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Case study data on productivity and factory performance...

DIESEL ENGINES

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By the

UNITED STATES DEPARTMENT OF LABOR
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The collection of the data presented in this report has been made possible not only by the cooperation of manufacturers in the United States but also by the advice and assistance of many individuals in the industry, in trade associations, and in labor unions. The men who have contributed their time and technical experience deserve particular appreciation for having made available data on man-hours, output, factory operations, production methods, managerial practices, and machinery -- data which represent the results of many years of research and observation.

The term productivity is defined as the ratio of a given quantity of production (output) to one or more of the various "input" factors that are required for such production. As used in this report the input factor concerned is labor, the most important and universal factor and the one that provides the most generally useful common denominator for comparing the efficiency of productive methods and techniques in different units of an industry or between the same industries in different geographic locations.

Full translation and reproduction rights are hereby granted to those groups desiring to translate this report into their own language for distribution to members of their industry and labor groups. Similar reports covering other industries and products are currently being prepared and will be released as soon as they are completed.

Reports in this series published to date and available are listed on the inside back cover of this publication.

The material in this report constitutes one aspect of the variety of services offered in the Technical Assistance Program of the Foreign Operations Administration. The Factory Performance Reports are prepared and published as a result of a request from the European Productivity Agency, under a project designated as EPA-94.

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Productivity and Factory Performance

DIESEL ENGINES

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FOREWORD

This report is primarily for the use of European production managers, superintendents, and methods engineers who are concerned with productivity problems. A study of the technical portions of this report should make it possible for these plant officials to compare manufacturing operations in their plants with the operations in one or more of the plants surveyed in this report. In addition, the general discussion of productivity and the presentation of man-hour requirements for certain diesel engines and their parts undoubtedly will be of interest to government, labor, and trade association officials in Europe.

The products covered in this report were selected on the basis of requests made by European industry groups and were transmitted to the Bureau of Labor Statistics by the Foreign Operations Administration. The plants selected for these case studies are intended to provide examples of the manufacture of these products in American plants but are not intended to represent a statistical sample of the American industry. In selecting plants for study the following criteria were considered: That the product made by the plant be similar to the product specified in the original European request, that the plant selected maintain records in sufficient detail to provide data, and that the cost of collecting the data be minimized.

Description of Report

This report is divided into three chapters. Chapter I is directed primarily to the reader who is interested in the less detailed aspects of productivity in the industry. Chapter II contains detailed case studies of each plant and will be of value to the plant superintendent or the production engineer. Chapter III contains a brief discussion of workers' earnings, the benefits to the worker which result from increased productivity, and unionization where applicable. The appendixes contain case studies of labor adjustments to technological change and a copy of the questionnaire used.

The data used for the case studies were obtained from plant records and from plant officials by representatives of the Bureau of Labor Statistics who visited each plant for the express purpose of making this study. The amount of detail shown in the case studies varies because some information was not obtainable from all plants, and some information was not usable in the form provided. Supplementary information was obtained from other Government agencies and from trade associations.

How To Use This Report

In using this report the following procedure is suggested to plant officials:

1. The plant official should refer to the tables in chapter I and to the case studies in chapter II, to identify the United States plants in this

study with employment, production volume, and integration most nearly approaching the situation of his plant.

2. Appendix II contains a reproduction of the questionnaire used to obtain the information from the United States plants in this study. If the European production official will use this questionnaire to calculate labor requirements in his plant, he will be able to compare performance in his plant with that of the plants discussed in this report, and to isolate areas in which his plant's performance is either relatively good or relatively poor.

3. The European plant official is now ready to compare the machinery and methods described in the report with those existing in his own plant, for those problem areas he has isolated. At this point the report does not give him the precise engineering information needed but it does suggest the approximate requirements in terms of volume, methods, machinery, and manpower necessary to achieve the productivity levels illustrated in the individual case studies.

4. For serious problem areas uncovered in this manner, the expert assistance of engineers, either those within his plant or outside consultants, will be needed. Intensive study must generally be made to correct the conditions found by comparison because these reports cannot replace on-the-spot engineers or other specialists, in the analysis of specific situations.

Case Study Data on
Productivity and Factory Performance

DIESEL ENGINES 1/

CHAPTER I: GENERAL REPORT

Highlights

Diesel engines are manufactured in the United States by a large number of companies who generally specialize in the production of particular types of diesel engines. For example, manufacturers of industrial or automotive diesel engines usually do not manufacture large stationary and marine diesel engines. However, any of these companies may build gasoline internal combustion engines and a variety of products that may or may not be related to the use of diesel engines.

There is a mixed pattern of integration among the manufacturers in this industry. All manufacturers buy some of the parts used in the engines they produce. Castings and forgings are usually purchased and then machined to final form, whereas many other parts, particularly such items as fasteners, hardware, and accessory items, are bought from suppliers completely finished and ready for direct installation into the engines. Within broad limits, manufacturers are interested in making only those items that they cannot purchase at a lower cost.

Diesel engine manufacture can be termed a semimass-production industry. This is true even for automotive diesel engines which are produced in the largest number. Production of the most popular automotive diesel engines in a plant is sporadic rather than in long continuous runs. Plants nearly always have excess production capacity, but are reluctant to produce engines for inventory owing to the numerous variations in accessories that are necessary to meet customers' needs. Some plants maintain a particular production line with accompanying machines and equipment which has been laid out to produce a frequently ordered engine, even though this technique occasionally results in some idleness of the line. When the line is left intact, other lines are set up to produce different engines. Plants have found this technique to be less expensive than to change the line to adapt it to other engines.

Comparisons between total man-hours required to manufacture and assemble diesel engines of varying size and horsepower are meaningless unless many different factors are considered. These include the number of parts in an engine and whether they are purchased or made in the plant; accessory equipment installed; characteristics of major parts such as cylinder block-crankcase

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1/ Prepared by Vincent A. Arkell and Thomas G. Gentel with additional work done on sections of report by George A. Hermanson, Stanley F. Miller, Maurice E. Moore, and Gabriel G. Rudney of the Bureau's Division of Productivity and Technological Developments.

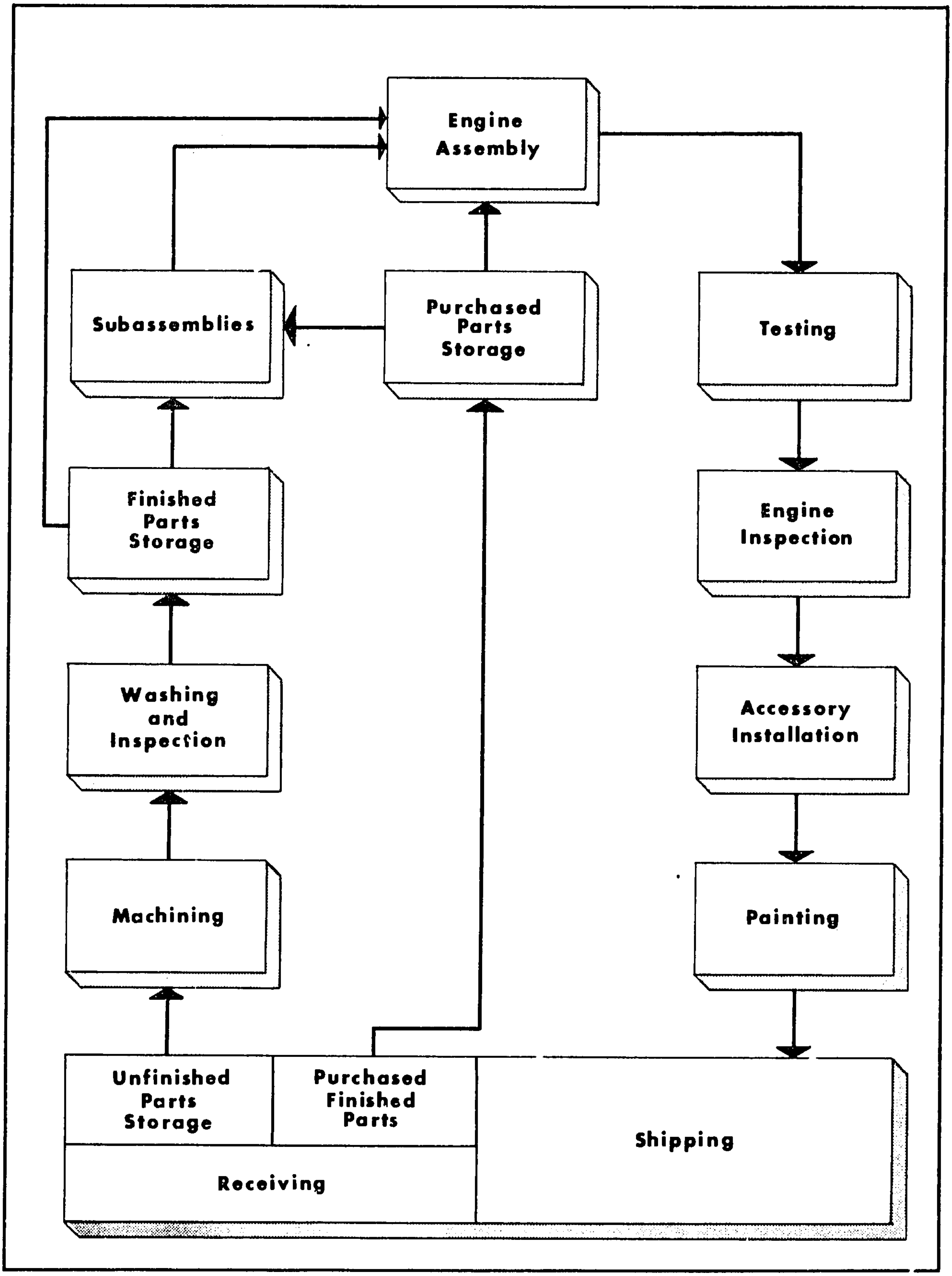

Figure 1. Work flow in manufacture of diesel engines.

and cylinder head(s); and type of construction such as wet or dry cylinder sleeves, overhead camshaft, and dual valves. A more meaningful comparison can be made between similar engine parts made in the plants, similar machining operations or engine assembly operations.

For this study, three engine parts were chosen to illustrate manufacturing methods and the required man-hours by operation. The parts studied are the cylinder block-crankcase (termed the cylinder block for convenience), cylinder head, and connecting rod. In addition, the time for individual operations required in assembling the engine is reported for those plants that supplied such data (see tables accompanying the individual case studies).

Five plants supplied man-hour data for a 6-cylinder industrial-type diesel engine. Two of these plants (A and B) also supplied data for a 4-cylinder engine, and a third plant (E) also reported on a 6-cylinder automotive-type diesel engine.

Direct man-hours are more meaningful than total man-hours which include indirect man-hours. Direct man-hours can be allocated to a specific operation or to the manufacture of a specific product, whereas indirect man-hours are usually allocated on a fixed ratio to the direct man-hour requirements. This ratio is determined by the plantwide ratio of indirect to direct man-hours. A summary of direct man-hour data supplied by the plants is shown in table 1. A typical sequence of manufacturing operations is shown in figure 1.

Table 1. Direct man-hours required for manufacturing specified parts and for the assembly of the reported 6-cylinder diesel engine, 5 selected plants, U. S. A., selected periods, 1953

Item 1/	Direct man-hours				
	Plant				
	A	B	C	D	E
Manufacture of specified parts					
Cylinder block-crankcase . .	4.47	11.84	4.62	11.50	14.50
Cylinder head (each head). .	1.49	2.74	5.84	8.63	2.60
Connecting rod	.60	1.10	.58	(2/)	.70
Engine assembly	5.17	10.60	3.41	(2/)	(2/)
Total direct man-hours for all manufacturing and assembling operations	50	100	80	200	(2/)

1/ Engine type and horsepower of reported 6-cylinder diesel engines, by plant:

Plant A - Industrial, 80 hp., 1 cylinder head.
Plant B - Industrial, 120 hp., 2 cylinder heads.
Plant C - Industrial, 215 hp., 2 cylinder heads.
Plant D - Industrial, 150 hp., 1 cylinder head.
Plant E - Automotive, 200 hp., 3 cylinder heads.

2/ Not reported.

GENERAL PLANT INFORMATION

Three of the plants in this study are housed in a number of buildings, but 2 plants (B and D) are each housed in 1 large building. Most of the plants have expanded as production increased and new buildings are added when needed. Plants are usually located in areas where land cost is low to allow the plant to expand.

Most of the buildings used by the plants in this study are constructed of steel and concrete with brick walls. Buildings are usually one story in height for the main manufacturing areas. Most modern American factories are similarly constructed. It simplifies change in plant layout, allows the use of overhead cranes and forklift trucks for materials movement, and buildings can be readily enlarged. Another important factor is that the increasing weight of modern machine tools and machinery would make building costs prohibitive if they were not installed on the ground floor.

Employment ranged from 170 in plant D to 2,500 in plant E (table 2). Plants B and C each had about the same number of production workers which was more than half the number employed in plant E.

Table 2. Selected plant information, 5 diesel engine plants, U. S. A., selected period, 1953

Item	Plant				
	A	B	C	D	E
Employment - total	1,050	1,600	1,800	170	2,500
Production workers	600	1,100	1,000	153	2,100
Nonproduction workers . .	450	500	800	17	400
Volume of production					
Reported engines	500	58	2,500	738	(1/)
Total sales (millions) . .	(1/)	$ 29	$ 30	(1/)	$ 55

1/ Not reported.

Internal Combustion Engines

Diesel and gasoline engines are both internal combustion engines and each type has certain advantages and disadvantages. Everyone is familiar with the gasoline engine; they are used by the millions in the United States to power automobiles and trucks. In a gasoline engine power is developed by burning gasoline under controlled conditions. A mixture of gasoline and air is drawn through a carburetor, compressed in a cylinder and ignited by an electrical spark. The resulting combustion of the gasoline develops a high pressure that forms the power stroke in the combustion cycle. Pre-ignition pressures are limited - at present- to a ratio of about 9 to 1. High pressures mean a more efficient burning of the gasoline but higher pressures also cause pre-ignition or "knocking." This is prevented by raising the octane rating of the gasoline and putting additives or chemicals in it that will retard the combustion rate and prevent pre-ignition.

Diesel engines compress air in a ratio of about 15 to 1. This high pressure raises the temperature of the air in the cylinder to about 1,000° F. When maximum pressure has been reached, fuel oil is injected into the hot air, burned, and the increased pressure causes the power stroke of the combustion cycle. A true diesel engine has no electrical ignition system. The high pre-ignition pressure causes a more efficient utilization of the fuel which eliminates the possibility of "knocking," and the excess air present during combustion prevents the formation of carbon monoxide gas in the exhaust, hence diesel exhaust fumes are nontoxic.

Owing to the higher pressures developed, diesel engines are much more massive and heavier in their construction than gasoline engines or similar horsepower. This rugged construction gives them a longer service life with less maintenance. There are three important factors that have kept diesel engines from replacing gasoline engines for automobiles: (1) greater weight and size; (2) higher cost to build, e.g., the fuel injection system is built to tolerances of less than a hundred thousandth of an inch; and (3) difficulty in starting engines at temperatures less than 32° F.

However, for many applications their advantages outweigh their disadvantages. The fuel they burn is unexplosive, they are more efficient, exhaust fumes are nontoxic, maintenance is less, they develop higher torque, and can operate continuously for weeks or months.

Products and Volume of Production

Diesel engines are usually classified by the use for which they are intended. Major classifications are industrial, automotive, marine, and stationary. In this report plants A, B, C, and D reported data on the manufacture of industrial-type engines; plant E, reported on an automotive engine. Industrial-type diesel engines have a wide range of uses whenever a semiportable source of power is needed. They are designed to operate continuously at a relatively high speed--up to 2,000 r.p.m. For intermittent duty they can be operated at higher speeds and develop correspondingly higher horsepower.

Automotive diesel engines are usually lighter in weight and are designed for intermittent operation. More engines are produced for automotive applications than for any other classification. They are used in trucks, busses, tractors, and a wide variety of road-construction and earth-moving vehicles. A large proportion of automotive diesel engines are produced by the manufacturers of the automotive equipment.

Stationary-type diesel engines are large, slow-moving engines designed for such applications as driving generators where the ability to operate continuously for very long periods of time is of paramount importance. They are designed to develop power over a wide range by varying the size and number of cylinders. Small stationary-type engines may develop horsepower that is equivalent to that developed by industrial-type engines. Some of the largest stationary-type diesel engines develop as much as 10,000 horsepower, are 30 feet high, 50 feet long, and weight nearly a million pounds.

Marine diesel engines fall into two broad categories - small high-speed engines similar to industrial-type engines, and large slow moving engines similar to stationary-type diesel engines.

Many manufacturers produce a wide variety of diesel engines to meet their customers' specifications and uses, as well as gasoline-type internal combustion engines. Because of this variety, the number of engines made in a particular model is relatively few.

Manufacturers achieve operating and manufacturing economies by standardizing models or parts whenever practicable. For example, an engine model may be produced with either 4, 6, or 8 cylinders, all with the same bore and stroke. By thus increasing the number of interchangeable parts, these parts may be produced in larger quantities, reducing the variety of parts kept in inventory. For a listing of interchangeable parts between a 4- and 6-cylinder engine, see table 6, page

Production figures were supplied only by plant A, which reported that it produced 50,000 diesel and gas engines in 1953. Plant D was building one engine a day of the reported industrial type during the period for which it reported. This could be stepped up to 12 engines a day, on a 3-shift basis if necessary.

