industrial undertakings, the procedures by which these principles are applied are necessarily different, just as much as the equipment and processes used in petroleum refining and similar continuous process industries differ widely from those found in the production-line type of manufacturing industries. The broad basic industrial engineering principles can be generally described as: organization, coordination, planning, standardization, review, and improvement.

In the relatively short time of its existence, the petroleum refining industry has overtaken most other major industries by the speed of its development and its flexibility in the face of the ever-changing challenges of the industrial world. This energy and creativeness were made possible largely by the commendable approach of the industry's managers and engineers. However, since process changes and improvements in operating techniques due to better equipment have always resulted in the most pronounced economies in petroleum refining, there has been a tendency to overlook the possible improvements in the mechanical methods and procedures of plant maintenance, which was always regarded as an inevitable but unfortunate cost to be charged against the finished products. A gross breakdown of capital expenditures in an average refinery shows a capital investment in process equipment of between $2,000 and $3,000 per process employee, while outlays of between $400 and $600 per maintenance man for tools and equipment are considered normal. Obviously, there can be no equalization of the two figures and none is intended by the above comparison, but considering the fact that other well-regulated industries show maintenance department investments of approximately $2,500 per man, it does appear that maintenance is not receiving the attention it merits in the petroleum industry.[5]

Petroleum refining generally is continuously expanding its production, and therefore the market for petroleum products is becoming increasingly more competitive, in spite of the great demands of a modern mechanized world. Consequently, it is necessary that the quality of petroleum products and the efficiency of their distribution and marketing must not only be maintained but constantly improved, and above all, the operating costs of production and refining must be kept to a minimum. While manufacturing costs are tending towards general stability, the greatest field of potential reduction in costs is in increasing maintenance accomplished per unit cost. This can be and is being achieved by the application of basic industrial engineering principles, such as work planning, craft scheduling, standardization of methods and of equipment, and by improved cooperation, procedures, and organization. Such activities are essentially industrial engineering techniques applied to refinery practices but they differ from the detailed studies which are customary in the production-line type of manufacturing industries.

CHAPTER VII

DESCRIPTION OF MAINTENANCE ACTIVITIES IN THE OIL REFINERY

The tasks of a maintenance department in an oil refinery are far-reaching, varied, and numerous. Table 3 attempts to list them according to the type of engineering work involved, namely mechanical, civil, electrical, plant utilities, and general. This list, or any list for that matter, cannot claim to be all-inclusive, nor does it have an absolute significance. There is a great deal of overlapping between the various divisions due primarily to the extreme complexity of the work involved in any modern plant. Rarely does a maintenance job concern only one craft, division or section of the maintenance department.

Mechanical Engineering.--The activities involved in the proper installation, inspection, servicing, and repair of the great multitude and variety of equipment used in a modern petroleum refinery are tremendous. Apart from normal depreciation due to usage, corrosion and erosion problems frequently arise; a large proportion of the equipment in the refinery is located out in the open without any cover or protection against the elements; harmful industrial atmospheres are sometimes encountered and have to be taken into account. All such rigours have to be overcome not only by the equipment but also by the men maintaining it. Many processes of oil refining demand the use of extreme conditions of temperature and pressure which increase the depreciation and hazards of the equipment. The processes are largely continuous, twenty-four hours per day, seven days a week operations, and hence the performance of maintenance is further complicated by the absence of frequently recurring inoperative periods in the plant, during which maintenance work could be carried out. The activities listed under the mechanical type of engineering are mostly self-explanatory. Each forms a wide subject in itself, and most of them occur in other branches of industry.

Civil Engineering.--These activities include the physical upkeep and construction of buildings, structures, grounds and roads. In most refineries, the construction activities of the maintenance department are limited in scope, since it is obvious that major fabrications, construction and installation of plants are highly specialized functions requiring outside consultants and contractors. However, much civil engineering work will be of a routine or minor construction nature, and as such will fall under the functions of the maintenance department.

Electrical Engineering.--Instrumentation in the modern oil refinery has become so vast and complicated a function that many refineries have set up completely separate departments to handle the selection, installation, maintenance and repair of instruments. In a large-size refinery, such an arrangement is often a necessity since

MECHANICAL	CIVIL	ELECTRICAL
Furnaces	Buildings	Instruments & controls
Pumps	Grounds	Motors & generators
Valves	Roads	Power supply
Piping	Structures	Power distribution
Vessels	Soil Mechanics	Communications equipment
Tanks	Site preparation	
Pressure vessels	Hydraulics	
Heat-transfer equipment		
Motors		
Compressors & blowers		
Transportation equipment		
Materials handling equipment		
Welding & tinning		
Carpentry		
Machining		
Cleaning		
Lubrication		
Construction & erection		
Insulating		

PLANT UTILITIES	GENERAL
Steam	Stores
Water	Safety
Electricity	Fire prevention
Heating	Janitoring
Lighting	House-keeping
Ventilating	Guarding & protection
Air-conditioning	Salvage
	Corrosion
	Painting & decorating

Table 3. Scope of Oil Refinery Maintenance

the nature and progress of modern instrument practice requires highly specialized personnel on a full-time basis to handle all the related problems.

Other functions which fall under this heading are the servicing and repair of electric motors used for every conceivable purpose, the provision and maintenance of power supply and distribution, all work connected with communications equipment such as telephones, radio transmission and reception, battery operated equipment for materials handling equipment, and many other duties occurring in an industry, which utilizes more electrical energy than do most other industries.

Plant Utilities.--Like instrumentation, plant utilities and services are often organized as a special department since they fall into a category between processing and maintenance, due to their similarity to other auxiliary units of petroleum refining processes. They require maintenance in themselves just like processing plants do, and yet their function is one of service to processing in the same way as maintenance provides service.

The proper upkeep of heating and lighting facilities in plant, buildings, and offices is a continuous function of the department which must be attended to efficiently and regularly for reasons of employee comfort, health, safety, and morale.

General.--Under this heading are listed miscellaneous other functions and divisions of a maintenance department which are not covered by the previous categories. Depending on company policy and on the size of the plant, some of them, such as safety and stores, may form separate departments of the organization. However, whether this is the case or not, such separation must not preclude close cooperation between them and the maintenance department.

Maintenance departments are indubitably the largest users of stores in a refinery, and hence the control of and responsibility for refinery stores are usually allotted to them. A great deal of clerical work will be involved in an efficient stores operation, and this is only one of many instances of the need for adequate office staffs to be provided for maintenance departments in order that foremen and supervisors, as well as staff engineers, should not be over-burdened with non-technical work.

Safety and fire prevention work which concerns the maintenance department is the upkeep of such equipment, while responsibility for training, inspection and administration of company policy in these matters is usually given to a safety director of executive status and his staff organization.

Corrosion engineering has become a highly specialized branch of science, and qualified engineers within the maintenance department will usually be provided. Protective painting is closely connected with corrosion prevention.

Such tasks as janitor service, house-keeping, and salvage are normally carried out by unskilled labor employed within the maintenance department.

CHAPTER VIII

TYPES OF REFINERY MAINTENANCE ACTIVITIES

There are essentially two types of maintenance activities in the oil refinery, namely continuous or routine maintenance and turn-around or shut-down maintenance. (6) The terms are more or less self-explanatory, and the two types differ only in scope and detailed character but are essentially the same as regards the organization, planning and scheduling techniques used in their performance.

Continuous Maintenance

The nature of a continuous process industry like petroleum refining makes it imperative that firstly, unscheduled shut-downs of plant be prevented at all cost, and secondly, that scheduled shut-down or turn-around time be kept to an absolute minimum consistent with the efficient conclusion of all necessary work. In accordance with the second requirement, it is essential that as much maintenance and fabrication work as is possible be performed in advance of the actual scheduled shut-down while the unit is on stream. Such preparatory work comprises one category of what is meant here by continuous maintenance; the second category includes normal routine maintenance work which may or may not be directly connected with the unit in question.

In continuous maintenance the time element is not of as great a significance as it is in the case of a unit shut-down where work must be performed at great speed within a specified minimum period. Many of the continuous maintenance duties allow for a fair degree of flexibility as regards manpower used and deadlines to be met. Nevertheless, the planning and coordination required are just as great as in shut-down maintenance.

Continuous maintenance may be logically divided into two broad categories:

(a) Preparatory work connected with scheduled unit shut-downs;

(b) Customary or routine duties of the maintenance department.

Preparatory Work.--The continuous maintenance functions connected with periodic and scheduled shut-downs of individual refining units can be further divided into work performed on certain types of equipment while the unit is on-stream and the actual preparatory work which can be performed in connection with and in advance of the scheduled unit shut-down.

In the first sub-division, there will be equipment which by its nature or function makes it economically desirable that it should be duplicated. Such installations will include pipe-lines, valves, pumps, heat-exchangers, and condensers, as well as certain types of equipment, such as motors and steam-drivers, in the case of which spare units are invariably available. Also, in most refining processes certain auxiliary equipment, such as instruments, utilities, and even certain vessels, is not or does not have to be in continuous use even though the processing unit as a whole is on stream without interruption between scheduled shut-downs. In addition, there is a multitude of duties pertaining to such maintenance and repair of specific equipment which can be performed while the unit is on stream, namely painting, lighting, insulating, structural and similar work.

The actual preparatory work has as its ultimate aim the limiting of shut-down maintenance to replacement, installation, and statutory inspection of equipment. This means that it is concerned primarily with the fabrication of and preparation for jobs, the necessity for which is indicated by inspection or factually determined. Most equipment which is subject to relatively uniform wear or corrosion, and the effective or safe lifetime of which can therefore be predicted, will fall into this category. Typical examples of such items are piping, furnace tubes, heat exchanger tubes and shells, rotors of pumps, fractionating tower linings and similar equipment.

Routine Work.--In addition to the work connected with the continuously operating processing units which are subject to periodic scheduled shut-downs, the maintenance department of an oil refinery has a multitude of continuous general plant engineering duties to carry out without which no plant could function. The problems presented by the variety and quantity of such duties require a high degree of planning and integrating activity, in order that labor and equipment available can be utilized most effectively.

The work considered under this heading falls into the following broad classifications: Auxiliary operating equipment, such as batch-treating, blending, packaging and materials handling plant is often either wholly or partly intermittent in operation, and it therefore affords adequate opportunity to the carrying out of planned maintenance;

Certain plant utilities and services, as for example water, power distribution, heating, lighting, or communications, may be shut down either partly or completely for limited periods of time to permit necessary work;

Some equipment is generally available for maintenance work, a most useful attribute from the point of view of planning. This includes roads, buildings, structures, maintenance shop equipment, materials handling installations and mobile equipment, vehicles, and grounds;

Miscellaneous functions of the maintenance department such as cleaning of equipment not in immediate use, preventive painting and upkeep of vessels, structures, buildings, general repair, janitoring, salvage, and similar work all have to have varying degrees of priority and effort allocated to them;

In most refineries, the maintenance department is often called upon to perform construction and erection work. However, there is usually a limit to the scope and size of projects of this type which a plant maintenance organization can handle; obviously,large-scale undertakings of this kind have to be handled by a specialized department or outside contractors.

Shut-down Maintenance

In the continuous process industries, special considerations enter into the planning, management and execution of maintenance, since there is an appreciable amount of work of inspection, upkeep, repair and replacement which can only be performed when the plant, or one of its individual units, is shut down. As has been stated, the economics of continuous operation demand that plant must not stand idle for more than an absolute minimum period of time, and therefore unscheduled shut-downs must be eliminated while scheduled shut-downs have to be highly planned and coordinated operations.

The overall process of refining petroleum from its crude form into a multitude of finished products is made up of a number of unit operations such as fractional distillation, solvent refining, cracking, and polymerization, which are all performed in almost separate plant entities even to the extent of requiring intermediate product storage facilities. It is indeed a rare occurrence, usually brought about by highly exceptional circumstances, that a whole series of refinery plant units is shut down at one and the same time; apart from many other reasons, one obvious obstacle to such action would be the inadequacy of the maintenance manpower and equipment. Hence, the practice is to stagger the periodic scheduled shut-downs of individual units over as long a time as possible. The frequency of shut-downs will vary entirely according to the type of unit concerned and the conditions under which it operates; there are certain types which require greater than annual overhaul frequency, while others will operate satisfactorily for numbers of years without a major unit shut-down.

It is customary that during a shut-down all man-hours not scheduled for top priority emergency or non-deferrable normal repairs are diverted into the specific work-pool, though of course such action is far from haphazard. Extremely careful advance planning and scheduling is performed so that the optimum in coordination of all processing, maintenance and construction activities is achieved. Furthermore, all maintenance personnel involved in shut-down operations are usually required to work overtime and on a round-the-clock shift basis until the work has been satisfactorily completed.

Planning of the shut-down must also take into account the necessity for thorough inspection of installations and equipment, the nature of which permits such inspection only when they are out of operation.

CHAPTER IX

ORGANIZATION OF A MAINTENANCE DEPARTMENT

The principal objectives of a maintenance system in an oil refinery are to anticipate and prevent unscheduled interruptions in the operation of the plant and auxiliary services, and to keep all equipment in optimum condition consistent with highly efficient production. In order to achieve these objectives, the organizational phase of maintenance and its improvement must receive a great deal of study and attention, much more so than it has done in most refineries in the past.

The essential requirement for the establishment of an efficient maintenance organization in this or any other type of industrial undertaking is the provision of means which will ensure that the maintenance contribution to policy is made before that policy has taken shape as a final production program. This means that decisions regarding the organization of a maintenance department are matters requiring top-level management consideration and approval; hence, management must be made aware of the great importance attached to the provision of effective maintenance in its plants.

The organization of the maintenance department will be largely influenced by the size of the plant concerned.

However, by their very nature, petroleum refineries generally fall into the medium to large categories compared with other industrial undertakings, namely from 500 employees upwards. As has been stated previously, the average oil refinery finds it necessary to have one maintenance man to approximately every two employees engaged in other work so that only rarely will there be a smaller staff than 200 men engaged in maintenance work. Judging by the number of employees involved alone, there is therefore no justification for the maintenance department in an oil refinery to be placed under the control of the production or processing department as used to be done in the past. Incidentally, such a situation still exists in other industries in which the size and scope of plant, as well as the possibly economical practice of breakdown maintenance, make such a system of control feasible.

Although most modern refineries have a separate department handling maintenance and minor construction work, there is still a widespread lack of recognition of the importance of such work which is often manifested in the subordinate position to which the maintenance department is relegated in the plant. In many cases, reconsideration of the status of the chief maintenance executive may be the first step towards more effective maintenance. He should be raised to at least an equal level in the plant organization with the head of the processing department; like the latter, he should be responsible directly and solely to the chief plant executive. Similarly, other maintenance supervisory personnel should be placed on an equitable footing with their counterparts in other departments.

The most important factor in the successful execution of maintenance is a clear definition of the functions of line and staff members of the department at all levels. In particular, individual responsibility for making plans and budgets and for exercising control over actual costs incurred within those responsibilities must be stressed. Only too often does an overlapping of responsibility result in confusion and bad personnel morale. Furthermore, responsibility must be closely allied with authority at all levels of a maintenance department.