In chapter II the descriptions of the reporting plants show the typical wide variation that exists in the products produced by diesel engine manufacturers. Plant E reported that it made only diesel engines whereas in plant B, diesel engines production amounted to only 20 percent of total sales. Owing to their similarity, most manufacturers make both gasoline internal combustion engines and diesel engines. In addition, a manufacturer may make a number of products entirely unrelated to diesel engines.

Reported Products

Construction of a diesel engine requires hundreds or even thousands of parts, depending upon its size and the accessories ordered for it. Owing to the large number of parts made in a plant it was not considered practicable to record manufacturing operations for each one. Three major parts were selected for study - cylinder block crankcase, cylinder head, and connecting rod - plus the assembly operations. Detailed information relating to complete manufacturing operations, assembly operations, machinery used, and man-hours per operation is shown in the case studies in chapter II only for plants A, B, and C which supplied such data.

Man-hours required to manufacture the three parts selected for study and the assembly operations involved in manufacturing the reported 6-cylinder engine are shown in table 1. Despite dissimilarities in the types of engines produced, some of the plants reported very similar man-hour requirements for the reported parts.

OPERATING PRACTICES

Most diesel engine manufacturers purchase their castings and forgings. Production usually is not large enough to justify the installation of the special equipment needed to produce such items. Foundries and forge shops which supply the needs of many types of manufacturers including engine producers, can make these items when needed and at a lower cost. Patterns and dies are usually supplied by the engine manufacturer.

Jigs and fixtures are used in manufacturing whenever their use can be economically justified. Most manufacturers try to amortize their costs for this equipment over a period of 2 years. Selection of a longer period always involves the possiblity that the part or piece may no longer be available. Manufacturers want to repay the cost of building or buying special equipment, from resulting savings, as quickly as possible. This is also true for special purpose machinery or for combining several general purpose machines into one machine that will perform a number of operations simultaneously. The philosophy behind these types of purchases is described in the case study of plant A, under the heading "Productivity Factors."

Diesel engines and their major parts are quite heavy. Accordingly, plants use a wide range of materials-handling devices to reduce costs and save manpower. Forklift trucks, conveyors, cranes and hoists, and industrial-type trucks are some of the major types of equipment used. In connection with materials movement, plant layouts are constantly studied for more efficient utilization of men and machines.

A detailed description of materials-handling methods and equipment used in each plant is presented in chapter II.

Engineering and Research

All the plants in this study reported that they had personnel who devoted all their time to methods and time study, product design, and production engineering. The number of employees engaged in this work ranged from 7 in plant D to 129 in plant E, the smallest and largest plants studied, respectively, in terms of total employment. However, plant C which has approximately the same total number of employees as plant B, has nearly three times as many employed in engineering and research.

It should be noted that all employees in this department are not working solely on diesel engine problems. A few of the plants make a variety of other products some of which are custom made. Plants that try to standardize their products generally need fewer engineering personnel than plants that produce custom products.

Marketing

Market analysis or sales forecasting is important for those plants that produce engines for inventory or who try to anticipate demand by having component parts on hand, ready to be assembled into engines. Most diesel engines are made to conform to customer specifications. In an effort to provide quicker deliveries and to estimate demand for repair of replacement parts, manufacturers resort to market analysis to aid them in their forecasting. In some cases this is merely a historical review of sales with forecasts based on past performances. Other manufacturers, in addition, attempt to estimate future orders by making a study of general business conditions determining the needs of their principal customers and the industries they represent, and gauging the effect on sales and production of their own new developments as well as those of competitors and of other industries.

Two of the plants, (B and E), reported they had personnel engaged full time in market analysis. Plants A and D reported that they had personnel engaged in informal studies. Plant C did not report on this topic.

All five plants reported similar marketing systems for their products. Products are distributed through two principal channels - company-owned outlets and privately owned retail outlets. These outlets provide both sales and service for ultimate user of the engines. Company-owned outlets are usually few in number and are located in principal cities. They usually serve as a distribution center to supply the retail outlets that are privately owned. Prompt servicing of a product after it has been sold is important in order to retain the customer's good will. Diesel engines, particularly those used on road construction work, are subject to abuse and a small broken part, if not readily available, can cause the same delay as a major breakdown. Hence, every manufacturer endeavors to have retail outlets strategically located in as many cities as is economical.

In addition, plants may also sell their engines directly to large commercial users for installation in their own products, or to the United States Government which uses many diesel engines.

Manufacturing Costs

All five plants in this study reported on their manufacturing costs (table 3). Despite a wide divergence in purchasing patterns, there was a striking similarity in their reported costs for raw materials and labor. Costs for raw materials ranged from 60 to 68 percent of all manufacturing costs, and averaged 64 percent for the five plants. Labor costs ranged from 20 to 26 percent for four of the plants. The fifth plant classified labor costs with "other factory costs." If a reasonable allowance were made for "other factory costs," this plant would probably have similar labor costs. The greatest divergence in manufacturing costs was found in the item "other factory costs" because the items charged to this cost vary among plants.

Selling Costs

Four of the five plants reported their total selling costs together with a distribution of these costs. These costs are shown also in table 3. Selling costs in these four plants ranged from 2.5 to 3.3 percent of total sales. Although sales costs were substantially uniform, there was a wide divergence among plants in the distribution of selling costs. Salaries and commissions formed the largest expense or cost in the four plants. Advertising was a relatively minor cost when related to total sales, ranging from 0.4 to 1 percent.

Table 3. Manufacturing costs and sales costs for 5 diesel engine manufacturers, U. S. A., 1952

Item	Plant				
	A	B	C	D	E
Manufacturing costs:					
Materials	60	64	67	62	68
Labor	24	24	26	20	1/ 32
Other factory costs	16	12	7	18	
	100	100	100	100	100
Selling costs:					
Salaries and commissions. .	60	44	39	65	(2/)
Advertising	16	25	37	14	(2/)
Other	3/ 24	31	4/ 24	3/17	(2/)
	100	100	100	100	
Selling costs as percent of total sales	2.5	2.5	3.3	3.0	(2/)

1/ Includes all other costs.
2/ Not reported.
3/ Selling costs of company outlets.
4/ Sales promotion, conferences, and training.

MANUFACTURING PRACTICES

Manufacturing methods vary among the reporting plants but, in general, the volume of production of any one diesel engine model is not sufficient to permit all machining operations in the plants to be performed by the mass production methods used in producing automobile engines. In automobile engine plants, huge transfer machines perform in sequence all the manufacturing operations needed to produce a particular part. Cylinder blocks for instance, are transferred automatically from one machining operation to the next until the finished block leaves the machine. Transfer machines such as these cannot be used economically in manufacturing diesel engines. These machines would be idle most of the time because output of diesel engines is limited. In addition, the man-hours required to change the setup to make another engine model would make the cost prohibitive. Diesel engine plants have achieved efficient production methods by other means. Usually this has been done by assembling standard machine tool components so that they can perform machining operations in sequence. Although this method is not as fully automatic as a transfer machine, the lower cost of the original equipment and its greater flexibility result in savings as compared with the use of general purpose machine tools.

Assembly setups such as those mentioned above can be used for parts produced in relatively large quantities. Connecting rods and connecting rod bearing caps may be used in several different engines. Thus, they may be produced in long runs in some plants. Jigs and fixtures, special machines, and conveyor systems between machines and operations are also used. Operating economies can be achieved so that the manufacturing line for these parts is often left intact between orders or production runs.

Semiproduction lines are often set up to produce components that have many similar machining operations. For instance, cylinder blocks used in making 4- and 6-cylinder engines for related models may be subjected to many similar machining operations. By using jigs and fixtures that allow for interchangeability between the two cylinder blocks, one setup can be used to machine both cylinder block sizes.

Similar operating economies can be achieved in assembling subassemblies and in final assembly operations for the entire engine.

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CHAPTER II: CASE STUDIES

In 4 of the 5 case studies presented in this chapter, labor time is given in terms of man-hours per 100 engines or parts. Because many of the manufacturing operations are performed in only a small fraction of a man-hour, a unit of 100 engines or parts was used to aid in visualizing the labor time required. Plant A reported in man-minutes per engine, part, or operation. This must be borne in mind when comparing the tables in the plant A case study with those for the other plants. In table 1, however, data on manufacture of specified parts and for assembly of the reported engine in plant A were converted to the same measure used for the other plants.

Comparisons among the plants for labor time expended for manufacturing or assembling operations should be made with a great deal of caution. This is particularly true for the overall labor time expended to produce the engine. Such factors as number and variety of parts purchased in finished form, complexity of engine, comparative horsepower rating, methods of manufacturing and assembly, all have an effect on total labor time levels. Therefore, high labor time, per se, does not necessarily indicate inefficient manufacturing methods or low productivity.

Manufacturers usually seek the lowest cost for the items manufactured. Sometimes this may not be true because there are numerous intangible factors to be considered in arriving at the actual cost of a product. For instance, a plant may decide to manufacture items it could purchase at a lower cost in order to keep intact an experienced work force. Or, it may decide to purchase items when its requirements would be too small to warrant the purchase of machinery that might be idle most of the time.

Each plant must make these decisions for every item they manufacture or use. Hence, overall labor time for production of a complete engine is a guide to but not an absolute measure of efficiency. More valid comparisons can be made between the manufacture of individual items such as the connecting rod or the cylinder head. Individual operations that are similar in nature permit even more valid comparisons. It is in the latter area that the labor time data in these reports can be most useful.

Data for these reports were collected by representatives of the Bureau of Labor Statistics who visited each plant. A copy of the questionnaire used is reproduced in appendix III.

For various reasons some of the plants failed to furnish information for all the questions. In order to protect the identity of each plant, some information in this report has been shown in general terms. Sufficient detail, however, is shown to enable the reader to get a broad knowledge of the plant and its processes.

CASE STUDY, PLANT A

PRODUCTS AND VOLUME OF PRODUCTION

Plant A produces both diesel and gasoline engines. Diesel production is exclusively high-speed, heavy-duty engines, portable or stationary, for automotive, marine, and industrial applications. All diesels are of the injection type with a 4-stroke cycle and range from 12 to 500 horsepower. The plant produces a total of approximately 30 different models of 2-, 4-, 6-, and 8-cylinder engines. Table 4 lists the major characteristics of the reported industrial-type 6-cylinder engine and a companion 4-cylinder engine that has many parts that are interchangeable with those in the 6-cylinder engine.

Engine production in plant A and its composition is shown in table 5.

GENERAL PLANT INFORMATION

This plant has been operating approximately 25 years and has expanded gradually over the years with little overall planning but rather to meet particular needs. Consequently the plant layout has suffered in terms of both adaptability to large-scale production and efficiency of day-to-day production. For example, the cylinder block line for the reported product is located a considerable distance from the beginning of the assembly line and on a different floor level. Similar situations exist for other major production lines.

Buildings

The plant property area covers about 20 acres and consists of factories, warehouses, administrative offices, yards, and railroad sidings. The plant includes about 40 buildings and sheds with floor levels up to 3 stories high and floor areas ranging from 200 to 115,000 square feet. The buildings are steel frame and brick structures. The plant is well heated, lighted, and ventilated.

Machinery

This plant has metalworking machines of the general and special purpose type. General purpose machines are often grouped around a holding jig to perform a special machining process on an engine part.

The machinery layout for the reported engines is on a line basis for the machining of the larger parts such as the cylinder block and cylinder head. For smaller parts such as connecting rods and gears, the machines are grouped in specific parts departments where a line system is less practical. Parts are moved in barrels or baskets by truck to where they are to be used. The machinery positions tend to be closely grouped to conserve floor area and to minimize manual materials handling. Workers usually operate several machines wherever practicable.

Table 4. Specifications 1/ of reported 4- and 6-cylinder diesel engines, plant A, U. S. A., 1953

Specification	4-cylinder model	6-cylinder model
Cycle	4	4
Horsepower (continuous)	50	80
Bore (inches)	3.6	3.6
Stroke (inches)	4	4
Revolutions per minute	2,000	2,000
Length (inches)	30	40
Height (inches)	20	20
Width (inches)	20	20
Weight (pounds)	500	700
Piston, displacement (cubic inches)	170	250

1/ Specifications of some items are shown as approximations to avoid disclosure of confidential plant information.

Table 5. Number of engines produced, 1/ by type, plant A, U. S. A., 1953

Item	Gas and diesel engines	Diesel engines				
		Total	4- and 6-cylinder	8-cylinder and misc.	Reported engine models	
					4-cylinder	6-cylinder
Production	50,000	10,000	5,000	5,000	500	500
Percent of total engine production.	100	20	10	10	1	1
Percent of total diesel engine production.	--	100	50	50	5	5

1/ Production statistics based on shipments data.

Almost all machines are powered by individual drives. Only about 10 percent of the machines are belt or shaft driven and these are being replaced with individual drives as new machinery is introduced.

Materials Handling

Horizontal roller conveyors are used on line operations in the machine shop and are generally used in the processing of large engine parts such as the cylinder block and cylinder head. The material is pushed along from machine to machine by hand at the level of machine operating tables. Similar conveyors are used on assembly line operations. Turnover fixtures and turntables are installed on the conveyor at a few stations on the cylinder block line. At some points the blocks are turned over by use of a simple hand lever bar. At each machine station on the conveyor, one or two skid bars or a metal slab are provided for sliding the block from the conveyor to the machine operating tables.

OPERATING PRACTICES

Plant A produces engines on a job lot (custom) basis as well as by a line operation. Much of the plant's operation is on a job lot basis because the plant receives many individual customer orders for a wide variety of diesel engines with diverse specifications. Some engines (including the reported engines), however, for which there is a sufficient and continuous demand are produced almost entirely by line operations. The job lot operation functions at a relatively lower rate of production and efficiency because operations on diverse job lots generally require time-consuming changeovers of machines and assembly techniques from one type of engine to another.

Operations and assembly are set up for popular engine series and involve only minor adjustments for models within these series. Each production line remains intact even when not in use - the line is simply stopped and labor is transferred to other operations and assembly. Finished engine inventories are avoided even for those engines having relatively greater demands.

At the time of survey the plant was in a slack period and was operating on the basis of current orders, because a sales forecast is rather indeterminable.

Plant employment is kept to a minimum. Production workers are moved from machining and assembly of one model to another as needed, to attain the production levels needed to satisfy customer delivery dates.

Orders for engines of specific models are received by the plant after customer consultation with the sales engineering department. The orders generally provide for specific modifications of the basic engine for special customer applications. Orders are received by the product engineering staff which designs the special parts. Wherever possible, an attempt is made to use the basic design of standard parts and adjust these to customer requirements as in the case of unique engine mountings. In some instances customers specify material composition such as a cast aluminum gear cover or oil pan. For the most part, however, special customer needs apply to the engine trim (starter, generator, and governor) which are accessories to the basic engines and which are generally purchased directly from suppliers.

The product engineering staff issues comprehensive specification orders for each engine ordered. The orders are delivered to the production and stores departments. The stores department checks the stocks of purchased and plant fabricated parts. If shortages of purchased parts occur, the purchasing department is informed and suppliers are immediately requested to ship additional parts. If shortages occur in the stock of parts made in the plant, the production department is notified and the foundries or other rough material suppliers are requisitioned. Great care is exercised in reviewing purchase orders to confirm supply delivery dates so that production and assembly proceed in continuous and efficient sequence.

The supply situation at the plant is good. There is, however, considerable investment in rough stores primarily because of the extensive material requirements for the numerous engine types produced. Large inventories are carried in order to meet early customer delivery dates.

Employment

The plant normally employs 675 production workers and 529 nonproduction workers on two shifts. At the time of the study, about 600 production workers and 450 nonproduction workers were employed; no union affiliation was reported.

Hours and Wage Practices

The normal workweek schedule for the plant's production employees is 40 hours but at the time this survey was made, the workweek was 37-1/2 hours. Office employees work 40 hours per week.

Direct workers are paid on a straight piecework system.

Employees receive a paid 10-minute rest period on each shift. A 1-hour unpaid lunch period is provided.

The plant is currently operating on a 2-shift basis. The second shift which is used primarily to clean up production bottlenecks, has only a small number of workers compared with the first shift.

Workers on the evening (second) shift receive a shift differential of 6 cents an hour. If a night (third) shift is worked, a shift differential of 9 cents an hour is paid.

One and one-half times the regular rate is paid for work beyond 8 hours a day or 40 hours a week. This rate is paid for Saturday work or for the sixth consecutive day of work. Double time is paid for work done on Sunday, for the seventh consecutive day of work, or on specified holidays. All employees of the company are covered by the same wage practices except that production and related workers do not receive premium pay for work on holidays.

Fringe Benefits 2/

Each work in the plant receives $2,500 of life insurance payable to a beneficiary designated by the employee. All premiums are paid by the company. In addition, the company provides accident and sickness insurance that pays weekly benefits of $20 to the worker for nonoccupational accidents or sickness.

A nonproduction bonus of $50 is paid to all plant and office workers as a Christmas gift.

Paid vacations are given to production and related workers on the following basis: 6 days for 1 to 5 years service; 12 days for 6 to 15 years' service; and 18 days for all service over 15 years. Office workers receive paid vacations of: 6 days for 1 to 3 years' service; 12 days for 3 to 12 years' service; 15 days for 12 to 20 years' service; and 21 days for all service over 20 years.

In addition, the company operates a cafeteria where the employees can purchase meals at low cost. Losses incurred in this operation are borne by the company

Variety of Products

The plant produced almost 50,000 diesel and gasoline engines in 1953 of which only about 20 percent were diesel engines of varying numbers of cylinders. Approximately 10 percent of all diesel engines produced are 4- and 6-cylinder models; the 2 reported engines accounted for half the production of such models and were approximately evenly divided in the production of the 4- and 6-cylinder types. Production figures shown in table 5 are based on 1953 shipments data.