The most common organizational scheme for maintenance departments in oil refineries is the line and staff arrangement or some modification thereof. A typical example of such an organization is shown in the chart in Figure 1. The advantage of this type of arrangement is that a distinct division of responsibility is achieved and that lines of communication are clearly defined in both directions.[7] However, the drawback of the organization shown is that even though provision for an industrial engineering division has been made, many of the functions, such as planning and estimating for which an industrial engineer is best fitted and should be responsible, are

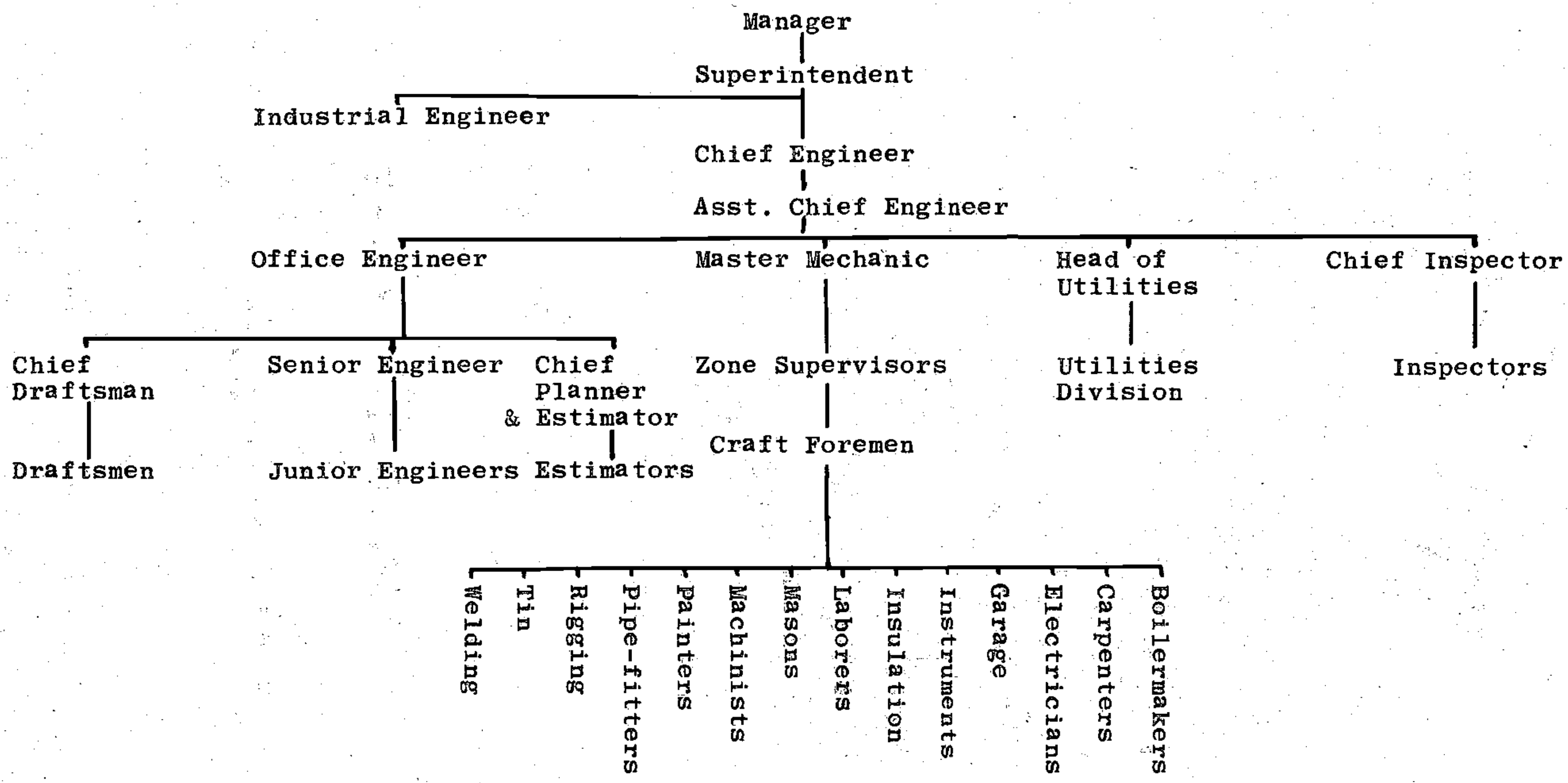

Figure 1. Organizational Chart of Refinery Maintenance Department

placed completely outside the sphere of that section's responsibilities. This may be one of the results of too rigid an insistence on the strict separation of line and staff duties.

The type of refinery maintenance department organization best fitted to utilize effectively the functions of industrial engineering is shown in Figure 2. The Chief Industrial Engineer would be responsible directly to the Superintendent of the Engineering Division in a staff capacity. He would be provided with adequate personnel to enable him to apply the principles of his profession to all maintenance activities. His work will include the planning and scheduling of preventive and other maintenance, even to the extent of initiating certain work orders. All inspection activities, both periodic and routine, and checking of completed work will be handled by the industrial engineering department; it is undesirable for maintenance inspectors to be directly responsible to the men who supervise and direct the work to be inspected. The maintenance foremen and supervisors should be free to devote themselves solely to the execution and supervision of maintenance work. In connection with this principle, it is recommended that all requests for maintenance work should be routed through the industrial engineering department which is then able to evaluate and interpret the work orders from the wider perspective of standards, better methods, safety and prevention of future recurrence. Thus all maintenance

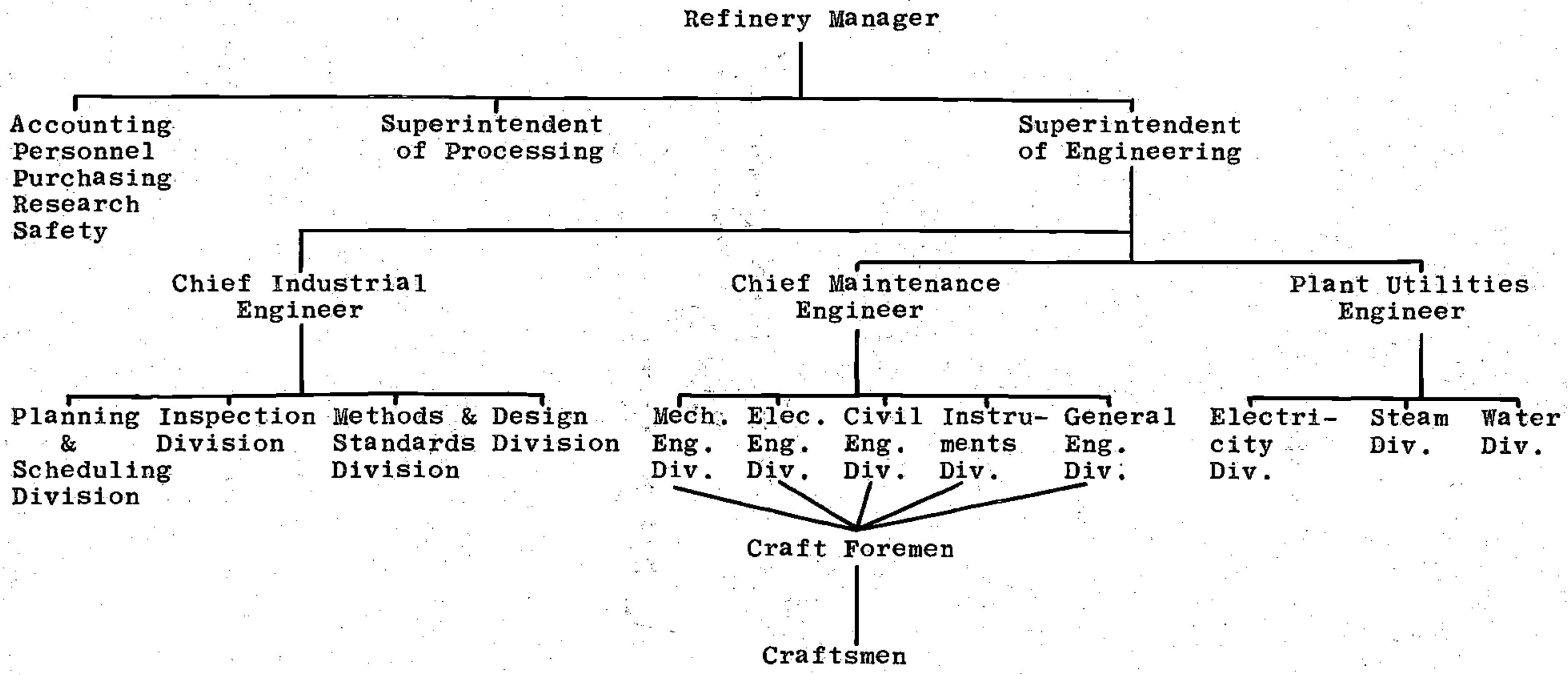

Figure 2. Proposed Organization of Refinery Maintenance Department

work would be detailed in the best possible way, and it would be possible for the industrial engineering staff to analyze and investigate the causes of and need for the performance of any maintenance tasks. Long-term planning of maintenance activities, scheduling of unit shut-downs, and periodic maintenance activities such as painting programs, all such functions could be executed or controlled by the industrial engineering staff, in addition to the setting of suitable standards for method, rate, and time of performance of maintenance tasks. The installation and administration of a possible wage incentive scheme for maintenance employees can be handled by the department. Other industrial engineering functions would be the provision of all maintenance reviews and reports to management, and the responsibility for investigating and recommending the employment of outside contractors for certain maintenance or construction work.

The principal benefits of such a modified line and staff organization would be firstly, that it will release maintenance personnel for their proper functions,thus utilizing most effectively the respective skills of the various engineering divisions, and secondly, it enables suitably qualified industrial engineers to concern themselves with the all-important planning and scheduling work which is of vital significance for the success of a full preventive maintenance program in an oil refinery.

CHAPTER X

WORK STUDY AND MEASUREMENT

The fundamental problem which is to be solved by work study and measurement of maintenance activities in an oil refinery is whether the size and utilization of the maintenance labor force are consistent with the most economical performance of the necessary work load. This is in effect a similar problem to that which often faces a production department in manufacturing industries. As has already been pointed out, there can be no objection to treating a maintenance department after the manner of a production operation, since the former also has a "product" to sell, namely a multitude of skills, crafts, services and duties. However, one great difficulty in this type of approach is that of suitably defining and measuring the productivity of a refinery maintenance department. The activities of maintenance in an oil refinery are so complex and varied that they do not yield any clear quantitative or arithmetical expression of output or "production" as is usually available in a manufacturing production department. Hence, it is very difficult to compare the results of maintenance with the effort expended in their achievement. Furthermore, unless some means of measuring maintenance can be arrived at, it will not be possible to determine (except by subjective opinion) whether inadequate maintenance is the result of an inadequate maintenance labor force or of an adequate force inefficiently utilized, or whether adequate maintenance is being obtained economically.

Work measurement is the means whereby an attempt is made to determine the amount of time which should be required for the execution of a given set of motions. A specific combination of these motions will constitute the accomplishing of a given task, and therefore the time that should be required to perform such a task is indirectly determined. In addition to the basic time value, it is necessary to make an allowance for certain factors connected with the work, and the final total figure will represent <u>the standard time</u> for the specific task.

The following may be considered as the four basic phases involved in any method of work measurement used:[8]

(i) Definition of the purposes of the study;

(ii) Determination of the best methods possible under the prevailing conditions to fulfill the purposes desired;

(iii) Establishment of a value for <u>the normal time</u>* for the actual work performed, the optimum method being practiced;

*The normal time is defined as the time taken by an average qualified worker performing at normal rate for the completion of the specific work being considered.

(iv) Determination of and making allowance for any factors relevant to the work so that a fair standard time for the job may be obtained.

The first of these phases has already been dealt with. The next two are mutually complementary since the best available method is that which allows for the attainment of the objectives in the shortest time consistent with minimum cost, optimum quality and adequate safety. A job will normally be broken down into smaller elements which can be studied individually with a view to their elimination or improvement; those remaining will have the basic normal times required for their performance determined. The extent to which this process of sub-division is carried forms an important point of difference between the various techniques available, and it is the degree to which it is economically desirable to proceed with it which determines the most suitable approach in a specific application. Methods study consists mainly of the elimination of unnecessary elements of work and the fullest utilization of mechanical aids available. It will be only rarely that the maintenance methods study will require the same degree of sub-division of the work as is usual in the case of production methods. This consideration will affect the choice of the type of work measurement to be used. In any case, the normal times will have to be determined for each element of the task, and the method of determination must vary according to their individual length. Generally speaking, the accuracy of the determination of normal times is adversely affected by undue increases in the length of interval; hence, a balance must be sought between the two requirements of accuracy and ease of determination.

The last phase of work measurement deals with allowance factors for fatigue, rests, unavoidable delays, working conditions, and similar related effects. These factors are usually empirically determined percentages added to normal time values to give the standard time for a job, and they will depend to a certain extent on management policy.

The attempt will now be made to trace the possible application to refinery maintenance work, modified where necessary, of the methods and techniques of work measurement and to compare them with the solution of similar problems in production departments of manufacturing industries. By their use in the latter, it is possible to arrive at a standard amount of effort, usually expressed in terms of man-hours of work, which is necessary for the production of a specific quantity of product in a specified manner. A comparison can then be made between the actual and standard performances, and hence a means for obtaining the labor utilization of the department is available. The desirability of having a similar criterion of effectiveness for the maintenance department is pronounced. Not only will the setting of proper work standards make the control of maintenance labor considerably easier, but it will be of utmost significance in the planning and scheduling of work, in the practice of preventive maintenance programs and in the scheduling of unit shut-downs. A comparison of standard times with actual man-hours expended in the performance of specific maintenance activities will disclose the effectiveness with which the refinery maintenance labor is being utilized. Last, but not least, proper work standards provide refinery management with a sound basis for establishing incentive systems for its maintenance personnel.

Essentially, the actual operations involved in a great number of maintenance activities are similar to those which form part of certain production procedures. Thus the work of a refinery maintenance machine shop, involving as it does, work on lathes, milling machines, shapers, power tools, etc., bears a marked similarity to that of the metal-working industries. However, unlike the work of production in manufacturing industries, certain types of refinery maintenance and most repair activities in an oil refinery contain only a limited number of operations which can be considered as being entirely repetitive, as for example the lubrication of mechanical equipment or certain frequent and periodic inspection procedures. Most of the work is either non-repetitive or recurs only at long intervals. Both the techniques and the expected results of work study applied to such maintenance activities must be modified in the light of this characteristic.

The several categories of work measurement techniques will now be considered in detail.

Gross Estimates.--As can be imagined, this is the crudest method of arriving at standard times for maintenance jobs. It consists of an overall estimation of the time to be allowed for the completion of a job and is based on past experience of identical or similar tasks. Such procedure contains little if any critical analysis of the methods employed since the methods of work, degree of effort, and any requisite allowance factors are all considered simultaneously as an entity.

The unrestricted use of this method in measuring the work of an oil refinery maintenance department is highly undesirable, but for certain activities it will be the only way of arriving at a standard time. In such cases, it will be better than no standard at all. However, the person who is made responsible for such estimating must be highly capable and fully experienced in the performance of the rated task. The accuracy of the estimating method is problematical at best; but it can be improved by placing strict limitations on the extent and range of operations over which estimating takes place. Wherever possible, such estimated standard time values should be combined with more scientifically determined ones in order to increase the overall accuracy. Constant attempts should also be made to break down and rearrange operations for which standards are thus being estimated in such a manner as to permit the setting of standards to be performed by one of the better methods of work measurement.

Time Studies.--According to Dr. Ralph E. Barnes, "time study is used to determine the time required by a qualified person working at normal pace to do a specified task".(9) Its further purposes are the establishment of time standards in connection with scheduling and planning work, their use as an aid towards determining standard costs and preparing budgets, and their application as a basis for the payment of wage incentives.

The technique of using time studies for measuring maintenance work (or any kind of work) is undoubtedly the most refined of all since it uses one of several accurate timing devices, such as a stop-watch, motion-picture camera driven at known synchronized speed, or some form of time-recorder. However, this very refinement is its economic limiting factor when maintenance work is under consideration. While most production operations consist of elements, the duration of which is measured in terms of seconds or fractions of a minute, the majority of maintenance activities will be made up of appreciably longer work elements which will usually amount to several minutes or even fractions of an hour at a time.

It is not so much the possibility of obtaining data by detailed time study which is limited per se, but rather the use to which such data can be put in establishing refinery maintenance work standards will be found to be so. The primary function of time study is to investigate an operation with a view to improving its performance when it next occurs and to establish the time required for its completion by the new method. Therefore, its application in this sense to refinery maintenance will necessarily be restricted by the degree of repetitiveness of the work concerned.