Standardization

Engines are designed and constructed for application to, or installation in, numerous machines for different uses. This is accomplished by modification of a "basic engine" to meet the specific need. Every engine model is available with a modification of such items as flywheels, flywheel housing, oil pans, front end gear covers, exhaust and intake manifold arrangements, and mounting positions. Starters may be electric, hand crank, air starting, or gasoline engine.

2/ Benefits supplemental to wages received by workers, at a cost to employers.

Plant A reported production of both a 4- and a 6-cylinder diesel engine of the 4-stroke type with valve mechanisms of the overhead type with cylinder block and crankcase cast as 1 unit. Wherever possible the reported engines are specifically designed to incorporate plant-machined parts which are standard for both engine models (table 6). Machined parts which vary in size between the two models, such as the cylinder block and cylinder head, are designed so that changes required in the machining process are simple and time saving.

The plant, at the time of this study, produced 10 engines per day of the reported model series. Six production workers (1 shift) operated the assembly line for the reported engines. At capacity, the plant could produce approximately 100 engines per day on a 3-shift - 22-1/2 hours a day-basis.

Table 6. Extent of standardization of parts of reported 4- and 6-cylinder diesel engines, by major part, plant A, U. S. A., 1953

Engine part 1/	Same part used in both models	Variation in size of part
Cylinder sleeves	X	
Cylinder block		X
Cylinder head		X
Valves	X	
Piston	X	
Piston pin	X	
Crankshaft		X
Main bearings	X	
Camshaft		X
Connecting rod and cap	X	

1/ Quantity of parts used varies among models.

Research

One department employing approximately 50 workers performs the functions of production engineering, methods and time study, and product design. Market analysis is performed informally by three persons in the sales department.

Purchasing

Over 1,600 parts are assembled in the reported basic 6-cylinder diesel engine. Most parts are purchased finished from suppliers. Only about 100 parts are finished in the plant, excluding engine studs which are also manufactured in the plant. Parts that are finished in the plant are listed in table 7.

Table 7. Engine parts processed in plant and number of parts per reported 6-cylinder diesel engine, by subassembly, plant A, U. S. A., selected period, 1953

Part 1/	Number per engine	Part 1/	Number per engine
Cylinder block assembly:		Water pump assembly:	
Oil trap	1	Water pump drive gear . .	1
Cylinder sleeve	6	Push rod assembly:	
Cylinder block	1		
Main bearing cap	7		
Nozzle stud	12	Push rod	12
Cylinder head assembly:		Rocker arm assembly:	
Cylinder head	1	Rocker arm	12
Connecting rod assembly:		Venturi housing assembly:	
Connecting rod	6	Control lever	1
Connecting rod cap	6	Shaft collar	1
Tube insert	6	Valve shaft stop	1
		Shaft	1
Oil pump assembly:		Housing	1
		Adapter	1
Oil pump gear	1		
Dowel pin	2	Idler assembly:	
Oil pan assembly:		Shaft	1
		Idler gear	2
Strainer cover	1		
Oil pan (upper)	1	Other:	
Oil pan (lower)	1		
		Flywheel dowel	2
Bayonet gage assembly:		Dowel pin	2
		Dowel	1
		Companion flange	1
Bayonet gage rod	1	Valve seat spring	12
Oil filter assembly:		Knob	2
		Nozzle	6
Adapter	1	Starter adapter	1
		Camshaft gear	1
Air intake manifold assembly:		Pulley	1
		Lever	12
Air intake housing . . .	1	Crankshaft gear	1
		Lifting eye	2
		Thermostat housing . . .	1

See footnote at end of table.

Table 7. Engine parts processed in plant and number of parts per reported 6-cylinder diesel engine, by subassembly, plant A, U. S. A., selected period, 1953 --Continued

Part 1/	Number per engine	Part 1/	Number per engine
Other--Continued		Other--Continued	
Valve tappet cover . . .	2	Flywheel	1
Gear cover	1	Front support bracket	2
Rocker arm shaft bracket	6	Water outlet manifold	1
Cylinder head cover . .	1	Inlet pipe	1
Exhaust manifold	1	Fuel pump drive gear . .	1
Bell housing	1	Hub	1
Clutch housing	1		

1/ Engine studs also are finished in the plant but are not shown in the table.

Many of the plant-processed parts are purchased originally as rough castings or steel forgings. These include the cylinder block, cylinder head, connecting rod and caps, bearing caps, oil pan, manifold, and various housings and brackets. Most drive gears and small drive shafts (idler shaft) are also machined in the plant. The large shafts such as the crankshaft and the camshaft are purchased in finished form.

Derivation of Man-Hours

Production of the reported 6-cylinder engine requires utilization of 67.5 man-hours, of which almost three-fourths is direct labor. The 4-cylinder engine required only 10 percent less direct labor (table 8).

The relatively slight difference in direct man-hours between the 4- and the 6-cylinder models indicates the degree of standardization developed between the two models. Wherever possible, the same dimensional parts are used in both models. If these parts must be produced in varying size, the extensive planning which went into the efficient tooling of the single process line allows machines to be easily adjusted, and jigs and fixtures to be simply and speedily changed.

Direct man-hours were derived from payroll tickets, payroll summary sheets, and actual timecards. Indirect man-hours were arbitrarily assigned to each engine from a plantwide ratio of direct to indirect labor. This method was used since it is not possible to measure the amount of indirect labor used in manufacturing each engine.

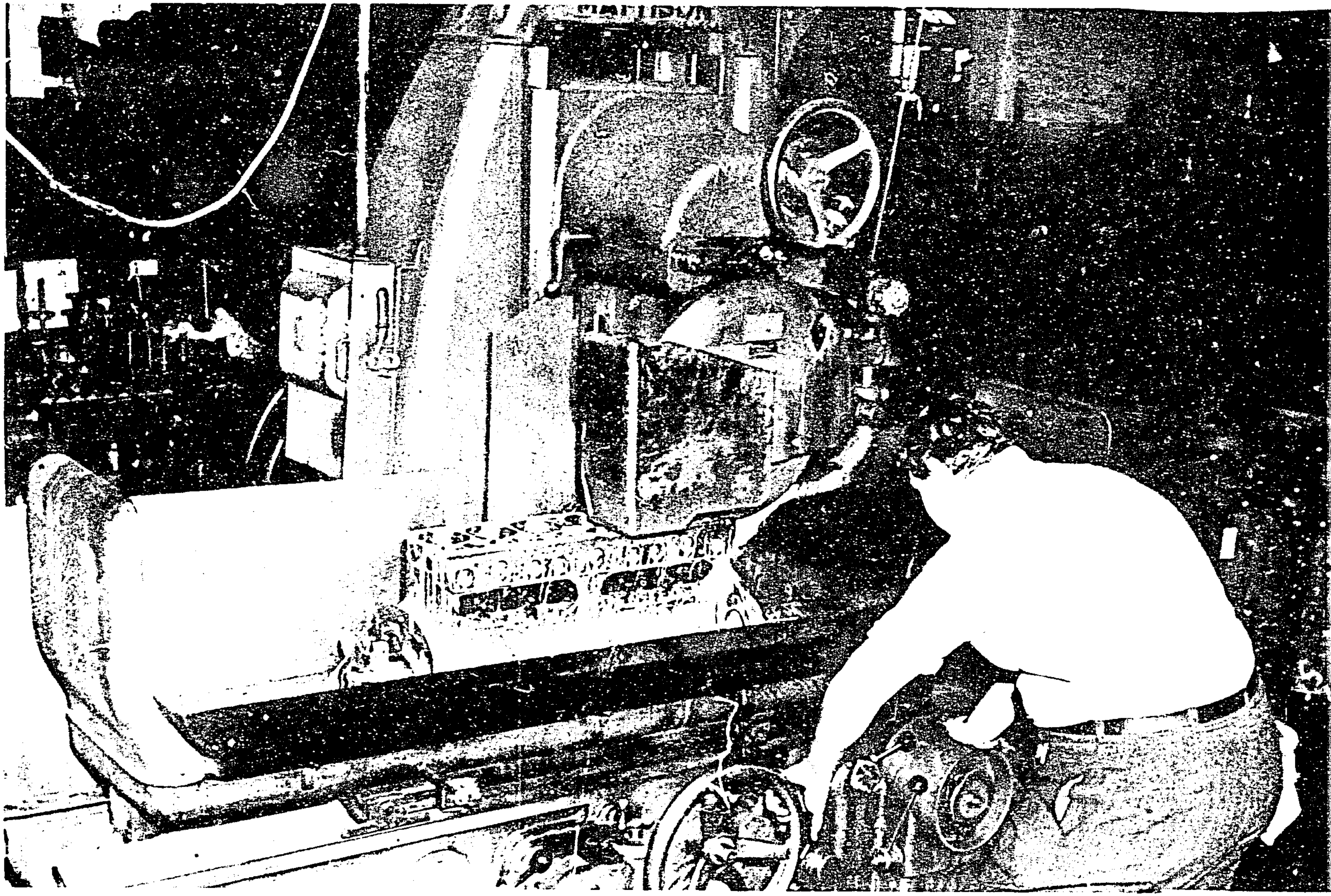

Figure 2. Surface grinding the top of a cylinder block.

Table 8. Direct and indirect man-hours per reported 6- and 4-cylinder diesel engines, plant A, U. S. A., selected period, 1953

Model	Man-hours per engine		
	Total	Direct	Indirect
6-cylinder	67.5	50.0	17.5
4-cylinder	60.75	45.0	15.75

Cylinder Block-Crankcase

The cylinder block-crankcase of the reported engine is made of 1-piece cast gray iron. For convenience it is usually called the "cylinder block". It is designed to carry the water jacket the full length of the cylinder bore for efficient and uniform cooling. Cylinder liners are of the dry type and may be pressed out and replaced. Lower cross-members of the crankcase are machined for the main bearings of the crankshaft which are held in place by cast steel bearing caps. A main bearing is located on both sides of each cylinder. The oil pan bolts to the bottom of the crankcase.

Machining Cylinder Block. Machining the reported cylinder block required 4.5 direct man-hours (table 9). Cylinder blocks are brought by truck from rough storage to the snagging and painting department. Cylinder blocks for all models produced in the plant are snagged and painted in one department. Snagging involves removing foundry core wires, sand, and grinding off or removing any rough spots on the casting. Sealing paint is used in the painting operation. After the painting operation, the cylinder blocks of the reported engines are trucked to the beginning of the cylinder block processing line. Details concerning the various machining operations on a cylinder block in the order in which they are performed are shown in table 9.

The first major operation on the cylinder block is milling; then the cylinder block faces are ground (fig. 2). The top oil pan rail and the main bearing channel are rough and finished milled, 4 blocks at a time, in one machining cycle on an Ingersoll plano-mill with 9 spindles and a table travel of 228 inches. Front and rear ends, and front arm pads also are milled in one operation. Rise and fall milling machines are used for such difficult milling as main bearing locations and the back of the fuel pump and accessory drive holes.

The numerous cylinder block holes are drilled by many types of multiple-spindle drilling machines both in horizontal and vertical positions. A special plant setup (fig. 3) is used for quick drilling small holes at varying angles. Eight special hand-fed spindles are mounted on a holding fixture and are driven by eight small air motors mounted in the drive end of the spindles. A special trunnion fixture is employed to drill and tap a number of holes at various locations in the block. The block is bolted to the trunnion

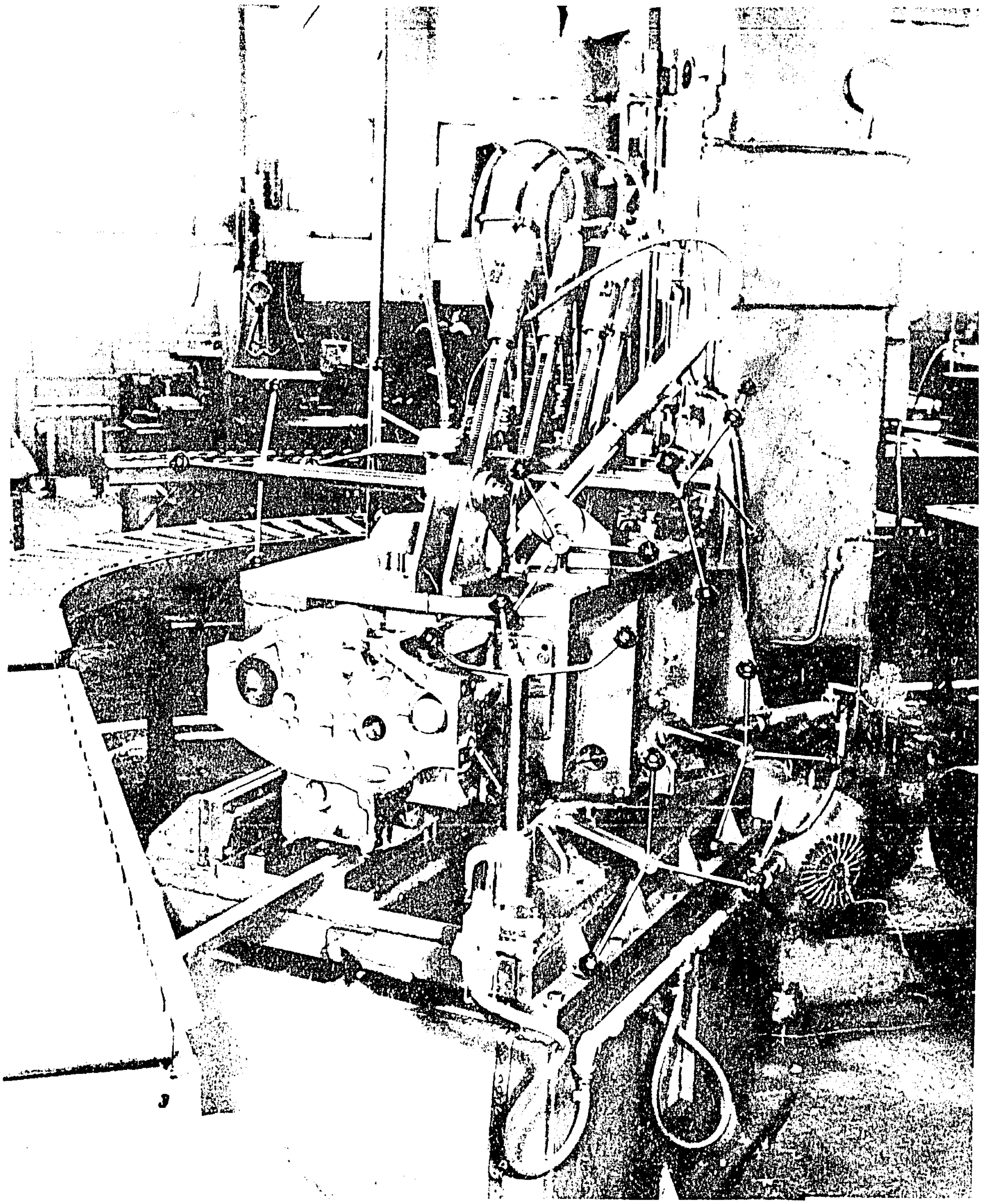

Figure 3. Special machine and holding fixture for drilling angular holes in crankcase-end of cylinder block.

fixture under a radial drill and can be turned and fixed in any position around a horizontal axis.

Rough cylinder holes are all bored at once on a multispindle hydraulic machine. The holes are then precision bored to size. Cylinder liners are assembled in the block and liners are finally finished-honed (fig. 4).

A combination of machines (fig. 5) around a holding fixture with two stations is used for facing the rear main thrust bearing, camshaft hole and idler hole, in addition to several reaming and tapping operations. (Operation 39, table 9). The main thrust bearing is faced to very close tolerances.

The cylinder block is washed before assembly of main bearing caps, camshaft bearings, and idler shaft bearings on the process line. It is water-tested before insertion of cylinder sleeves.

Cylinder Head

The cylinder head of the reported engine is made of a special alloy heat-treated cast gray iron and is secured to the top of the cylinder block by heat-treated alloy studs. It is made in one casting purchased in a rough condition from the foundry. The valve seats and valve guides are part of this casting. Valve guide bushings are removable. The cylinder head gasket is an annealed solid copper plate about 1/16-inch thick.

Machining Cylinder Head. Machining of the cylinder head requires 1.5 direct man-hours. Milling the bottom and top of the cylinder head as well as the exhaust and air intake pads is performed on 5 cylinder heads at one time on a fixed-rail milling machine with 2 stations. Drilling is performed by multiple spindle machines. The cylinder head is water tested during the processing. Valve guides are assembled before inspection. A roller conveyor is used in this line operation. Details concerning the various machining operations on the cylinder head in the sequence in which they are performed and the man-minutes for each operation are shown in table 10.

Connecting Rods

The connecting rods and the connecting rod caps processed in this plant are alloy steel drop forgings with I-section bodies. The rods and caps are forged separately and are purchased in a rough condition.

Machining Connecting Rods. The connecting rods are drilled to permit oil to pass from the crank-end bearing up to the piston pin. The upper ends are fitted with bronze bushings for piston-pin bearings. Lower ends have drop bearing caps secured by alloy steel studs. Connecting rods and caps are matched for each engine installation. Details on machining a connecting rod are shown in table 11 and for the rod cap in table 12.