Elemental Standard Data.--The short-comings of the application of time studies to maintenance work can be largely overcome by a suitable modification in method. This is based on the principle that common work elements are found in a large number of jobs performed, even though specific jobs may be of a non-repetitive nature. Not only has this been proved to be true, but most jobs are made up of different combinations of relatively few such elements.

When the detailed time studies are begun, the elements are suitably selected and isolated from representative jobs so that it is possible to construct tables or graphs of normal times applicable to all the elements making up a great number of jobs. In such nomographs, the different factors of variation between similar but not identical jobs will be allowed for and specified. The total normal time for the completion of a task can then be found by determining and adding together the relevant elemental times. When suitable allowance for extraneous factors has been made, the standard time for the performance of a task by a specified method has been obtained. It is evident that in many cases this type of procedure offers a considerable advance on plain time studies.

The method makes it possible for a job to be standardized without a large number of detailed time studies being necessary and with a minimum time taken to set the standard. It enables formulae to be prepared which will facilitate quick calculation of the standard time for a given job. In fact, it will often be possible to determine the standard time without any time studies having to be taken at all. Furthermore, advance determination of standard times can be made before the actual performance of the task. This will obviously be of great significance in the planning of maintenance work for unit shut-downs.

A warning is needed in the case of the formulae based on elemental time standards and the tables of allowance factors for extraneous conditions. Their limitations should be determined and clearly specified in order to avoid undue discrepancies, the existence of which would place the whole system of work measurement into a state of undeserved ill-repute.

In oil refinery maintenance work, a great number of standard data may have to be determined to cover all the many activities to which the method can be applied. Not only will this mean the expenditure of much effort and time in the setting up of a work measurement program in the refinery, but also the administration and clerical work involved are liable to seem great. It is therefore recommended that extensive training be given initially to the staff personnel who will be called upon to administer the system. Furthermore, after the initial studies have been made, there will invariably be scope for combining individual elements into composite ones in order to reduce the work of reference and measurement while maintaining an acceptable standard of accuracy.

Predetermined Basic Time Standards.--Whatever their detail and however comprehensive the elemental standard data available may be, certain maintenance activities will have to be scheduled for which complete information will not exist. That does not mean that all the elements of a particular task will be unknown; any relevant elemental standards applicable which are available should be used. However, a number of elements may still remain for which standard times have not been established previously. It is highly desirable to avoid mere guesswork in their determination.

A number of recently developed techniques exist which have not heretofore been applied to oil refinery maintenance operations. They go under a variety of names such as the

Work Factor System, the M.T.A., or Segur System, Methods Time Measurement (M.T.M.), the B.M.T. System, and others. Essentially, these techniques consist of the breaking-down of the job, or of its grosser elements, into micro-elements which represent the fundamental motions of the human body and limbs. Any manipulative element used in the performance of a task is necessarily composed of these fundamental motions. The various systems claim to have obtained experimentally the normal times for the performance of such basic motions, and they provide appropriate allowance factors for the effects of such variables as weight, distance, speed and precision relevant to the required expenditure of effort.

It is neither the purpose nor is it within the scope of this work to analyze critically the various systems; any attempt to do so would be greatly hindered by the conspicuous lack of factual information which exists regarding some of the systems. However, it should be noted that valid criticisms have been raised of the sweeping claims made by their originators concerning accuracy, scope, and application of some of the systems.[10] On the other hand, the various systems have been applied in a number of cases with reputedly considerable success; such applications undoubtedly require suitably qualified and trained personnel to be employed in their planning and execution. It is claimed that under such conditions the work of constructing standard time values based on synthetic data will be less tedious and lengthy than when conventional time studies are used.

Limitation of Work Measurements.--As has been shown, the application of the principles of work study and measurement to any activity consists fundamentally of the selection of a method of its performance and the determination of a time to be allowed for its completion. It is axiomatic, therefore, that no time value obtained can be accurate unless the method used in practice is and remains the same as that on which the determination of that time was based. For optimum accuracy of work measurement, rigid specification of and adherence to the standard method of performing the task is necessary.

Since the conditions under which much maintenance work in a petroleum refinery is performed do not allow for such strict observance of a specified standard method, the resultant accuracy of individual time values is likely to be lower than in comparable highly-repetitive production work. However, over a period of time there will be a mutual compensation of any positive and negative errors which will result in a generally acceptable set of standards.

It is evident that there is a limit to the detail of investigation in work measurement of refinery maintenance beyond which it will not be economically desirable to proceed. Exactly where such a limit lies will depend on the nature and conditions of the work under consideration. What is likely, as well as desirable, is that as the form of maintenance in a particular refinery progresses from the break-down and repair type through scheduling and planning to full preventive maintenance, so will the techniques of work measurement advance from some kind of gross estimating to the more refined, effective and scientific methods described.

CHAPTER XI

WAGE INCENTIVES

So far as the author has been able to ascertain from the available literature, very few, if any, oil refineries have wage incentive plans in operation for their maintenance personnel. There appears to be no overwhelming reason for their absence unless it is the fact that direct wage incentive plans are not in general use in the processing divisions of petroleum refineries either, and hence managements may be reluctant to create a possible source of dissent within their organization. However, maintenance wage incentive plans are becoming widely accepted in other industries, and there have been many instances of success beyond all expectations when they have been properly and judiciously applied. This fact alone should be a sufficient reason for refinery managements to consider wage incentives as a tool for improving their own maintenance organization.

The two prerequisites of a successful wage incentive system are firstly, a systematic job evaluation of the many employee categories involved, and secondly, the establishment of fair standards for all tasks to be performed. The most important consideration in the installation of a wage incentive plan is that full agreement on and understanding of its purposes and operation must be reached between all groups concerned, namely employees, management, and unions. Furthermore, the scheme must be based from the beginning on a true and sound relationship between performance and payment.

The type of incentive scheme used will vary according to individual cases and tasks. While certain maintenance jobs are amenable to the establishment of standard times by the various methods of work measurement and hence to the setting of fair rates, there are some activities where it may not be practical to do so. In the former case, it will not be difficult to install wage incentives, although closer inspection and checking for quality of the work performed may be required than would be necessary in production operations. In the latter case, it will be necessary to use one of several other measures. For example, it is possible to standardize the amount of maintenance to unit operating time over a given period; such a ratio will remain approximately constant except, of course, at periods of major expansion or cut-backs in production and at the time of a scheduled shut-down. Wage incentives for maintenance workers can then be based on several factors which affect the given ratio, such as quality of product, departmental or unit cleanliness, accident rate, and break-downs of equipment.

Two examples are given below of the application of wage incentives to maintenance work:

In one Chicago company(11), financial incentives for maintenance and repair work have been in existence at its plants since 1928 and they now cover more than 2,000 maintenance workers, ranging from 30 to 600 men per plant. The average effectiveness of the maintenance labor force has risen from 65 per cent of normal to 20 per cent above measured normal performance. The scheme includes more than 90 per cent of the total maintenance force. The first step in its installation was to establish normal times for the operations involved. A total of 750 mechanics from twenty different crafts were studied over a period of months; sufficient studies were made of each job to allow the determining of normal times under average conditions. About 15 per cent of the maintenance activities were found to be of a repetitive nature; the remainder were classified under the following divisions for the purpose of establishing standard times:

(a) Initial trips. The time consumed in getting to and from the job and in traveling from one job to another are tabulated. All possible combinations for the plant have been studied and are listed.

(b) Material trips. Standards have been set up for their storage points to the job, with due allowance for weight of material, location of job, etc.

(c) Basic operations. These standards cover the work of removing and replacing parts, fittings and equipment, each varying with the relevant controlling factors such as weights, size and shape, ease of handling, and accessibility of work place. Data are recorded during progress of the job at sufficiently frequent intervals to insure credit to the worker for all elements of the job.

(d) Miscellaneous operations. This standard covers operations necessary for the completion of a maintenance job which it was found impractical to isolate on account of their complexity. Exhaustive studies of many complete repair and construction jobs led to the conclusion that there existed a definite relationship between the normal times taken for the principal operations and those for various smaller operations involved in the task, as for example receiving instructions from foremen, studying and planning the job, conversing with other workmen, instructing helpers, cleaning tools and personal hygiene, connecting extension lights and minor adjustments of tools. A table was set up to allow credit for such auxiliary operations on the basis of total normal work credit.

(e) In addition to the above basic divisions of standards, various allowances have been established. The process allowance deals with unbalance due to a number of workers being employed on the same job. A variable standards scale is used to control extreme variations of bonus earned from week to week. Condition factors allow for unusual working conditions such as extreme temperatures, location of work, and occupational hazards.

The chief requirement of the wage incentive system has been found to be efficient inspection and checking of the work performed; one checker to every eighteen maintenance men has been found to be sufficient. In order to keep the standards up-to-date and to establish new ones where necessary, the company employs one time-study man for every 250 men on incentives.

Another company [12] uses substantially the same method of setting its time standards as the above. However, it uses a modification of the split-premium plan in its wage incentive system in order to bring employees within the incentive range before they actually reach 100 per cent of standard performance. A process allowance is added to maintenance work performed at between 66 2/3 per cent and 133 1/3 per cent of standard. This allowance decreases from 33 1/3 per cent at the low point to zero at the high point, and it is applied after the job is completed. The company states that since the installation of the incentive system the effectiveness of utilization of the maintenance labor force has more than doubled the previous figure of about 60 per cent efficiency. It is conceded that the wage incentive plan for maintenance activities is not easy to operate and that a great deal of time is required for its administration. However, the effort expended has been found well worth while both financially and from the point of view of general satisfaction of management, supervision, and labor alike.

Various bases for maintenance incentives have been used in different types of industries, but the only generally satisfactory plans are those based on the ratio of actual time to standard time required for a task. In an oil refinery maintenance department, the latter is the only sufficiently flexible basis to allow for the necessary variations in assignment of work and craftsmen. Although in the limiting case, it requires standards to be set for each job and reports made of the actual time taken, in practice a great deal of simplification is feasible and much of the work can be handled on a group incentive basis. The character of refinery maintenance work is such that it is particularly important to achieve reasonable standardization of methods and procedures before attempting to introduce wage incentive schemes. To this end, consistent and efficient management is a prime requisite.

The incentive idea in maintenance should be promoted as a recognition by the management of the importance of good maintenance and as encouragement to cooperation, attentiveness, and careful workmanship. It must never be used to stimulate speed, and any signs of deteriorating quality of work must be checked immediately.

CHAPTER XII

PREVENTIVE MAINTENANCE IN PETROLEUM REFINING

The ideal of preventive maintenance in oil refining is to forestall any breakdown of equipment by proper operation, upkeep, modification and replacement. It is obvious that the maintenance force is not the sole governing factor in the establishment and operation of a successful preventive maintenance program. In fact, the efforts and cooperation of practically all line and staff groups in the refinery are required to attain success and therefore the control of preventive maintenance must be a function of refinery management.

In the following pages, some of the activities included in preventive maintenance are described. It is not possible to cover completely all the aspects of the subject. Let it be remembered, however, that preventive maintenance has been described as a "philosophy and approach" to the problems of maintenance rather than any one specific technique in their solution. The key to success in its practical application lies in the manner and method by which such a way of thinking will manifest itself in management and labor, engineer and craftsman, accountant and stores-clerk.

The activities of preventive maintenance are widespread and numerous. All of the departments, staff groups, and employees of the refinery contribute in some measure to its successful operation. The industrial engineer plays the major part in its control and execution, but probably the most important of his functions in the preventive maintenance program is the constant study of all records and reports concerning its cost and performance. It is his objective to investigate its operation continuously from every possible angle so as to establish possible future improvements from historical facts and new technical developments. He will act as an advisor to management on all phases of the program thus assuming a significant role in the formulation of refinery policy.

Refinery Maintenance Manual.--As the first step in installing a complete preventive maintenance program in an oil refinery, it is highly recommended that consideration be given to the compilation of an extensive plant manual. In most refineries the large quantity of information relevant to plant engineering activities already exists but it is usually widely scattered in files, blue-prints, catalogs, contracts and correspondence. The function of such a manual would be:

(1) To satisfy the continuous need of maintenance and operating executives for a quick and reliable source of information on all physical details of properties, buildings, plant units and equipment;

(2) To provide a comprehensive and continuous inventory of equipment which will serve as a basis for preventive maintenance records;

(3) To help in the training of new maintenance employees;

(4) To specify the standard methods and procedures for servicing and maintaining the physical assets of the refinery.

The work of compilation will consist of the collection and search of all existing sources of information, the inspection of refinery units and installations to obtain a complete description and inventory, and the contacting of manufacturers of equipment in order to ascertain detailed procedures for the best operation and maintenance of their products.

When all the necessary information has been gathered together, the most useful and intelligible layout of the manual must be chosen. A suggested form of publication would contain three major sections: the first dealing with general information about the maintenance organization and system; the second, listing all equipment, plant and buildings showing specifications, design data and dimensions complete with plans, charts and diagrams; and the last section should give all the relevant facts pertaining to correct operating and maintenance procedures.[13] It is necessary that a large amount of detail be provided in such a manual in order to cover fully the requirements of all personnel who will be using it. This does not mean that all maintenance employees need be issued with the complete publication, although most supervisors and staff engineers will require a copy of the whole manual.

It is suggested that the general information section should include full information on such topics as the organizational structure of the department and a definition of the authority and responsibility of all levels of maintenance personnel. The cost accounting system in use and the maintenance work order scheme should be adequately described. It is often necessary to have information on legal and statutory requirements pertaining to safety and health, or local, state and federal regulations concerning land, buildings, structures, waste disposal, and other similar ordinances which have to be complied with in industrial operations.

The section dealing with equipment should include details of plant layout, equipment location, and floor areas, all complete with the relevant drawings and plans. Such information is indispensable to good planning of process modifications and refinery maintenance programs. Plans should be provided showing all heating and lighting installations and distribution equipment, also charts of floor loadings, internal and external piping, and fire protection facilities. Details of built-in materials handling equipment and permanent emergency medical supplies should be given. As regards actual items of equipment, manufacturers' name, design particulars, serial numbers, specifications and ratingsshould all be listed. Where necessary, flow-sheets and wiring diagrams should supplement engineering drawings of all equipment.

The section on procedures should give a brief description of the equipment, its nature and function and materials of construction. Detailed instructions regarding the proper operation, inspection and the servicing of all equipment, buildings and grounds should be given.

Naturally, adequate indexing and cross-referencing should be a part of the manual. It may be necessary to review, improve, and enlarge such a manual on a continuous basis to keep it up to date.

Inspection and Records.--The cornerstone of preventive maintenance is the periodic inspection of all processing equipment. The optimum frequency of inspection will vary with the type and service of equipment, but it is obvious that it should always be kept to a minimum consistent with the aims of the program. The initial frequency of inspection will have to be determined by judgment based on past experience and on instructions issued by the manufacturers of the equipment. Inspection and maintenance records will show when frequency should be changed. In most cases, optimum inspection frequency will have to be synchronized with the requisite periods of accessibility of equipment. It is axiomatic that the inspection itself should be performed by highly experienced personnel who have been trained in the proper method of inspecting the equipment allotted to them.

An equally significant requirement of successful maintenance is the keeping and analyzing of records of all information uncovered by inspections. This system of records forms the basis for scheduling necessary repairs of equipment and it must therefore be flexible and all-inclusive. Adequate continuous records must include details of work performed and inspections carried out. If an inspection reveals equipment to be in a satisfactory condition, only the date of inspection need be noted. If maintenance work is required on the equipment, the inspector must note its details and relay such information to the proper supervisory authority for the issue of the required maintenance work order. As has been stated previously, much of the work of inspection and keeping of records should be handled under the auspices of the industrial engineering department.

Design, Layout, and Tooling for Maintenance.--Refinery preventive maintenance begins in fact with the design of the plant. It is here that much can be done to simplify the continuous work of unit maintenance by providing for better planning, handling, and working conditions. If the design is satisfactory from the maintenance point of view, the down-time of plant is reduced by minimizing the time required for specific maintenance tasks.