Initially, the rods are straightened at a bench in the rough-storage department and are trucked in steel baskets or barrels (on skids) to the connecting rod department in the machine shop. There the machines are

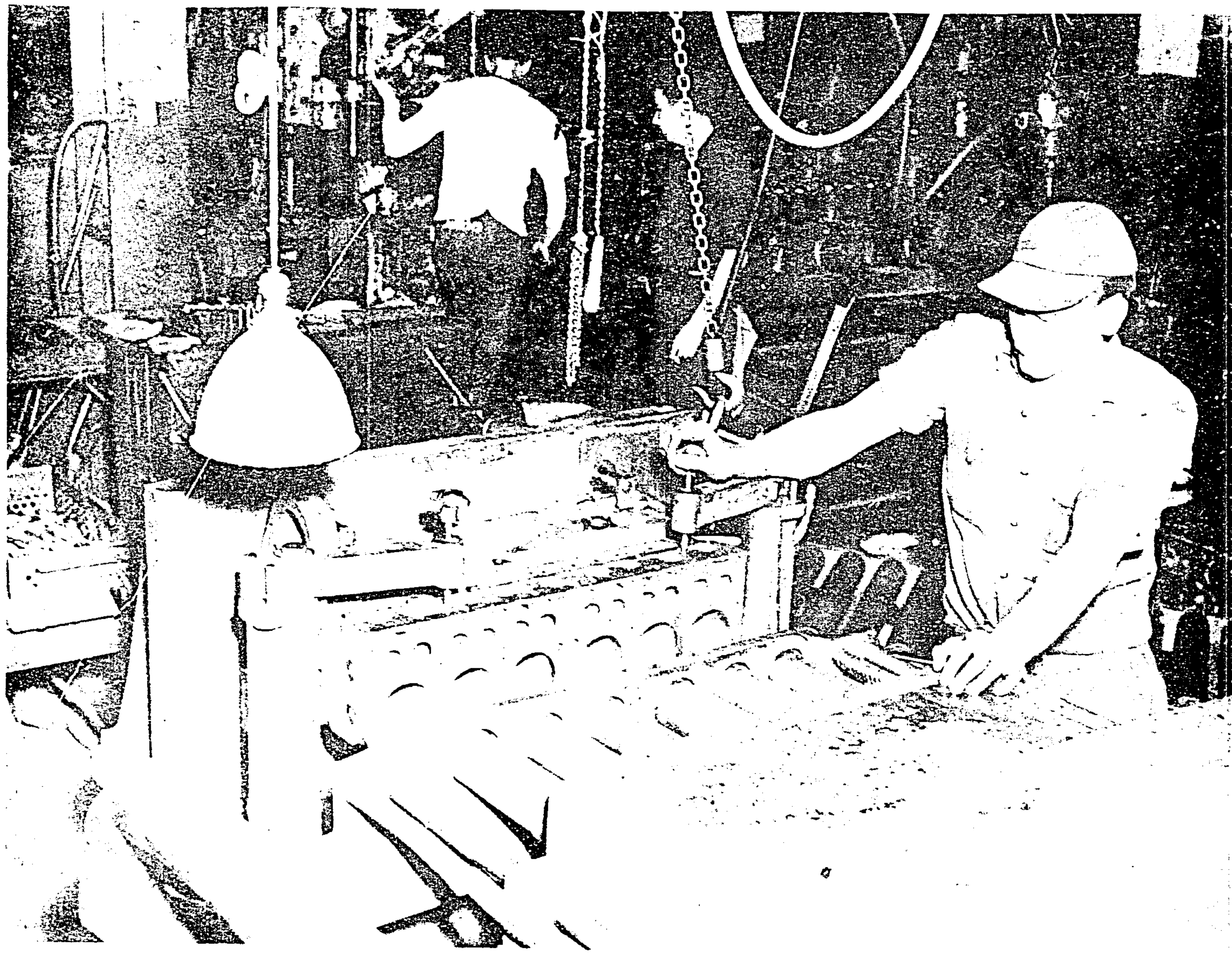

Figure 4. Honing cylinder bores in cylinder block.

grouped to allow for efficient materials handling during the sequence of operations. First, a machine operation locates the piston pin hole and mills one side of the piston pin end and the crank end for locating purposes in the next operation (fig. 6). Then a combination operation is performed which involves drilling and reaming the piston pin hole and rough boring the crank end. The other side of the crank end is milled next. The rod attaching face is then broached flat. An oil hole is drilled from the crank end to the piston pin end. Bolt holes are drilled, rough reamed, and counterbored in the rod in combination with the drilling, rough reaming, and spotfacing of bolt holes in the rod cap. Bolt holes are tapped at the next station. Face keys are broached on the attaching surfaces of the rod and cap in combination. The long oil tube is then reamed and air holes are drilled. The rod and cap are burred, washed, and assembled. The crank end is semifinish bored and both sides of the crank end are ground. The crank and piston pin end are precision bored and both sides of the crank end are chamfered. The rod and cap are disassembled and both are placed in a fixture for milling the bearing lock notches in both pieces. The rod and cap are burred and reassembled. The crank end is then honed to size. The piston pin bushing is inserted and the bushing hole is precision bored to size. Finally, the rod and cap are inspected.

Most significantly, the connecting rod operations in this plant are characterized by the application of engineering practices which provide not only modern machines for efficient productivity but also unique jigs for accurate locating purposes, holding fixtures with quick-acting holding and releasing devices, and the adaptability of such jigs and fixtures to quick change in size and length of connecting rods.

The general use of modern machines in the shop, of course, develops efficiency in production. In some instances, however, the substitution of machines for labor occurs for other reasons - such as safety considerations and operational difficulties.

For example, at the time of the survey, a broaching machine performed operations which broach the rod attaching faces flat and cut joint face keys (table 11, operation Nos. 5 and 9). The machine, an expensive replacement, was a substitute for a milling machine which by an arrangement of two holding fixtures performed the same operations. But in the latter case, operational difficulties arose when cutting tools broke too often and a safety hazard occurred when rod pieces were thrown from the fixture occasionally. Despite the greater efficiency of the milling machine over the broach, it was replaced.

The fixtures on the replaced milling machine (fig. 7) were so arranged that the operator was continuously unloading and reloading one fixture while the cutters were machining the workpiece within the other fixture. In the broaching operation a significant number of man-hours is lost while the operator idly watches the machine perform. The advantages of using a machine with two loading stations are obvious. It was stated previously that when the connecting rod department production requirements approach capacity with the current layout, the operational difficulties and the safety hazards

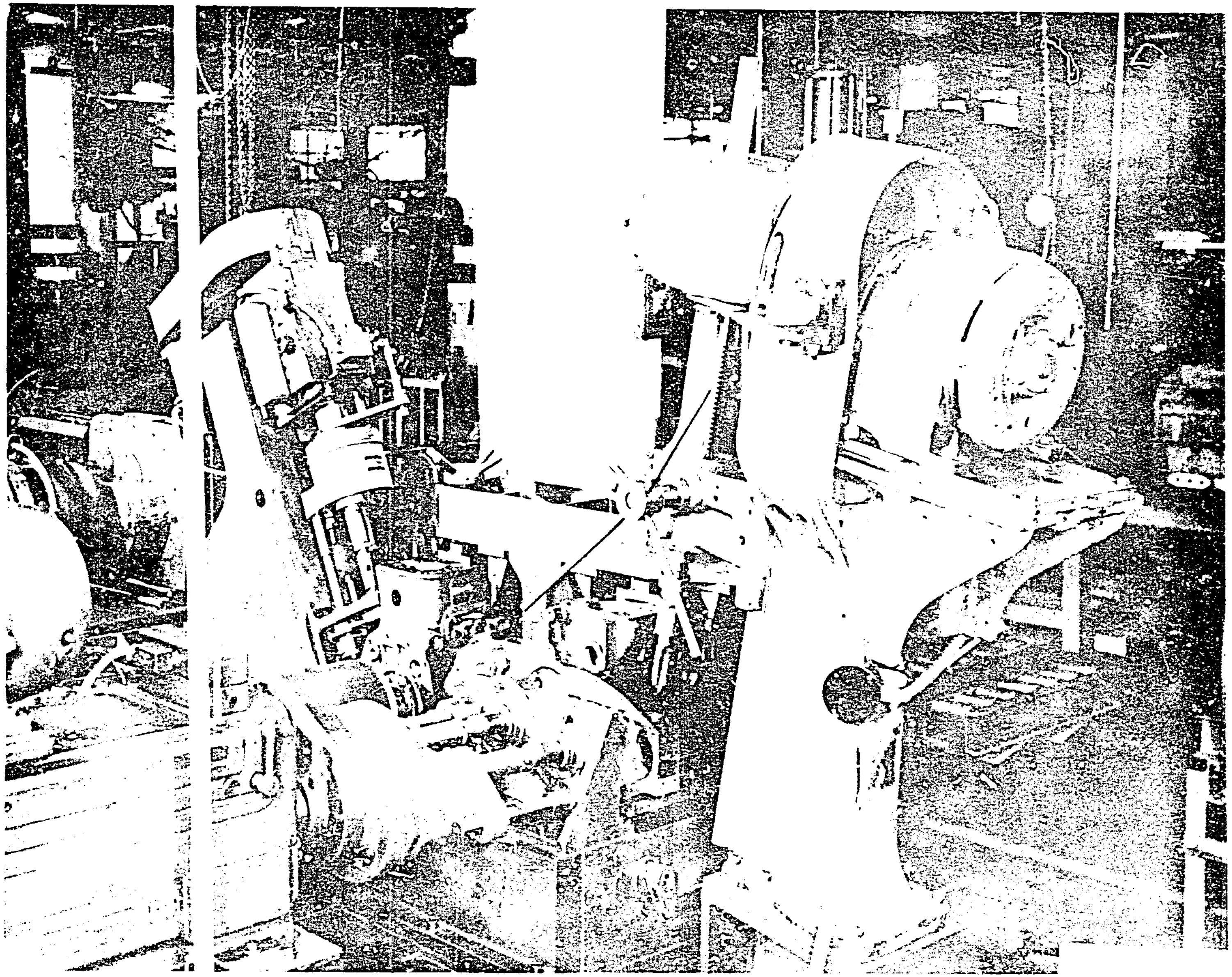

Figure 5. Special machine for performing multiple operations in cylinder block.

of the original milling machine operation would have to be eliminated somehow, and the milling machine would then replace the broach.

Assembly

To completely assemble the reported 6-cylinder diesel engine, including all necessary subassemblies, required 5.17 direct man-hours. Six assembly workers on a 1-shift basis were working on the line at the time of the survey.

All parts are trucked from storage or from the various process departments and machining lines. The cylinder blocks, brought from a lower floor level by platform trucks, initially are fitted for pistons, cleaned of any sand, their camshaft bearings and tappet guides are reamed, and their cylinder head studs driven; and then the cylinder block is washed. These operations are not performed on the line but at a floor station close to the beginning of the line. Power hoists move the cylinder blocks between the initial operations and onto the roller conveyor. There the cylinder blocks are bolted by their bell housing to platform fixtures and are moved by hand along the conveyor. Subassemblies are completed on benches beside the assembly line and parts are stacked on benches, lines, and racks along the line in appropriate places. When it has been completely assembled the engine goes to the testing department. The operations involved in assembling the major subassemblies and in assembling the reported 6-cylinder diesel engine are shown in tables 13 and 14, respectively.

Inspection

One inspector is generally employed for every 12 production works. The total number of inspectors ranges from about 50 to 150 men, depending upon the production and employment level of the plant.

All parts manufactured are checked by the inspection department to close tolerances using all types of gauging equipment including special devices designed by the department. There is no formal statistical quality control program. Scrap in the processing stages is kept to a minimum by close supervision and constant inspection of work.

Productivity Factors

The reporting plant has made great strides toward efficient production both by applying standardization and simplification principles in the design of the reported products, and by use of efficient tooling practices. It has been handicapped, however, by its own physical characteristics. The growth of the plant has been sporadic over a long period of years, and at the time of the survey, manufacturing operations were tailored to the old building structures. This has led to a somewhat cramped plant layout. In addition, the plant is of multistory construction in many parts which adversely affects materials handling, a costly and vital element in the efficient utilization of labor, equipment, and materials. For example, the cylinder block line for the reported product is located on another floor, a considerable distance from the beginning of the assembly line. Similar situations exist for other major parts.

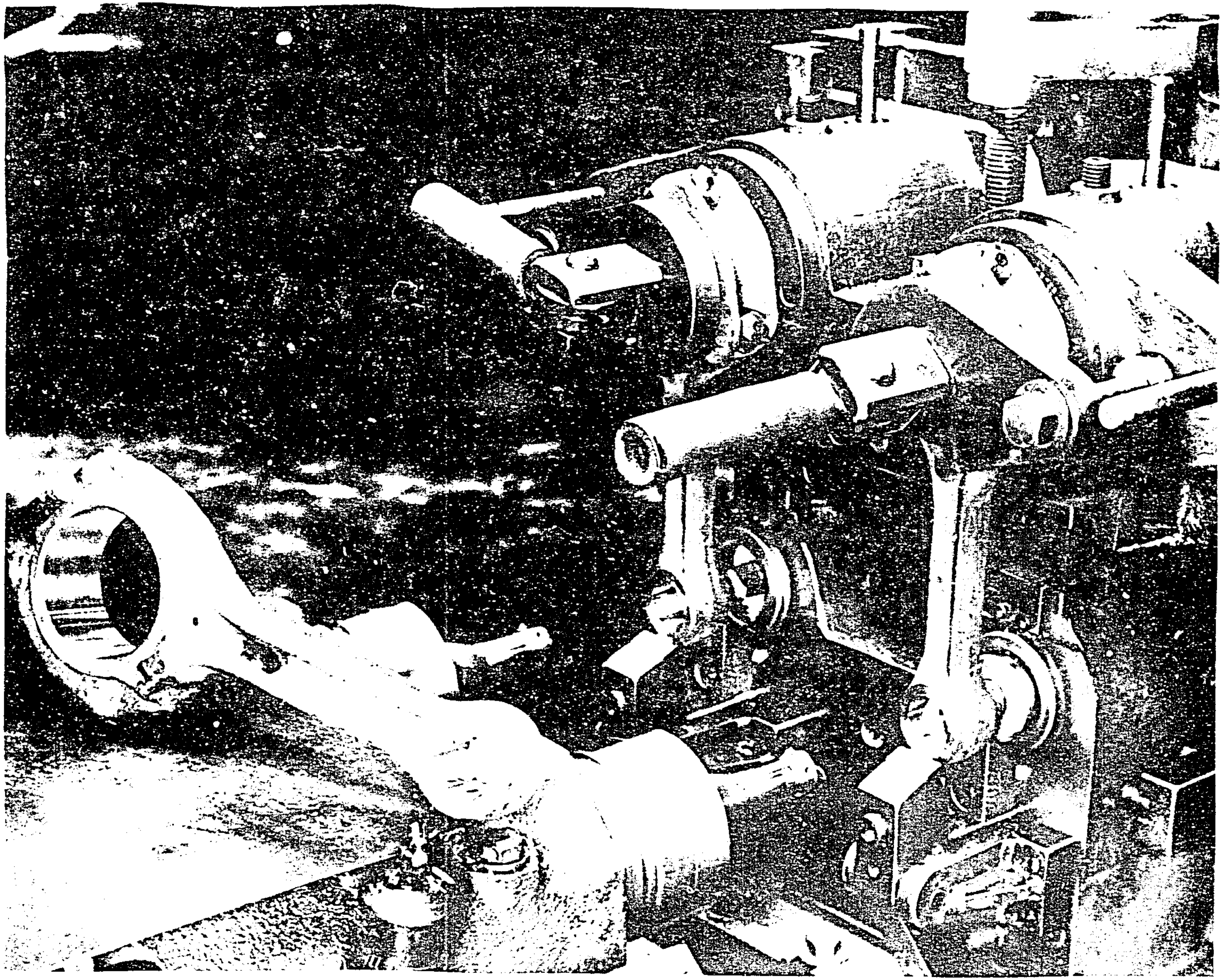

Figure 6. Precision boring piston pinhole in connecting rod.

Despite these handicaps, the plant is operating at a relatively high productivity rate, especially in the production of the reported engines. These are designed wherever possible to incorporate purchased and plant machined parts which are standard for both models. Machined parts which vary in size such as the cylinder block and cylinder head are designed so that changes required in the machining process are simple and time saving. Parts thatare interchangeable between the 4- and 6-cylinder diesel engine are listed in table 6.

Efficient tooling is emphasized by this plant. The basic advantages to the plant are reduced labor time and costs due to: (1) higher production rate; (2) increased automaticity (also reduction in errors which result in scrap); (3) efficient handling and loading; and (4) closer machining limits (avoids secondary operations).

The plant has invested heavily in efficient jig and fixture constructions; these provide time and motion economy in the form of easy loading and unloading, by using quick acting clamps and holding devices. In addition, considerable attention is given to jig and fixture flexibility which permits a machine without adjustment of setup to process pieces of varying sizes such as connecting rods and flywheels. The practice of flexible or combination fixtures is applied extensively in the connecting rod department. There each machine fixture is designed with interchangeable parts so as to adapt it to connecting rods of most models produced in the plant. Plant officials point out the following advantages of concentration on such efficient tooling:

1. Parts of varying sizes can be readily machined on a single machine.

2. The large basic fixture need never be removed from this machine, thus initial alinements are never disturbed.

3. Cost of a combination unit is less than the cost of individual fixtures required for each connecting rod size.

4. Changeover time is substantially reduced.

5. Newly designed parts can be added to the fixture as long as it is within the established size range.

A set of simple formulas is used by plant officials to determine the feasibility of introducing new jigs and fixtures. The formulas may be stated simply, as follows:

(1) Given an estimated cents savings in direct labor cost per piece, how many pieces must be run to pay for a fixture of a given estimated cost?

(2) Given the number of machined pieces to be run and the cents savings on direct labor cost per piece, how much can be invested in the construction of the fixture?

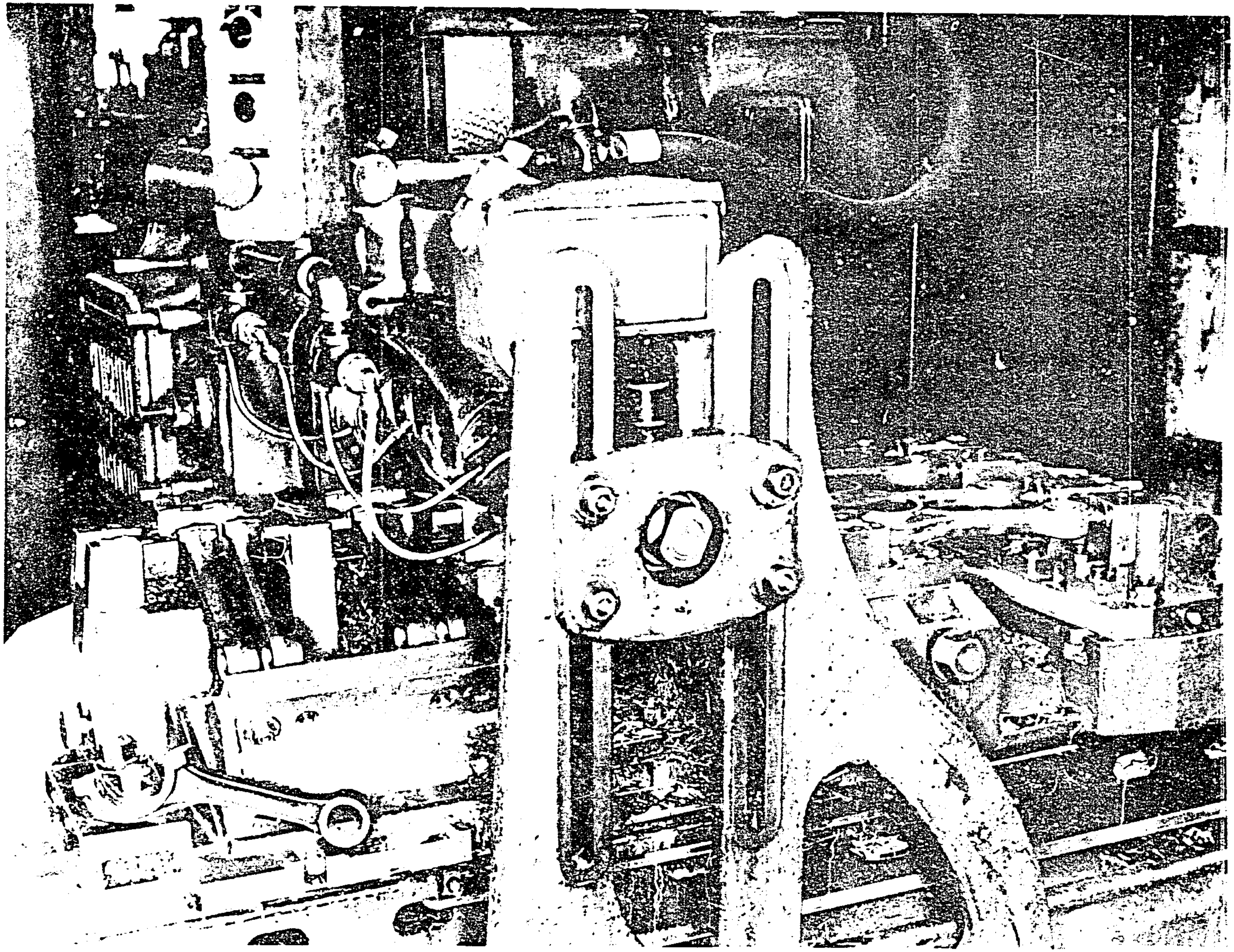

Figure 7. Milling machine and special fixtures for milling operations on crankshaft ends of connecting rods.

(3) Given an estimated cents savings on direct labor cost per piece and given a production rate, how long will it take for a proposed fixture to pay for itself?

Special purpose machinery is a great cost saver if the production rate is high. Such machinery is then introduced in the plant wherever practicable. For example, lower costs, greater accuracy, and superior finish are obtained in the machining of flywheels by the introduction of a special purpose machine which combined four operations (originally performed individually) into one.

A combination turning, facing, and superfinishing machine was specially designed for machining the clutch face and oil seal pilots on all flywheels produced by the plant ranging in size up to 26 inches in diameter and 6 inches in thickness. Initially, the machine faces and turns the clutch face and the oil seal pilot. The machine then superfinishes both surfaces to a low microfinish. The most unique feature of the machine is that machining is performed simultaneously on both the clutch and engine sides of the flywheels. With this method the plant obtained a lower cost, better accuracy, and a superior finish than when the four operations were performed singly.

The plant has reduced man-hours by introducing a new crankshaft balancing device. Originally shafts which were stacked on end near a balancing machine of old design (fig. 8), had to be loaded by the balance machine operator to the proper cradle position for measuring purposes. The worker then checked the crankshaft balance, picked up the shaft from the machine and placed it in appropriate stacks on the floor. Considerable time was required to change the machine for various size crankshafts. The total time required to perform this operation was 18 man-minutes.

By the introduction of a new machine (fig. 9) the man-minutes were reduced by two-thirds. Crankshafts of all sizes are loaded into the machine from a special ingoing conveyor. The part is dropped gently into the cradles of the balancing machine, the crankshaft balance checked, and the part rolled out of the machine on an outgoing conveyor.

Two men perform the operation. One man loads and unloads the conveyor - the other operates the machine. Thus, the machine is kept working steadily without costly idle time required to hoist the part in and out of the machine. Time per operation by the new method is 6 man-minutes.

Often, the design of the pieces to be processed affects the productivity rate. In this plant the main bearing caps are cast in blocks of four. Four complete blocks are machined during each cycle of the machine in the bearing cap department. For example, a vertical multispindle drilling and boring machine drills and reams eight bolt holes and rough bores the crank hole. The machine consists of a multiple head, six holding fixtures and an index type table. Bearing caps of varying sizes can be run through this machine by adjusting the fixtures.

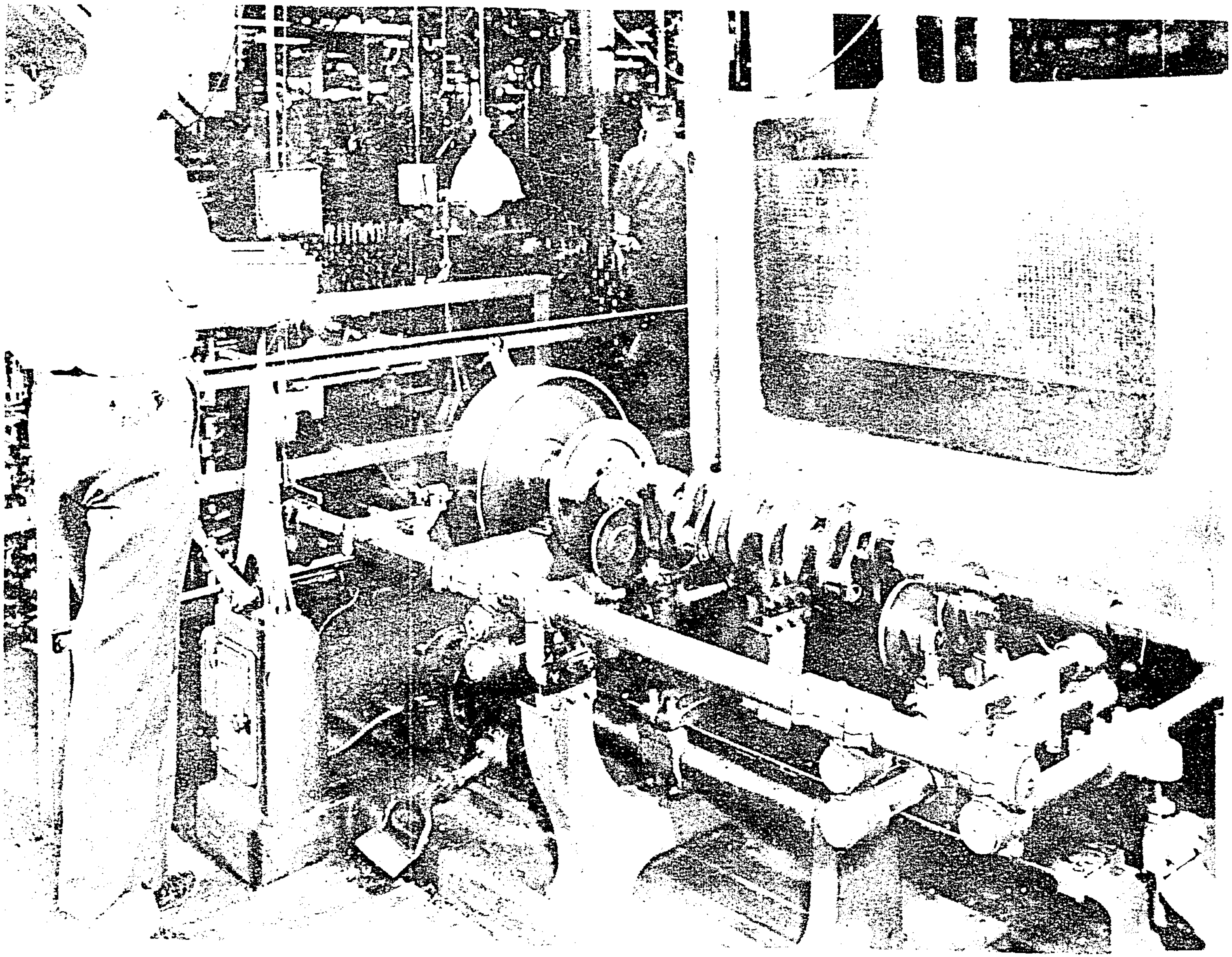

Figure 8. Old method of balancing crankshafts.

The cast blocks of four main bearing caps are milled on a plain milling machine (fig. 10), on their attaching faces, the ends are chamfered and milled, and the top bolt bosses are milled in one operation. One fixture holds the cast block for machining the attaching faces and the ends; another fixture holds the casting for milling the bolt bosses. The fixtures are designed so that the same arbor and cutter tools machine both operations simultaneously with any changeover.

The plant makes considerable use of portable power tools. These are driven either by electricity or compressed air and are designed as nut runners, drillers, reamers, tappers, and grinders. When applied to machining and assembly, the hand power tools cut costs significantly.

An increased production rate such as in the line operation of the reported engines requires the introduction of many labor-saving materials-handling devices. Horizontal roller conveyors are used on line operations and are generally applied in processing large engine parts such as the cylinder block, and cylinder head. The material is pushed along from machine to machine by hand at the level of the machine's operating tables. Similar conveyors are applied on assembly line operations.

Turnover fixtures and turntables are installed on the conveyor at a few stations on the cylinder block line. At some points the blocks are turned over by use of a simple hand lever bar. At most machine stations on the conveyor, one or two skid bars or a metal slab are provided for sliding or skidding cylinder blocks from the conveyor to the machine's operating tables.

At other stations monorail conveyors are used for movement of parts across gaps in the conveyor line or from conveyor machines. Both manually operated and power hoists are provided for movement of pieces at many individual machines and wash tanks, and in the assembly process. Industrial trucks are used both for delivery of pieces to the production area and for handling during production. They are also used for receiving, storing, and shipping.

COST DISTRIBUTION

The manufacturing costs of the reported engines are distributed approximately as follows: 60 percent for direct material costs, 24 percent for labor costs, and 16 percent for "other factory costs." Maintenance of equipment and supplies costs are by far the largest cost items in other factory costs.

Selling expenses generally average about 2-1/2 percent of total sales. Sixty percent of selling expense is salesmen's salaries and commissions, 16 percent is applied to advertising, and 24 percent represents the selling cost of company retail outlets.

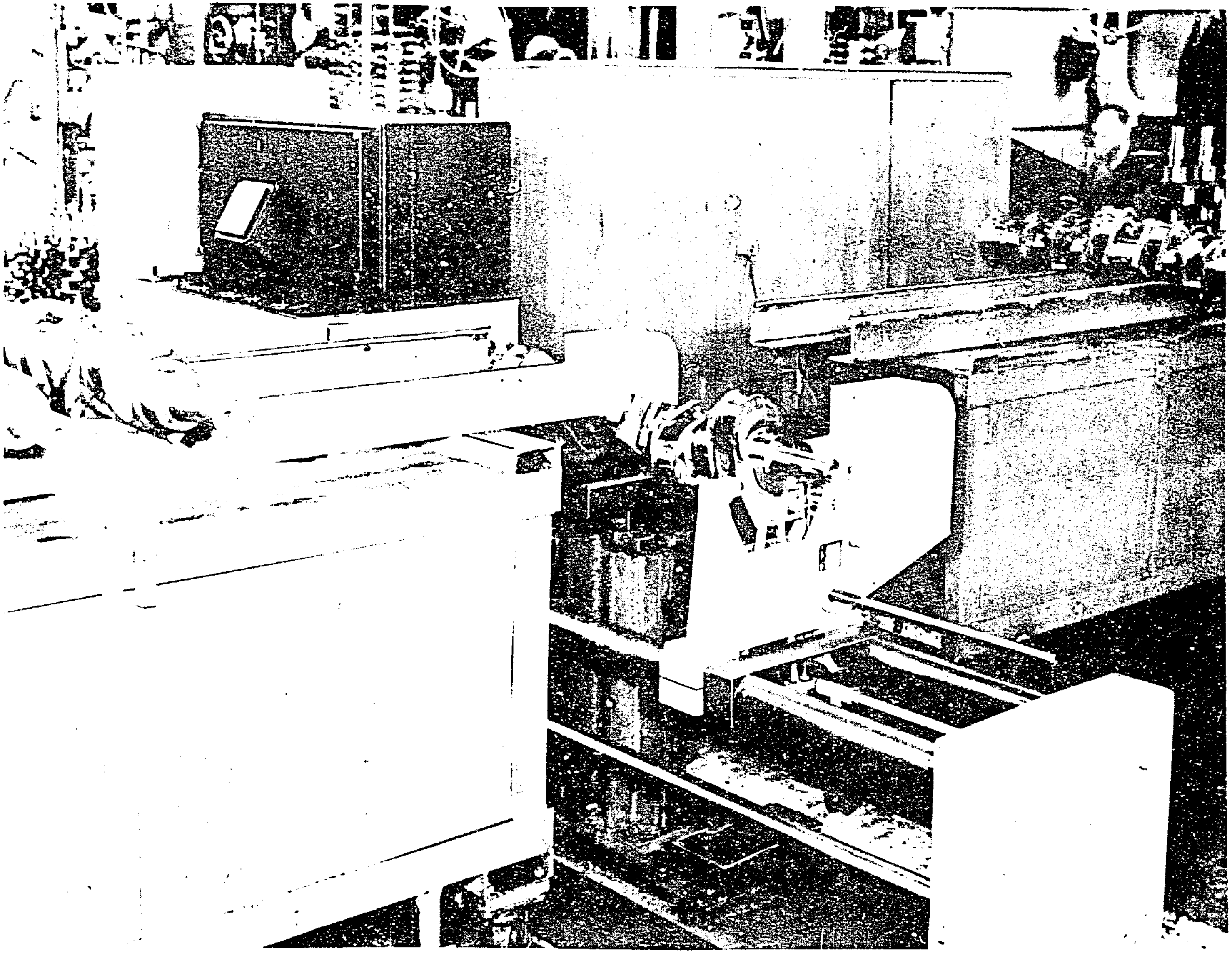

Figure 9. New method of balancing crankshafts.