Firstly, all equipment on the unit must be fully accessible so that men and materials can move in and out of the unit with ease. All equipment subject to overhaul or replacement must have a ready means of approach and sufficient space for manoeuvre necessary for such work. Enough room must be provided for the movement of mobile equipment such as cranes, trucks and fork-lifts.

Process units are often crammed into small areas. While certain savings are thus achieved, very often these have been far outweighed by increased costs of maintenance resulting from lack of space. The servicing of pumps, the removal for cleaning of heat-exchanger tube bundles, the positioning of man-hole covers, all these are matters for consideration while the unit is still in the drawing-board stage. Similarly, built-in installations which facilitate the maintenance of the unit, both routine and shut-down, are basic design problems. They should cover such fixtures as proper width of stairways, provision of platforms, permanent scaffolding, gantries, monorail beams, and bridge cranes.

The designer must make utmost use of the latest available instruments which will facilitate preventive maintenance by disclosing and interpreting faulty conditions. Spare items of equipment must be installed in order that it may be possible to carry out periodic inspections of certain critical equipment with a view to avoiding major repairs or emergency shut-downs.

It is necessary that each piece of equipment and its arrangement in the unit should serve two complementary purposes: the requirements of efficient operation and those for convenient maintenance. It is the designer's duty to reconcile low initial costs with low operating and servicing costs.(14)

The location and layout of most refinery maintenance shops leave a great deal to be desired. Craft shops and their stores facilities are usually scattered about the plant in a number of small buildings and sites. The tooling of men and equipment is bad, handling facilities and hand-tools are outmoded and old, worn out machine tools are made to turn out inaccurate work requiring much unnecessary time for completion. It is seldom that any one craft, working alone, can complete a maintenance job. Usually, a number of them have to perform their respective duties on a piece of equipment; therefore, with scattered craft-shops and stores, the amount of handling and rehandling will be unnecessarily excessive. The principal field for improvement is in the centralization of maintenance facilities; all craft-shops, offices for field crafts, stores, cleaning facilities, and garages should be brought together into a given area, even into one central building where possible. Such centralization will reduce and simplify handling, improve supervision, systematize the flow and control of work through the machine shops and give greater flexibility during peak loads. Furthermore, certain facilities common to all crafts will no longer have to be duplicated and greater coordination as well as closer cooperation within the maintenance department will result.

The craft-shops must be properly tooled for their tasks. Good machinery, good machine and hand tools, bring about efficient utilization of the maintenance workers' efforts. Costs of maintaining the department's own equipment must also be kept to a minimum. Good machine shop facilities are essential especially during unit shut-downs when unpredictable jobs have to be performed at highest speed and quality.

An oil refinery needs proper materials handling and transportation equipment. Jib-cranes, hoists, fork-lifts, various trucks and trailers are all great savers of time and effort, and they should be used wherever possible. Good straight roads are essential prerequisites to fully effective utilization of all mobile equipment since they reduce the internal distances within a refinery and prevent costly delays, especially at times of bad weather. The use of short-wave radio communications generally is to be recommended, in particular for quick and efficient maintenance operation during unit shut-downs. In the latter case, the use of mobile stores and offices in maintenance work has also been found to be highly successful.

Corrosion, Painting and Chemical Cleaning Programs.--A large proportion of the work in a modern oil refinery involves the detrimentary effects of corrosion and erosion of equipment. The loss or failure of metal surfaces in vessels, pipes, pumps, furnaces and heat transfer equipment present a multitude of problems which require the continuous application of specialized metallurgical knowledge. Many refineries recognize the need for employing highly qualified specialists in the maintenance departments to perform such work.

It is desirable that continuous corrosion records be kept, which should be based on frequent periodic field inspections and on data obtained during shut-downs. So as to facilitate ready identification of the types of materials of construction in use at any particular unit or equipment, a standard color scheme should be used on the records to denote various corrosion-proof materials. [15]

One of the measures of counteracting the effects of external corrosion of equipment is the protective painting of exposed surfaces. Refinery process and auxiliary equipment is often exposed to deleterious industrial atmospheres as well as to severe and varying conditions of the weather. The losses resulting from painting neglect are often obscured by other factors of operation and maintenance, and they may not be recognized for their true worth. In practice, it may be economically advantageous, depending on the size and scope of the refinery, to appoint a well qualified engineer to handle all technical work in connection with plant painting procedures and practices. Such a position should be a staff function within the maintenance department.[16]

The economic level of painting maintenance will vary from one refinery to another and from one type of equipment to another, but in all cases it is a sufficiently important problem to merit close attention by refinery management and technical departments. Paints and coatings have to be scientifically formulated and selected, usually with the aid of outside paint manufacturing chemists and engineers, so as to provide the most economical protective device to a wide variety of specific refinery conditions.

The execution of a painting program is a function of the maintenance department and must be coordinated with its other activities within the whole plant. The program is dependent on periodic inspections of equipment. Most of the work connected with painting of equipment will have to be carried out during unit shut-downs, since painting procedures carry excessive safety hazards when performed on operating equipment. Good scheduling of such work will therefore be necessary.

Apart from protective painting and coating programs, also important are the various color schemes used to attain specific objectives in an oil refinery. Such color schemes are not standardized throughout the industry but the trend is in that direction. Major equipment such as vessels, tanks, columns and reactors are usually painted in a combination of aluminum and black or gray paints, while machinery such as compressors, engines and motors are painted dark green. Machines in the machine shops are painted in contrasting colors to accentuate and differentiate between various critical or hazardous parts. All fire-fighting equipment is painted in brilliantly distinctive colors, usually bright red. Foam lines, steam and water pipes are all painted in different colors to distinguish and identify them easily. Pipe lines for various products are provided with distinguishing color bands to facilitate ease of recognition and location and to provide warning of possible hazards.

Most refinery equipment, such as fractionating towers, reaction vessels, heat-exchanger and furnace tubes, pumps, and steam-boilers, has to be cleaned periodically to remove surface scales, deposits and impurities which reduce its operating efficiency. The scales and deposits usually found in refinery equipment consist of relatively simple inorganic compounds, highly complex organic substances and mixtures of the two. It has been usual in the past to remove most of them by mechanical means such as reaming and sand-blasting; these operations require the by-passing or shutting down and dismantling of equipment, and they are in themselves time and labor consuming. Chemical cleaning[17] involves the contacting of equipment with a suitable solvent or acid under conditions which will bring about the greatest effectiveness of scale removal. The selection of the proper solvent will depend on the physical and chemical characteristics of the scale or deposit concerned. Such chemical cleaning is more economical if properly applied than any mechanical methods which generally require a great deal of manual labor. However, it will not be possible to use chemical cleaning in every case, depending largely on scale composition and conditions. Procedures have been developed which give solvent concentrations, temperatures and time intervals to be used on a variety of types of metal under given scaling conditions. Certain inhibitors are in use which permit rapid solution of deposits while protecting the base metal from attack by the solvent.

Chemical cleaning is more effective and economical in the long run if it is practiced at reasonably frequent intervals, since the complexity of deposits increases with scale thickness while the solubility power of solvents decreases. Thus the decision whether and when to use chemical cleaning methods becomes one of engineering economics in the light of the overall preventive maintenance program.

When spares or by-pass facilities are provided, it is possible to clean certain equipment _in situ_. Furthermore, in limited cases, such as the water-side of heat transfer equipment, it is practicable to clean while the equipment is in normal operation. The use of mobile cleaning facilities mounted on trucks is indicated in such cases.

Work Orders and Accounting Systems.--Successful preventive maintenance is founded to a large extent on historical records of work done. Such records are the basis of maintenance labor scheduling, cost control and of any review of procedures. Hence, the fundamental rule should be that no maintenance work must be performed without a written order.

There will be exceptions to this rule in the case of emergencies when time is of the essence and normal procedures may be circumvented, but even in such contingencies a work order should be issued as soon as possible afterwards.(18)

The work orders in use in refinery maintenance vary according to requirements and maintenance practices. Most of them include brief work instructions on how the job should be performed, more elaborate guidance being given in standard practice manuals. All the necessary data regarding the equipment and its location must be given, and material requisitions must be made out to match the requirements somewhere along the line between the issuing authority and the maintenance worker to whom the task has been assigned.

In the type of maintenance department organization suggested, the industrial engineering section would be responsible for clearing all maintenance work orders. It is preferable to place a limit on the expenditure which can be authorized by employees below the higher executive level, in order that close control over maintenance costs can be achieved. Also, work orders should be clearly separated into those covering regularly recurring preventive maintenance work and those for non-repetitive activities involving specific repair or construction. The former should usually be issued in the form of blanket orders covering continuous maintenance activities on a periodic basis; examples of such work orders would be those involving inspection, cleaning, overhauling and checking of various types of refinery equipment such as motors, instruments, valves, compressors, and other machinery, the servicing of utilities equipment such as heating, lighting and ventilating systems, the execution of painting programs and similar activities. Special instructions for the methods to be used in all preventive maintenance work are a necessity.

Non-repetitive work of repair and construction must be handled on an individual day-to-day basis, though the clerical and work order procedures will be the same.

Several copies of work orders are made out, varying usually from three to five, according to plant requirements. As in most other administrative operations, there is scope for work simplification and method improvement of the forms used and of their routing. It is desirable that the number of people who should be given copies of maintenance work orders, either for perusal or for filing, should be kept to a minimum consistent with the successful operation of the department.

Turnaround and shut-down scheduling requires a high degree of planning, an integral part of which is the issue of relevant work orders and material requisitions. Co-operation between planning, estimating, stores control, and purchasing departments must be extensive in order that all necessary work possible can be performed before the shut-down is ordered. Much of the actual maintenance work involved will be predictable;as such, it will be subject to such anticipatory treatment, while the remainder will be dealt with as the need for it arises or becomes evident. To this end, it is advisable to appoint a number of job coordinators from the ranks of the craft foremen, with responsibility over certain integrated multi-craft operations.

One of the objectives of a good maintenance work order system is the segregation of maintenance costs by various units or products, and the resultant basis for future budgetary estimating and control of all refinery maintenance work. Like all other refinery activities, maintenance must be subject to close cost accounting control, in order that extreme fluctuations may be detected, analyzed, and corrected. It is not usual for maintenance costs to be allocated to each plant on a labor-materials utilization basis, while construction work is usually booked separately.. The latter will always be a matter for top management decision, which alone can coordinate the construction projects of the company as a whole to avoid duplication and uneconomical purchase. The cost accounting procedures for maintenance must provide management with adequate information to be considered in deciding the overall financial and operating policies of the company.

CHAPTER XIII

CONCLUSIONS AND RECOMMENDATIONS

Maintenance is an engineering service by which the physical assets of an industrial undertaking are sustained for optimum production. Its long-term purpose is the safe-guarding of an investment, hence maintenance work is a continuous function, not an intermittent one.

The general classification of maintenance involves four types: breakdown, scheduled, planned, and preventive maintenance. Breakdown maintenance is primitive and solely curative; it does not attempt to forestall the need for repair or replacement of equipment by adequate upkeep and servicing. It involves the acceptance of low equipment efficiency resulting in low productivity. Scheduled maintenance is the first step both in time and principle towards preventive maintenance. It will be most useful in achieving more efficient utilization of maintenance facilities by disclosing when and where maintenance work is to be performed. The scheduling of maintenance can often be integrated with regular periods of plant idleness if the latter are readily determinable. Planned maintenance carries scheduling still further by endeavouring to specify also what work is required and by whom it is to be performed. This form of maintenance will be justified economically in continuous process industries operating under high plant throughput rates. The analysis of maintenance performance and its comparison with advance estimates should reveal possible improvements and cost reductions. Preventive maintenance comprises a philosophy and approach to maintenance, in which detailed inspection and study of existing equipment and methods will result in effective economies through improvement in design, alteration in the frequencies of scheduled work, and the development of new maintenance techniques, methods and materials. Preventive maintenance is the ultimate development of scheduled and planned maintenance, and it places an emphasis on upkeep, modification and replacement of equipment to the exclusion of mere repairs. It requires a high degree of cooperation between all departments and at all levels.

A published survey of existing maintenance practices revealed that one out of every three plant employees in the oil refining industry was engaged in maintenance work. This ratio is between three and twelve times as high as in other types of industry; this fact is thought to be primarily due to the low operating labor requirements of refinery process departments resulting from a high degree of automatic control. Furthermore, the high capital investment necessary in continuous process industries like oil refining makes adequate maintenance of operating equipment economically essential.

In order to measure the effectiveness of a maintenance department it is necessary to establish certain performance criteria; these are the size of the maintenance task, the size of the maintenance labor force and its efficiency, the quality of maintenance obtained, and the intensity of maintenance desirable.

The nature and economics of the petroleum refining industry demand that forced shut-downs of processing units be prevented at all cost and scheduled shut-down time be kept to a minimum consistent with the efficient performance of all necessary work. In the light of these requirements, it is essential that as much of the work of maintenance as is possible should be performed while plant units are in operation, so that shut-down maintenance may be limited to statutory inspection, replacement and installation of equipment. A high degree of coordination and planning are necessary prerequisites to success.

Good organization of the maintenance department is the foundation of efficient operation. The essential requirement for the establishment of an efficient maintenance organization is the provision of means which will ensure that the maintenance contribution to operating policy is made and considered before that policy has taken shape as a final production program. Decisions regarding the organization of maintenance activities are matters for top-level management consideration and approval; hence, management must be informed of the true significance of effective maintenance.

From the information available, it appears that the maintenance organization in an oil refinery often occupies a subordinate position to the processing department. Such a state of affairs is highly undesirable and should be remedied. In connection with this principle, the status of the Chief Engineer and of his staff should be raised to the level of their respective counterparts in the processing department. The most common type of refinery maintenance organization has been found to be the line and staff arrangement. This has its proven advantages and disadvantages; as regards maintenance, the rigidity and complexity of this type of organization, with its frequent separation of authority from responsibility, may result in confusion and inefficiency. A modified line and staff maintenance organization is recommended which should include an industrial engineering staff division within the maintenance department. The Chief Industrial Engineer should be responsible directly to the Superintendent of Engineering, and he should be provided with adequate staff to fulfill all the functions connected with the planning and scheduling of maintenance activities; all work orders should therefore be routed through this division for purposes of analysis, recording, and control. The activities of the industrial engineering section would also include responsibility for all inspections, methods analysis, work measurement, wage incentives, maintenance reviews and reports, cost control and outside contracts.

Work study and measurement is to be recommended as one of the most useful tools in the application of industrial engineering to oil refinery maintenance. It is considered to be the best means of determining and controlling the effectiveness of maintenance, an indispensable aid to planning, scheduling and preventive maintenance, and a necessary foundation for wage incentives. Of the several methods described, the most suitable is thought to be that based on Elemental Standard Data. This recognizes the fact that although most maintenance activities may be non-repetitive, common basic elements will be found in a variety of specific tasks. Standard times are determined for the relatively small number of these basic elements, and suitable combinations of such values will be used in measuring the effectiveness of past and present maintenance activities and in planning for the future.

Wage incentives are recommended as motivating agents for better performance of maintenance after proper standards have been established. There is no single outstanding plan that can be applied to all industrial plants or even to all oil refineries; individual companies must match specific conditions with particular plans or suitable modifications. Group incentive plans are considered to be better than none, but where possible, individual incentives should be used. Any wage incentive plan must be based on a true relationship between performance and output, and its purpose must be understood and agreed upon by all employees concerned.

Preventive maintenance is singled out as the most important activity in an oil refinery. Examples are given to illustrate the underlying philosophy of this function. It is conceded that no preventive maintenance program can be successful without the cooperation and active effort of all refinery personnel. It will be the function of the industrial engineer to coordinate, investigate and control the practice of preventive maintenance.

It is concluded that this paper has covered only a limited number of the potential improvements and savings made possible by the application of the principles of industrial engineering in an oil refinery. However, it appears that the numerous and complex activities of refinery maintenance offer a most rewarding and significant field of endeavour to such efforts.

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