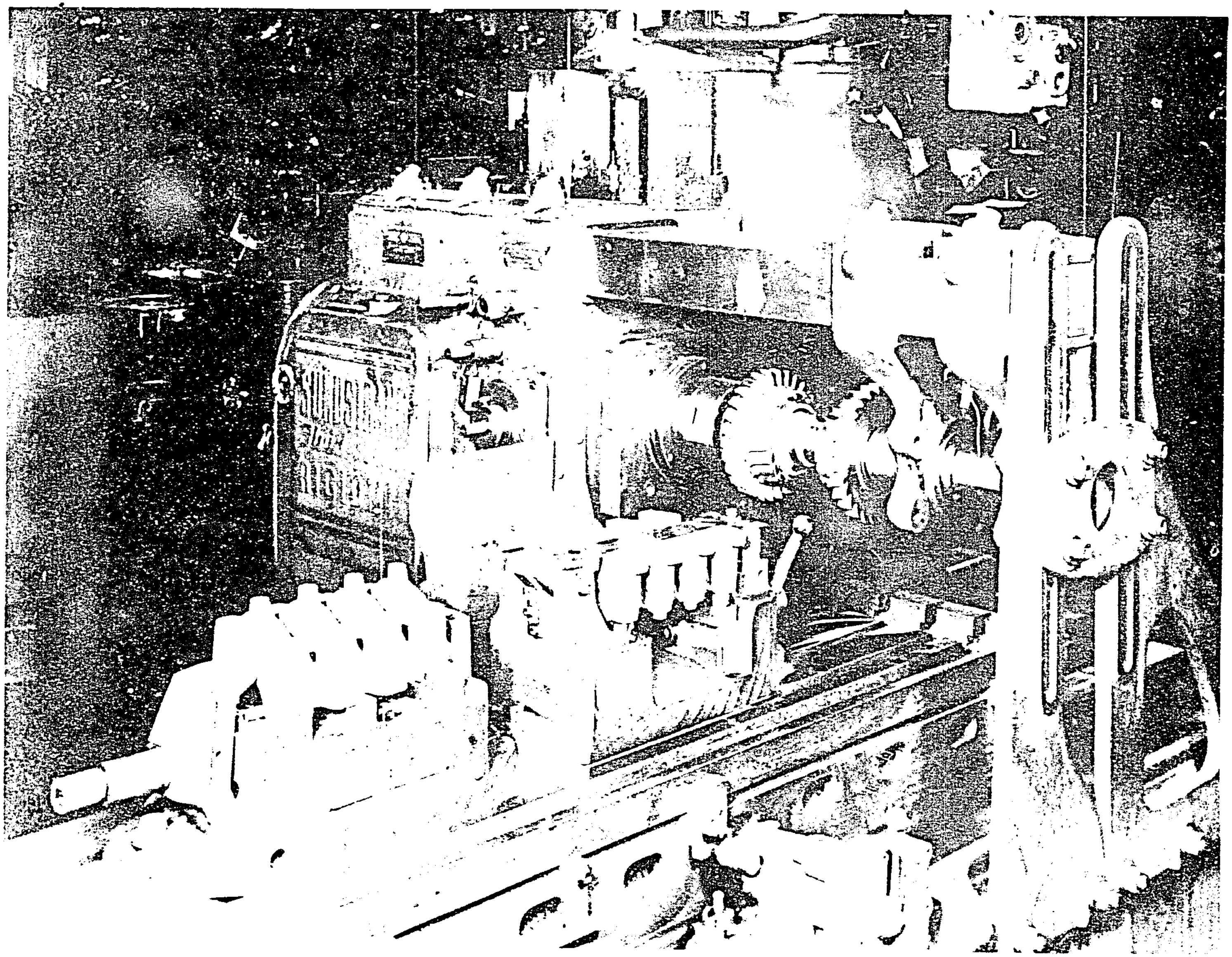

Figure 10. Milling main bearing rod caps in blocks of 4 caps.

Table 9. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
1. Snag block	Bench	4.0	12.0
2. Paint block	Bench	1.9	25.2
3. Rough and finish mill . . . (block top, (leave .010"), pan rail, and bearing channel. (4 blocks machined in 1 operation).	Ingersoll 9-spindle milling machine, 228" table travel	2.3	21.2
Bottom up position:			
4. Combination drill and . . . ream 2 process holes .570" 7 bearing lock holes 9/32", and 1 hole 9/16" by 5" deep.	No. 2 Baush hydraulic multiple, 24-spindle drill	5.8	8.3
End mill 13/16" diameter .. clearance for gallery hole at both ends of block.	Two No. 20 Ex-Cell-O, 1 spindle		
5. Mill front end, rear . . . . end, front arm pad (1 side), and front arm pad (opposite side).	Ingersoll milling machine	6.8	7.1
6. Rough bore all . . . . cylinders.	Moline hydraulic boring machine	5.8	8.3
Top up position:			
7. Drill 22 holes 15/32", . . . 8 holes 9/16", and 1 hole 27/64" in block top.	Natco multiple drill	4.5	10.7
Drill oil gallery hole . . . halfway in 1 block end.	Barnes horizontal single-spindle drill.		

Table 9. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
Top up position:--Continued			
8. Drill 12 push rod holes 9/16" (combination drill and ream 2 holes). Drill 4 holes 9/16", 5 holes 5/16", 8 holes 15/32", and 6 holes 13/64".	Natco multiple drill	5.6	8.6
Drill oil gallery hole half-way, in opposite end (see operation No. 7).	Barnes hydraulic single-spindle drill		
9. Core drill cam line to 1.815" from both ends of block. Rough bore crank 1/2" hole to 2.992" from both ends. Rough bore idler hole to 1.565", fuel pump hole to 3.690", and accessory hole to 2.815". Core drill plug hole to 1-47/64".	Foote Burt 2-way boring machine	7.9	6.1
10. Straddle mill main bearings (leave .010" on each side of rear bearing).	Ingersoll rise and fall machine	5.6	8.6
Bottom up position:			
11. Mill valve door pad and nozzle pad.	Cincinnati hydromatic duplex mill	8.8	5.4
12. Mill 3 bosses at pan rail	No. 3 Rockford rigid mill	3.2	15.0
13. Mill generator pad on valve side of front end.	No. 3 Sunstrand rigid mill	3.1	15.3

Table 9. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
Top up position			
14. Mill back of fuel pump hole.	Cincinnati hydro-matic rise and fall mill with tracer	4.3	11.1
15. Mill back of accessory shaft hole.	Cincinnati hydro-matic rise and fall mill	5.6	8.3
16. Rough bore and spotface 6 combustion cups	Moline rail drill, hydraulic feed	2.8	17.1
Combination core drill 1-7/16" and ream to 1.500" and chamfer oil trap hole on valve side.	No. 21 Ex-Cell-O drill		
Drill 1 hole 7/16" x 6" deep and 1 hole 7/16" x 1" deep.	Barnes hydraulic drill		
17. Drill front end holes, 15 holes 5/16", 7 holes 27/64", 1 hole .188" (combination drill and ream).	Baush 2-way hydraulic multiple drill	3.7	12.9
Drill rear end holes, 4 holes 27/64" and 4 holes 17/32".			
Drill 25° angular hole on nozzle side, combination core drill breather to 1-15/32" and 1-1/4", combination 21/64" and 23/32" drill bayonet gage hole.	No. 21 Ex-Cell-O hydraulic drill		
Drill 10° angular hole on nozzle side, combination 11-13/32" drill, 1-1/2" diameter counterbore and 2" spotface, 1 hole.	No. 21 Ex-Cell-O hydraulic drill		

Table 9. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
Top up position--Continued			
18. Drill 20 holes on valve side, 11 holes 27/64", 4 holes 5/16", 2 holes, combination 27/64" drill and 11/16" counterbore, 2 holes 13/64", and 1 hole 1-1/8" . . .	Natco hydraulic unit and base	4.5	10.6
19. Finish mill rear end	Sunstrand rigid mill	3.7	12.9
20. Chamfer bolt holes	--	1.5	32.0
21. Bore bellhouse pilot 6.252" .	Natco single-spindle, horizontal, hydraulic boring machine	2.2	21.8
22. 6 combination 1/2" diameter and 1-7/16" diameter bore holes for combustion passage. Turn block over and drill 12 push-rod holes 29/32".	Baush 24-spindle multiple drill	5.2	9.2
Bottom up position:			
23. Drill 16 angular holes, . . . 5 holes 21/64", 37° crank to gallery, 2 holes 21/64" x 12-11/16" deep.	Barnes hydraulic drill	10.7	4.5
4 holes 27/64" nozzle side	No. 21 Ex-Cell-O drill		
3 holes 9/16", 40° on valve side	Avey drill		
1 hole 21/64" on nozzle side	No. 20 Ex-Cell-O drill		
1 combination 5/16" drill and 1" spotface on nozzle side.	No. 20 Ex-Cell-O drill		

Table 9. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
Bottom up position--Continued			
24. Drill 26 holes 5/16", 6 combination 9/16" drill and .697" counterbore, 4 combination 15/32" drill and .572" counterbore, 1 hole 21/64", and 2 holes 1/4". . . .	No. 15 Fox, hydraulic multiple drill	5.2	9.2
Bottom up position, 16° angle:			
25. Drill 24 holes in nozzle pad 12 holes 5/16", 6 holes 21/64", 6 holes 5/8". . .	Natco vertical unit and base, put in horizontal position and block-mounted at an angle.	3.4	14.1
26. Semifinish nozzle holes 6 combination .672" and 31/32" bore, rough bore 5 cup plugs to 31/32". . . .	Natco horizontal hydraulic	3.7	12.9
27. Finish bore 6 nozzle holes and ream 5 holes to 1" diameter. .	Natco horizontal unit	2.0	24.0
28. Drill 8 angular holes, 1 hole 21/64" bottom compound, 2 holes 21/64" at 25° angle on valve side, 4 holes 21/64" at 25°, cam to valve chamber, 1 hole 1/2" compound in accessory hole. . .	Special machine	7.9	6.1

Table 9. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
Bottom up position:			
29. Bore 12 push rod holes . . . to .990", Size ream 12 push rod holes	Natco hydraulic vertical drill Natco 24-spindle drill	3.5	13.7
30. Assemble 12 valve tappet . . bushings	Hannifin hydraulic press	3.8	12.6
31. Drill 4 vent holes 3/16" . .	Air drill	2.5	19.2
32. Precision bore cylinders . .	No. 45 Heald Borematic	6.1	7.8
33. Radial drill holes, ... fron end; 1 hole 24/32", 1 hole 3/4"-14 pipe tap, 1 hole 1-1/2"-11 1/2 pipe tap, 1 hole 3/8"-18 pipe tap, 1 hole 27/64"-redrill 1-7/8" deep, and mill oil header boss. Rear end; 1 hole 3/8"-18 pipe tap and 4 holes 1-1/8" back spotface. Nozzle side; bore and ream 5 cup plugs.	Carleton 3' arm radial drill	12.5	3.9
34. Tap bottom rear end, and . . front end. Bearing size valve tappet holes.	Hammond radial tapper	15.0	3.2
Top up position:			
35. Tap top, tap nozzle pad . . 16°, tap nozzle side and tap valve side.	Hammond radial tapper	13.0	3.7
36. Wash and blow	Tank	4.0	16.0

Table 9. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
Bottom up position:			
37. Drive main bearing . . . . . studs and assemble main caps.	Chicago pneumatic stud runner	7.8	6.1
Top up position (main caps on):			
38. Finish gear centers: . . . . semifinish and finish bore crankline, camline, idler hole, fuel pump drive hole, and accessory shaft hole.	Barnes hydraulic horizontal boring machine	9.2	4.1
39. Face and backface rear . . . thrust bearing	Special machine		
Ream oil filter hole and ream bayonet hole	2 No. 25 Ex-Cell-O units Cincinnati Rite Speed drill		
Face front end of camshaft hole, face and chamfer front end. Spotface and counterbore 10° angle hole and 1-1/2"-12 tap oil filler hole roll over	No. 21 Ex-Cell-O unit	5.5	8.7
40. Ream cam line	Air gun with boring bar cutter	2.4	20.0
Bottom up position:			
41. Assemble camshaft bearings . and idler shaft bearing.	Oilgear horizontal hydraulic press	3.5	13.7
Top up position:			
42. Finish bore and babbit . . . in idler hole.	Special machine	2.1	22.8

Table 9. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
Top up position:--Continued			
43. Assemble plugs and screws . .	Bench	8.5	5.6
44. Water test	--	2.0	24.0
45. Surface grind top	Mattison surface grinder	6.5	7.4
46. Counterbore top of bores for cylinder sleeves. Drive in spray nozzle bushings. . .	No. 242 Barnes drill Hammer	6.8	7.0
47. Finish-bore combustion cups .	No. 217 Baker drill	4.1	11.7
48. Assemble cylinder sleeves . .	Hannifin 4-column hydraulic press	3.1	15.4
49. Hone cylinders, rough and finish . .	2 Barnes cylinder honing machines, equipped with hydraulic index tables.	14.6	3.3
Drill 23/32" hole for 1/2" tap .	--		
Total, all operations		268.3	

Table 10. Cylinder head for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
1. Rough and finish mill top and bottom, rough mill exhaust pad and air intake pads. . . .	Ingersoll fixed-rail milling machine	1.4	35.0
2. Drill 12 holes 19/32", 2 process holes 1/2" combination drill and ream 10 holes 1/2", drill 4 holes 5/8", 1 hole 5/16", and 6 manifold pad holes 5/16". . . .	Baush 28-spindle hydraulic multidrill	8.9	5.4
3. Drill 26 holes 5/8", core drill 8 holes 23/32" and drill 4 holes 5/16". . . .	No. 32 Natco 36-spindle multidrill	6.8	7.1
4. Machine valve holes	Natco 60-spindle multidrill	8.5	5.6
5. Drill top: 4 holes 5/16" 6 holes 23/64", and 14 holes 23/32". Drill air pad: 6 holes 21/64" and 4 holes 23/64". . . .	Natco multidrill	4.2	11.4
6. Tap 6 holes 3/8"-16 in manifold pad, 6 holes 1/8" pipe in air intake side, 4 holes 7/16"-14 in air intake pad, 4 holes 3/8"-16 in top and 6 holes 7/16"-14 in top.	4' Hammond tapper	18.6	2.6
7. Tap 14 holes 1/2" pipe tap in top, core drill and ream 2 cup plug holes in ends, tap 8 holes 1/2" pipe tap in bottom, and drive pipe plugs in top and bottom.	Carleton radial, 3' arm	7.4	--
8. Water test	Tank	3.3	14.5
9. Surface grind top and bottom face. . .	Mattison surface grinder	14.1	3.4
10. Rough and finish 1.6255" combustion cups. . . .	No. 310 Baker drill press	13.8	3.5
11. Assemble valve guides, 2 at a time.	Hannifin air press	2.5	19.2
Total, all operations	. . . .	89.5	

Table 11. Connecting rod for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
1. Straighten rod forging	Bench	0.6	96
2. Center drill piston-pin end, mill 1/2" locating spot, mill 1 side of crank end (allow .010" on side for grinding). Check contour of rod.	2 Sunstrand milling machines	2.1	23
3. Rough bore crank end, drill and ream piston-pin hole.	Barnes 6-spindle drill	2.9	17
4. Mill other side of crank end .	--	1.0	48
5. Broach cap attaching face . . .	--	1.0	48
6. Drill oil hole 7/37"	Leland-Gifford 4-spindle drill	3.6	13
7. Drill 2 bolt holes 27/64" rough ream 2 bolt holes 1/2" and counterbore to .575". . . .	Natco multiple-spindle drill with 36" index table	2.1	23
8. Tap 2 holes 9/16"-18	Bakewell tapper	2.5	19
9. Broach joint face keys	American 15-ton dual-ram broaching machine	.9	53
10. Ream 1/4" oil tube hole	Sensitive drill	.5	96
11. Drill 2 air holes 1/8"	Sensitive drill	.6	80
12. Burr and wash	Bench and tank	3.3	15
13. Assemble rod and cap	Bench	2.0	24
14. Semifinish bore crank end to 2.545". . . .	Ex-Cell-O double-3-spindle boring machine	1.5	36

Table 11. Connecting rod for reported 6-cylinder diesel engine: Machinery and man-minutes required for production, by manufacturing operation, plant A, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
15. Precision bore both crank end and piston-pin end. . .	Ex-Cell-O double-end 4-spindle boring machine	1.5	36
16. Chamfer both sides of crank end.	Single-spindle drill	.9	53
17. Disassemble rod and cap	Bench	2.0	24
18. Mill bearing notch in rod . .	Kent Owens handmill	.7	69
19. Mill bearing notch in cap . .	Kent Owens handmill	.7	69
20. Burr and reassemble rod and cap. .	Bench	2.0	24
21. Hone crank end to size	Micromatic hone	1.5	36
22. Assemble piston-pin bushing. .	Air press	1.8	27
23. Precision bore piston-pin bushing hole to 1.126"-1.1255" . .	Ex-Cell-O 2-spindle precision boring machine	(1/)	(1/)
Total, all operations . . .	. . . .	35.7	

1/ Information not available.

Table 12. Connecting rod cap for reported 6-cylinder diesel engine: Machinery and man-minutes required per unit, by manufacturing operation, plant A, U. S. A., selected period, 1953

Operation	Machinery and equipment	Man-minutes per operation	Hourly machine capacity
1. Rough disc grind attaching face of cap.	Gardner double-end grinder	0.5	96
2. Mill both sides of crank hole	Kearney Trecker milling machine	(1/)	(1/)
3. Drill 2 bolt holes 17/32" ream 2 bolt holes 37/64", rough and finish spot-face 2 bolt holes 1-1/8".	Natco multiple-spindle drill with 36" index table	(2/)	(2/)
4. Broach joint face and key slots.	American broach	.9	53
5. Assemble to rod and chamfer 2 bolt holes.	Sensitive drill	(3/)	(3/)
Total, all operations		1.4	

1/ Part of rod operations Nos. 2 and 4, table 11.
2/ Part of rod operation No. 7, table 11.
3/ Part of rod operation No. 13, table 11.

Table 13. Subassemblies of reported 6-cylinder diesel engine, by operation, plant A, U. S. A., selected period, 1953

Operation
A. Crankshaft:
1. Assemble woodruff key.
2. Shrink on crankshaft gear.
3. Assemble flywheel bolts.
4. Wash and blow off.
B. Camshaft:
1. Assemble woodruff key.
2. Press on camshaft gear.
3. Assemble thrust washer.
4. Wash and blow off.
C. Connecting rod:
1. Weigh 6 connecting rods for likeness in weight.
2. Check tension on rod cap screws.
3. Check bore of crank end for size and roundness.
4. Remove rod cap.
5. Wash out long oil line in rod.
6. Assemble oil line insert tubes.
7. Assemble shells in rod and cap.
8. Check piston pin bore.
9. Weigh 6 pistons for likeness in weight.
10. Assemble pistons to rods.
11. Check rod and piston assembly and straighten when necessary.
12. Assemble rings to piston.
D. Idler gear:
1. Press small gear on idler shaft.
2. Assemble large idler gear and bolt to small gear.
3. Wire cap screws in place.
E. Gear cover:
1. Press oil seal in gear cover.
2. Assemble 2 thrust screws.

Table 13. Subassemblies of reported 6-cylinder diesel engine, by operation, plant A, U. S. A., selected period, 1953—Continued

Operation
F. Combustion cup liners:
Assemble dowel in upper half.
G. Cylinder head:
1. Snag.
2. Ream valve guides.
3. Grind valve seats.
4. Wash and blow out.
5. Assemble valves complete.
H. Lower half of oil pan:
Assemble baffle plate and wire screws in place.
I. Rocker arm:
1. Assemble adjusting screws in rocker arms.
2. Assemble rocker arm bracket on center of shaft and lock in place with cylinder head cover shoulder screw.
3. Assemble spacer springs, 2 brackets, 6 rocker arms, 2 retaining screws in end of shaft.
4. Assemble 2 cylinder head cover shoulder screws to 2 rocker arm brackets (2 separate assemblies required).
J. Cylinder head cover:
Assemble 2 cylinder head knobs.
K. Air intake manifold:
1. Assemble plug for nozzle opening.
2. Assemble plug for electrode opening.
3. Assemble plug for ground electrode opening.

Table 14. Final assembly of reported 6-cylinder diesel engine, by operation, plant A, U. S. A., selected period, 1953

Operation
1. Fit pistons.
2. Snag (remove sand and rough edges).
3. Ream camshaft bearing and tappet guides.
4. Drive cylinder head studs.
5. Wash.
6. Inspect and blow out.
7. Remove main bearing caps.
8. Assemble shells in block and cap.
9. Assemble tappets.
10. Reassemble main bearing caps.
11. Check crankline bore side.
12. Remove main bearing caps.
13. Lay crankshaft (see subassembly A).
14. Reassemble main bearing caps and 4 thrust flanges to rear main bearing cap.
15. Assemble oil pump on front main bearing cap.
16. Assemble camshaft (see subassembly B).
17. Pipe plug oil header hole in bellhousing and gear cover ends.
18. Assemble metering plug in oil line in water pump drive bore in gear cover flange.
19. Assemble front half of bellhousing and indicate oil seal bore.
20. Assemble oil seal in bellhousing.
21. Assemble 6 connecting rod assemblies (see subassembly C).
22. Assemble dowel pin in idler bushing.
23. Assemble idler gear (see subassembly D).
24. Assemble gear cover (see subassembly E)
25. Check height of piston to top deck of block.
26. Assemble 2 parts of combustion cup liners (see subassembly F).
27. Assemble valve tappet cover.
28. Assemble water pump studs in block.
29. Assemble water pump.
30. Wire connecting rod cap screws.
31. Assemble spray nozzle studs.
32. Rough assemble spray nozzle clamps for further assembly of spray nozzle.

Table 14. Final assembly of reported 6-cylinder diesel engine, by operation, plant A, U. S. A., selected period, 1953--Continued

Operation
33. Assemble cylinder head (see subassembly G).
34. Assemble all oil lines to pump and to block and wire in place.
35. Assemble oil purifier studs to block.
36. Assemble oil purifier.
37. Assemble upper half of oil pan.
38. Study upper half of oil pan
39. Assemble lower half of oil pan (see subassembly H).
40. Assemble studs in lower half of oil pan for strainer.
41. Assemble oil strainer to lower half of oil pan.
42. Assemble push rods.
43. Assemble rocker arm assemblies (see subassembly I).
44. Assemble exhaust manifold studs to head.
45. Assemble exhaust manifold.
46. Assemble cylinder head cover (see subassembly J).
47. Assemble air intake manifold to head.
48. Assemble air intake manifold (see subassembly K).

CASE STUDY, PLANT B

PRODUCTS AND VOLUME OF PRODUCTION

Product Description

The reported industrial-type 4-cylinder, 4-cycle diesel engine for plant B has overhead valves, wet sleeve cylinders, pressure lubrication and a radiator cooling system which forces the coolant entirely around the removable cylinder sleeves, valves, and combustion chambers. It is designed to operate on fuel of 45 centane or above and develops approximately 31 horsepower at 2,000 r.p.m. for continuous full-load service. The cylinder block is combined with the crankcase and is machined from a 1-piece iron casting. The cylinder head is also machined from an iron casting. The 3-bearing crankshaft is a heat-treated steel drop forging, as are the connecting rods. Pistons are of aluminum alloy with 3 compression rings and 2 oil control rings. The engine is assembled with varied mountings and flywheels to accommodate different service or installation needs. Its application is primarily industrial such as in power pumps, small generators, concrete mixers, silo fillers, and portable saws.

The reported 6-cylinder, 4-cycle diesel engine has characteristics similar to those of the 4-cylinder engine, except for the cylinder head, and crankshaft, and in its size and uses. The cylinder head is composed of twin, interchangeable castings, front and rear. This 6-cylinder engine develops approximately 120 horsepower at 1,400 r.p.m. for continuous full load service and is adaptable to oil field uses, construction machinery, agricultural equipment, logging and lumbering, and small community lighting plants.

Production

During 1953, plant B reported production of 58 6-cylinder and 124 4-cylinder engines of the reported types, representing approximately 1 percent of the value of the plant's total production.

Man-hour requirements for the production of the reported engines are shown in table 16. Man-hours required, by operation, to process selected parts for the reported 4- and 6-cylinder engines are presented in tables 22 through 27.

GENERAL PLANT INFORMATION

Buildings

The plant property area, consisting of factories, warehouses, administrative offices, yards, and railroad sidings, covers about 20 acres. The major factory building is a 1-story brick, steel frame structure of saw-tooth architectural design.

OPERATING PRACTICES

Purchasing

The 4-cylinder diesel engine reported on by plant B contains approximately 850 separate parts. About 185 of these parts are manufactured in the plant and the remaining parts are purchased. The parts required for the production of the cylinder block assembly, cylinder head assembly, and the connecting rod assembly, are listed in tables 17, 18, and 20, respectively. Miscellaneous parts, which are purchased, are listed in table 19. Parts which are manufactured in the plant are listed in table 21.

Listings of manufactured and purchased parts for the production of the reported 6-cylinder engine were not obtainable, but it was estimated that of approximately 1,624 parts required, 21 percent were manufactured in the plant.

The wide divergence in the number of parts required for the manufacture of the reported 4- and 6-cylinder engines is due to the dissimilarity between these two models.

Unionization

At the time of this survey, plant production employees were covered under a contract with the International Association of Machinists (AFL).

Employment

During the reporting period, plant B employed approximately 1,000 production and related workers including 40 women. Office and administrative and other nonproduction workers totaled approximately 500 additional employees including about 300 women.

LABOR PRACTICES

Wages

Indirect workers are paid on an hourly wage basis according to specified rate ranges for various job classifications.

Direct workers are paid incentive rates based upon standard work measurements. Individual operations are time studied and standard time rates are established by the following formula which is applied to all incentive jobs or operations:

Item	Employment group 1	2	3
1. Actual stopwatch time (percent)	100	100	100
2. Personal allowance (percent of item No. 1)	5	5	5
3. Machine or assembly allowance (percent of item No. 1)	15	10	5
4. Allowed time (items No. 1, No. 2, and No. 3) . . .	120	115	110
5. Incentive allowance (40 percent of item No. 1) . .	40	40	40
6. Standard time rate (percent of item No. 1)	160	155	150

Incentive workers are placed in one of the 3 groups by a formula that includes such factors as skill, physical effort, responsibility, and job conditions. By producing in less time than the standard time rate, the employee earns a bonus. The factors that determine the standard time rate are sufficiently flexible to permit most employees to earn a production bonus.

Hours

Plant B operates on an 8-hour day, 40-hour week work schedule, Monday through Friday. Work in excess of 8 hours per day and work on Saturdays is considered overtime and is compensated for at time and one-half of the earned rate. Work performed on Sundays and six specified legal holidays is paid for at double the earned rate. Pay for work performed on these holidays is computed on the basis of the average hourly earnings of the employee during his first 90 days of employment or his average hourly earnings from January 1 to approximately June 1 if employed during that period.

Paid vacations are also provided to eligible employees based on length of continuous service. Compensation for these vacations is based on average hourly earnings from January 1 to approximately June 1 of the year in which the vacation is granted. Paid vacations provided for varied lengths of service are shown below:

Length of service	Vacation hours granted
6 months but less than 9 months	20
9 months but less than 12 months	30
1 year	40
4 years, 3 months but less than 6 months	50
4 years, 6 months but less than 9 months	60
4 years, 9 months but less than 12 months	70
5 years	80
14 years, 3 months but less than 6 months	90
14 years, 6 months but less than 9 months	100
14 years, 9 months but less than 12 months	110
15 years and over	120

Plant workers receive a 10-minute paid rest period and a 5-minute paid period to wash and clean up at the end of each work shift. Office personnel are granted two 10-minute paid rest periods each day. A 45-minute unpaid lunch period is provided all employees.

Fringe Benefits

After 2 months' employment employees become eligible to participate in group life and hospital expense insurance plans, including surgical reimbursement benefits for themselves and their dependents. The plans provide $1,000 life insurance and $7 daily hospital expense for each employee, $140 maximum reimbursement for additional hospital expense, and $200 maximum surgical reimbursement for each employee and his dependents. The costs of these plans are shared by the employer and the employee.

A pension plan which is in effect at the plant permits a participating employee to retirement income supplemental to that provided under the Federal Social Security Act. All regular employees who have completed at least 5 years of continuous service and who have not reached age 65 are eligible. Employees who are over 65 and have more than 5 years of continuous service are eligible for a retirement annuity with more liberal benefits. Contributions to this pension plan are made by both the employer and the employee. Each member of the plan will, upon retirement, receive a monthly retirement income based on the number of years he has contributed and his earnings during the period of contribution.

VARIETY OF PRODUCTS

In addition to the production of the reported 4- and 6-cylinder diesel engines, plant B produced other types of diesel engines. The total of all diesel engine types produced accounted for approximately 20 percent of the value of all shipments. These shipments included gas and gasoline engines, railroad air-conditioning units, and sales of miscellaneous services.

PROFESSIONAL AND ENGINEERING SERVICES

Plant B maintains its own engineering department which performs production engineering, methods and time study engineering, and product design engineering. This department is staffed by 41 employees, including 9 women.

Market analysis is made by 6 employees in the sales force at the general offices.

Production Control

Planning of the entire sequence of operations in this plant is begun after the receipt of an order from a customer. First, a specification is written and sent to the production control department where it is divided into product classes. Each product class is sent to the model controller where it is posted on cards. Orders requiring these products are grouped until a sufficient number is accumulated to permit economical runs. Castings are then purchased and orders are issued to the shop for manufacture.

Copies of each production order form are prepared and used for various purposes. One copy is used for control scheduling on which all material and disposition of parts are recorded. This copy is held until all parts are completed or accounted for and routing is closed. Another copy is sent to the shop clerk to record time and quantities. The payroll office receives a copy as a comparative check with the shop clerk. An inspection copy records the number of good pieces and rejections. Another copy is used for operating instructions, tool numbers, machine numbers, times, and quantities. The cost department receives a copy to record labor and burden.

Inventory Control

Records of new materials withdrawn from inventory and delivered to the shop to be made into finished parts are kept on a series of multicolored forms for easy identification. A master form records all raw materials delivered to the shop and shows the number of parts to be made. A copy is sent to the posting department to record the progress of manufacture. The first posting occurs when the master form is sent to the rate department to determine the various factors needed for manufacture, such as standard hours per piece and machines to be used. A second posting is made when the parts are actually in the process of manufacture.

Another copy is sent to the inspection department. It is used to establish the quantities of raw materials received from the stockroom and the number of finished goods parts returned to finish stock.

Two additional copies of the master form are sent to the shop clerk to establish the quantities of parts between the payroll department and the shop clerk.

Some items are purchased on a "maximum-minimum" basis according to a perpetual inventory system. Under this system when the supply of a certain item falls to a predetermined minimum number an order for the item is placed to bring the inventory up to its maximum specified number. The quantity ordered is usually the smallest economical lot the plant can purchase. For example, the smallest economical order for steel bar stock might be one carload. This system is employed for regularly used items such as copper tubing, bar stock, and certain fasteners such as bolts and nuts.

MANUFACTURING PRACTICES

Derivation of Man-Hour Data

Direct man-hours were derived from time cards and payroll summary sheets.

Indirect man-hours were obtained from Controllable Expense Percentage Reports prepared by the company and based on productive labor factory reports.

Cylinder Block-Crankcase for 4-Cylinder Diesel Engine

The cylinder block is integral with the crankcase and is cast in one piece. It is made of special cast iron, heavily ribbed to provide strength and rigidity for maintenance of alinement under working conditions. The lower cross members are machined for the crankshaft bearings. Sides of the cylinder block extend downward, well below the crankshaft centerline and have flanges for fastening the oil pan. The upper part provides for full length water jackets for the wet cylinder sleeves. The camshaft is mounted in the upper portion of the cylinder block at one side. An enclosed space at the side of the block is provided for the valve push rods. Feet or pads for mounting the engine are provided on the base.

Machinery and equipment used in man-hours required per 100 cylinder blocks, by operation, are presented in table 22. The parts used in the cylinder block assembly are listed in table 17.

Cylinder Block-Crankcase for 6-Cylinder Diesel Engine

The cylinder block for the reported 6-cylinder engine is a single high-grade iron casting with 7 heavily ribbed main bearing supports and locations for 6 wet-type cylinder sleeves, and is integral with the crankcase. A coolant passes between the cylinder block walls and the removable cylinder sleeves. The cylinder block has four locations for the camshaft bushings. These bushings support the camshaft at the front, rear, and two intermediate points. During operations, the bushings are supplied with oil under pressure. Above the camshaft are 12 valve lifter bores machined in the cylinder block. These bores may be rebushed if necessary. Drilled holes from the lifter compartment drain oil from the valve mechanism to each lifter and cam lobe.

The forward end of the crankshaft provides a housing for the crankshaft drive gear, cam gear, idler gear, fuel pump drive gear, and the oil pump drive gear. The rear of the cylinder block provides a surface for the flywheel housing. To assure accurate mounting of the clutch or other drive units on the flywheel housing, the rear surface of the cylinder block is held to close tolerances and the flywheel bore and face are machined true after assembly. Inspection panels are provided on the left side of the cylinder block to permit cleaning. A rifle-drilled passage on the left side of the cylinder block forms the main pressure oil header.

Faced mounting bosses and connections are provided at various points of the cylinder block exterior for mounting accessories, lines, and other equipment desired by the purchaser.

Operations, man-hours required, and machinery used in the manufacture of the cylinder block are shown in table 23.

Cylinder Head for 4-Cylinder Diesel Engine

The cylinder head is cast in one piece for this 4-cylinder engine. It carries the combustion chambers and the intake and exhaust valves. The combustion chambers with their fuel injectors are set at an angle at one side of the cylinder head in order to be outside of the valve and gear enclosures. Chrome-silicon alloy intake and exhaust valves and hardened alloy valve seats are used. Brackets bolted to the top of the cylinder head carry the valve rocker fulcrum pins. Removable covers enclose the valve ends and valve gear on top of the cylinder head. Valve rockers are actuated from the camshaft by hollow push rods.

Machinery and equipment used and man-hours required per 100 cylinder heads, by operation, are shown in table 24. A list of the parts used in the cylinder head assembly is presented in table 18.

Cylinder Head for 6-Cylinder Diesel Engine

Two interchangeable cast iron cylinder heads are used on this model. Three intake valve guides and three exhaust valve guides are pressed into each head. Stellite inserts are pressed and rolled into each valve seat. Intake manifold mounting pads are located on the left side of each head; exhaust pad on the right side.

The combustion chambers with their fuel injectors are set at an angle at one side to be outside of the valve and valve gear enclosure. They can be removed from the engine without disturbing any other parts.

Operations, man-hour requirements, and machinery used in the manufacture of the cylinder head are shown in table 25.

Connecting Rod for 4-Cylinder Diesel Engine

The connecting rods for this engine are drop-forged from heat-treated alloy steel and fitted with stout piston pins and heavy duty steel-backed, copper-lead-babbit precision-type, replaceable crankpin bearings. The upper ends of the rods carry hard bronze bushings for the full-floating piston pins. Bearing caps are heavily ribbed and fitted to the rod with alloy steel, heat-treated bolts. All rods are carefully balanced and installed in precision-matched sets. The machinery and equipment used and man-hours required to produce these rods are shown, by operation, in table 26. A list of the parts used in the connecting rod assembly is shown in table 19.

Connecting Rod for 6-Cylinder Diesel Engine

Six drop-forged and heat-treated, H-section connecting rods are used on this model. Four heat-treated bolts and slotted nuts retain the rod cap. The rods and caps are forged, heat-treated, and rough machined in one piece, separated and spaced with shims and then bored for steel-backed bearing shells. The shells are located in the rod and cap by small offsets which engage reliefs in the rod and cap at the split line. Hard bronze bushings are pressed into the piston pin end of the rod and diamond bored for size and alinement. These bushings are used as a reference point for boring the lower end bearing seat. A rifle-drilled passage through the rod from the large end bearing conducts oil to the piston pin and piston cooling jet.

The crankpin bearing shell seats are then bored and ground. During assembly, laminated shims are used between the rod and the cap in order that the shims may be peeled apart for adjustments.

Operations, man-hour requirements, and machinery used in the manufacture of connecting rods are shown in table 27.

Assembly

The reported 4-cylinder engine is assembled by means of a full line conveyor system and the use of a monorail track and electric hoists. During the reporting period, the plant estimated that a crew of 16 men assembled 250 of the reported engines in a 40-hour week. The sequence of operations is shown below.

1. Hoist crankcase to conveyor with electric hoist and assemble four cylinder sleeves to crankcase.
2. Assemble camshaft to crankcase.
3. Assemble crankshaft to crankcase.
4. Hoist engine to line assembly with electric hoist, and assemble flywheel housing to crankcase.
5. Subassemble piston rings and connecting rods to pistons.
6. Assemble flywheel to crankshaft.
7. Assemble gear cover to crankcase.
8. Assemble pistons and connecting rod assemblies to crankcase.
9. Assemble oil pump to crankcase.
10. Assemble fuel pump to crankcase.
11. Assemble combustion chamber cups and caps to cylinder head.
12. Assemble four fuel injectors to combustion chamber caps.
13. Assemble cylinder head to crankcase.
14. Assemble oil pan to crankcase.
15. Electric hoist engine to roller conveyor and assemble water pump to crankcase.
16. Assemble rocker arm assemblies to cylinder head.
17. Assemble combination manifold to cylinder head.
18. Assemble lubricating oil filter to crankcase.
19. Assemble generator to bracket.
20. Assemble electric starter to flywheel housing.
21. Finish bore and face flywheel housing.
22. Assemble fuel injector lines to motor.
23. Assemble fuel oil filter to crankcase.
24. Assemble rocker arm cover.
25. Electric hoist engine to monorail track to test room.

Two subassembly operations, in addition, are necessary to prepare for final assembly.

1. Subassemble rocker arms, rocker arm shaft, and rocker arm supports.
2. Subassemble water pump.

Assembly of the 6-cylinder engine is somewhat similar, but the plant estimates that 4 men are required to assemble 15 engines during a 40-hour week. The sequence of operations follows.

1. Hoist crankcase to rail assembly fixture (full line) and assemble cylinder head studs to crankcase.
2. Assemble 6-cylinder sleeves to crankcase.
3. Assemble camshaft to crankcase.

4. Assemble crankshaft to crankcase.
5. Assemble oil cooler to crankcase.
6. Subassemble piston rings and connecting rods to pistons.
7. Assemble pistons and connecting rod assemblies to crankcase.
8. Assemble oil pump to crankcase.
9. Assemble water pump to motor.
10. Assemble combustion chamber cups and caps to cylinder heads.
11. Assemble 2 cylinder heads to crankcase.
12. Assemble rocker arm assemblies to cylinder heads.
13. Assemble oil pan to crankcase.
14. Assemble flywheel housing to crankcase.
15. Assemble flywheel to crankshaft.
16. Assemble intake manifold to cylinder heads.
17. Assemble 6 fuel injectors to combustion chamber caps.
18. Assemble gear cover to crankcase.
19. Assemble 2 lubricating oil filters to crankcase.
20. Finish bore and face flywheel housing.
21. Assemble fuel pump to crankcase.
22. Assemble fuel oil filter to crankcase.
23. Assemble fuel injector lines to motor.
24. Assemble exhaust manifold to cylinder heads.
25. Assemble generator and regulator to bracket.
26. Assemble electric starter to flywheel housing.
27. Assemble rocker arm covers.
28. Electric hoist engine to monorail to test room.

In addition to the above, two subassemblies are necessary to prepare for final assembly.

1. Subassemble rocker arms, rocker arm shaft, and rocker arm support.
2. Subassemble water pump.

Inspection

Each part processed in the plant is inspected at least once, generally after the completion of processing. In addition, inspectors constantly check the entire production lines for conformity to specifications. When necessary, adjustments are made to machines by setup men to correct discrepancies.

Productivity Factors

During the past 5 years this plant has changed some production methods which have greatly increased production and decreased costs. Examples of some of these changes are presented below.

1. A production line was redesigned and machinery installed which made it possible to machine wet cylinder liners in four simple operations. As a result, labor costs were reduced from 30 cents per sleeve to approximately 6 cents.

2. The plant had previously subcontracted the flame hardening of the bearings of their crankshafts. The plant's engineers designed and manufactured a machine to flame harden 2 crankpin bearings and another machine to flame harden 7 main bearings simultaneously. The use of these machines reduced the cost of flame hardening considerably compared with the cost involved in having the work subcontracted.

3. A completely new machinery line was installed to machine camshafts. This line included a machine to make master camshafts which are used as templates for the grinders. The plant reported a significant reduction in cost as the result of this new line setup.

Percent Distribution of Cost

Direct material costs amounted to 64 percent of the total manufacturing cost of the reported engines. A breakdown of the entire costs is shown in the tabulation following.

Cost item		Percent
Labor		24.0
Direct materials		64.0
Other factory cost - total		12.0
Electricity	.5	
Fuel	.5	
Maintenance (supplies and equipment)	1.0	
Miscellaneous factory cost	10.0	
Total		100.0

Selling costs amounted to 2.5 percent of the total operating costs during the reporting period. These costs were distributed as follows: Advertising, 25 percent; salesmen's salaries and commissions, 44 percent; and other miscellaneous expenses, 31 percent.

Marketing

This plant operates branches in three large cities in the United States in addition to its main plant. These branches, or warehouses, maintain complete supplies of parts for rapid servicing of their independent retailers and distributors. Distributing and servicing representatives are located throughout the United States and in every important market in the world.

Table 15. Specifications of the reported 4- and 6-cylinder diesel engines, plant B, U. S. A., 1953

Specification 1/	4-cylinder model	6-cylinder model
Cycle - stroke	4	4
Bore - inches	3-1/2	5-1/4
Stroke - inches	3-3/4	6
Horsepower - continuous full load	31	120
Revolutions per minute - continuous full load .	2,000	1,400
Length - inches	31	56
Height - inches	28	48
Width - inches	19	27
Weight - pounds - excluding accessories	475	2,300
Piston displacement - cubic inches	144	780
Main bearings - number	3	7

1/ Specifications of some items are shown as approximations to avoid disclosure of confidential plant information.

Table 16. Direct and indirect man-hour requirements per unit for production of the reported 4- and 6-cylinder diesel engines, plant B, U. S. A., 1953

Model	Man-hours per engine		
	Total	Direct	Indirect
4-cylinder	96	28	68
6-cylinder	337	100	237

Table 17. Parts for cylinder block-crankcase assembly for the reported 4-cylinder diesel engine, plant B, U. S. A., 1953

Parts (manufactured in plant)	Number required per engine	Parts (purchased)	Number required per engine
Cylinder block	1	Lockwashers	6
Main bearing caps	2	Front cam bushing	1
Main bearing cap, thrust	1	Headless pipe plugs	3
Main bearing cap screws	6	Headless pipe plugs	2
Governor gear bushing sleeve	1	Pipe plugs, rear of case	3
Governor gear bushing	1	Pipe plug	1
Timing gear oil tube	1	Expansion plug, rear cam	1
Push rods	8	Main bearings, lower	2
Valve lifters	8	Main bearings, upper	2
Rear oil retainer	1	Main bearings, thrust	2
Stud	1	Cap screw	1
Oil retainer, outer	1	Copper washer	1
Oil retainer, inner	1	Oil retainer spring	1
Cylinder head dowels	2	Idler gear bushings	2
Idler gear bushing sleeve	1	Front seal	1
Oil relief valve screw	1	Oil filler tube	1
Oil relief valve plunger	1	Rear oil retainer gasket	1
Hour meter hole cover	1	Cap screws	8
		Lockwashers	8
		Oil relief valve screw gasket	1
		Oil relief valve spring	1
		Distributor hole plug	1
		Name plate	1
		Escutcheon pins	4
		Street ell	1
		Drain cock	1
		Governor hole plug	1
		Hour meter cover gasket	1
		Cap screws	4
		Cup plug	1
		Cap screw	1
		Copper washer	1

Table 18. Parts for cylinder head assembly for the reported 4-cylinder diesel engine, plant B, U. S. A., 1953

Parts (manufactured in plant)	Number required per engine	Parts (purchased)	Number required per engine
Cylinder head	1	Expansion plugs	2
Valve guides, intake	4	Intake valves	4
Valve guides, exhaust	4	Exhaust valves	4
Inserts, intake	4	Valve springs	8
Inserts, exhaust	4	Valve spring tapers	16
Combustion cup dowels	4	Valve spring retainers	8
Combustion chamber cups	4	Valve stem seal guards	4
Combustion chamber caps	4	Valve stem seals	4
Combustion chamber cap studs	8	Combustion chamber cap gasket	8
Combustion chamber cap studs	8		
Dowels	2	Marsden nuts	16
Rocker arm shaft	1	Combustion chamber rubber rings	4
Rocker arms	4	Cylinder head gasket	1
Rocker arms	4	Rocker arm shaft plugs	2
Rocker arm supports	4	Adjusting screws	4
Rocker arm support stud	1	Half nuts	4
Rocker arm support studs	3	Adjusting screws	4
		Half nuts	4
		Rocker arm springs	2
		Rocker arm shaft washers	8
		Rocker arm shaft cotter pins	4
		Hex nuts	4
		Lockwashers	4
		Cylinder head cap screw	1
		Cylinder head cap screws	7
		Cylinder head cap screw	1
		Cylinder head cap screws	4
		Washers	13
		Copper tube, oil line	1
		Nuts	2
		Elbow	1
		Elbow	1

Table 19. Miscellaneous parts purchased and used in the production of the reported 4-cylinder diesel engine, plant B, U. S. A., 1953

Parts	Number required per machine	Parts	Number required per engine
Cylinder sleeve packing rings	8	Gear cover and front plate assembly—Continued	
Piston assembly:		Copper washers	4
Pins	4	Cap screws	11
Pin retainers	8	Cap screw	1
Rings, top	4	Lockwashers	12
Rings, No. 2	4	Fan pulley felt	1
Rings, No. 3	4	Pipe plug	1
Rings, oil	8	Oil pan assembly:	
Crankshaft assembly:		Drain plug	1
Key	1	Drain plug gasket	1
Washer	1	Street ell	1
Lockwasher	1	Pipe plug	1
Camshaft assembly:		Pan gasket	1
Key	1	Cap screws	25
Thrust button spring	1	Lockwashers	25
Idler gear assembly:		Cap screws	2
Plunger spring	1	Water pump assembly:	
Key	1	Flinger	1
Oil pump assembly:		Seal	1
Vane spring	1	Cover gasket	1
Cap screws	4	Snap wire	1
Lockwasher	4	Cap screws, flathead	4
Screen	1	Lockwashers, shakeproof	2
Cotter pin	1	Gasket, pump to case	1
Cap screw	1	Cap screws	4
Lockwasher	1	Lockwashers	4
Gear cover and front plate assembly:		Cap screws	4
Gear cover	1	Lockwashers	4
Thrust buttons	2	Oil gage assembly:	
Front plate gasket	1	Blade	1
Gear cover gasket	1	Blade washer	1
Gear cover post gasket	1	Intake manifold gaskets	2
Flathead machine screws	2	Pipe plug, intake manifold	1
Fuel pump gear cover	1	Exhaust manifold assembly:	
Fuel pump gear cover gasket	1	Gaskets	4
Cap screws	4	Washers	2

Table 19. Miscellaneous parts purchased and used in the production of the reported 4-cylinder diesel engine, plant B, U. S. A., 1953--Con.

Parts	Number required per engine	Parts	Number required per engine
Exhaust manifold Assembly:--Continued		Injection pump assembly:	
Nuts	4	Fuel injection pump	1
Cap screws	2	Spring	1
Lockwashers	2	Restrictor elbow	1
Pipe plug	1	Washers, shakeproof	2
Air cleaner assembly:		Lockwasher	1
Air cleaner	1	Hex nut	1
Gasket	1	Gear hub cap screws	2
Cap screws	2	Brass wire	1
Lockwashers	2	Cap screws	2
Breather gasket	1	Fuel pump cap screw	1
Fan drive pulley assembly:		Copper tube	1
Pulley, stationary half	1	Inverted nuts	2
Pulley, adjustable half	1	Sealing wire	1
Lock screws	3	Sealing wire	1
Lock screw washers	3	Fitting	1
Lock nuts	3	Fitting	1
Thermostat housing assembly:		Fuel injector assembly:	
Gasket	1	Fuel injectors	4
Thermostat	1	Nozzle	1
Cap screws	2	Holder	1
Cap screw	1	Hex nuts	8
Lockwashers	3	Drip line tube	1
Flywheel housing attachment parts:		Tube nuts	2
Cap screws	8	Tee	1
Lockwashers	8	Tees	3
Cap screws	3	Elbow	1
Lockwashers	3	Tube	1
Timing cover	1	Nuts	2
Cap screws	2	Injector tubing assembly:	
Lockwashers	2	Tube No. 1	1
Flywheel attachment parts:		Tube No. 2	1
Cap screws	6	Tube No. 3	1
Lockwashers	6	Tube No. 4	1
		Ermetto nuts	8
		Ermetto sleeves	8
		Cap screws	4
		Hex nuts	4
		Lockwashers	4

Table 19. Miscellaneous parts purchased and used in the production of the reported 4-cylinder diesel engine, plant B, U. S. A., 1953--Con.

Parts	Number required per engine	Parts	Number required per engine
Rocker arm cover assembly:		Fuel oil filter assembly:	
Name plate	1	Fuel oil filter	1
Drive screws	6	Cap screws	2
Gasket	1	Lockwashers	2
Hex nuts	4	Cap screws	2
Copper washers	4	Lockwashers	2
Oil filter assembly:		Hex nuts	2
		Copper tubing	1
Oil filter	1	Elbows	2
Gaskets	2	Bushings	2
Cap screws	2	Clip, tubing	1
Lockwashers	2	Cap screw	1
Cap screws	3	Copper tube	1
Lockwashers	3	Elbow	1
Pipe plugs	4	Connector	1
Machine screw	1	Fuel Supply pump parts:	
		Gasket	1
		Cap screw	2
		Copper washers	2
		Street ell	1
		Fuel pump	1
		Copper washers, electrical equipment	4

Table 20. Parts for connecting rod assembly for the reported 4-cylinder diesel engine, plant B, U. S. A., 1953

Parts (manufactured in plant)	Number required per engine	Parts (purchased)	Number required per engine
Connecting rods	4	Piston pin bushings	8
		Connecting rod bolts	8
		Connecting rod nuts	8
		Connecting rod bearings	8

Table 21. Miscellaneous parts manufactured in plant for the reported 4-cylinder diesel engine, plant B, U. S. A., 1953

Parts	Number required per engine	Parts	Number required per engine
Cylinder sleeves	4	Oil gage assembly:	
Pistons	4	Oil gage cap	1
Crankshaft assembly:		Oil gage blade nut . . .	1
Crankshaft	1	Intake manifold	1
Crankshaft gear	1	Exhaust manifold assembly:	
Starting crank jaw . . .	1	Exhaust manifold	1
Camshaft assembly:		Studs	4
Camshaft	1	Clamps	2
Cam gear	1	Exhaust flange	1
Thrust button	1	Air intake elbow	1
Idler gear assembly:		Breather	1
Idler gear	1	Thermostat housing	1
Idler gear spindle . . .	1	Flywheel housing assembly:	
Idler gear plunger . . .	1	Dowel pins	2
Oil pump assembly:		Dust plate	1
Oil pump body	1	Timing pointer	1
Oil pump cover	1	Flywheel attaching dowels	2
Oil pump shaft	1	Fuel injection pump assembly:	
Oil pump vanes	2	Reducing bushing	1
Oil pump drive gear . .	1	Fuel pump gear	1
Oil pump gear pin . . .	1	Fuel injector assembly:	
Gear cover and front plate:		Studs	8
Front plate	1	Drip line	1
Dowel pins, plate and cover	2	Injector tube clamps . . .	4
Oil pan	1	Rocker arm cover	1
Water pump assembly:		Oil filter adapter, lubrication	1
Water pump body	1	Fuel oil filter bracket	1
Water pump shaft	1	Glow plug hole plugs . . .	4
Water pump impeller . .	1		
Water pump cover	1		
Fan hub	1		
Water pump pulley . . .	1		
Generator pulley	1		

Table 22. Cylinder block-crankcase for reported 4-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953

Operation	Machinery	Standard man-hours per 100 cylinder blocks	Setup man-hours
1. Mill top and bottom . . . . (Leave 1/32" on top and bottom).	Davis and Thompson rotary mill	8.7	12.20
2. Drill and ream locating holes, . bore and ream breather hole, core drill hour meter pad.	Avey drill press	8.7	1.30
3. Rough and finish mill both ends . and chamfer breather hole.	Davis and Thompson rotary mill	8.7	8.30
4. Finish mill pan rails and cap . . shim faces.	Ingersoll vertical mill	8.7	8.00
5. Rough and finish bore cylinder . sleeve bores, and rough counterbore. (Leave .015" to .030" on depth and .030" on diameter of counterbore).	Ingersoll hole hog Moline hole hog	8.7	16.50
6. Straddle mill mains and mill . . fuel pump, oil filter, and distributor pads.	Newton straddle mill Milwaukee horizontal mill	8.7	5.30
7. Mill hour meter pad and drill . . 3 oil galleries.	Milwaukee vertical mill	8.7	1.35
	Avey 2-spindle horizontal deep hole driller		3.65
8. Drill and tap top, bottom, both . sides, and ends and chamfer bearing stud holes.	3 Natco horizontal 2-way drillers	1/8.7	46.02
	3 Natco horizontal 2-way tappers	2/8.7	
9. File pan rails, assemble caps, . rough bore main cam governor and idler bores.	Rockford horizontal boring machine	8.7	8.30
10. Finish bore front cam and . . . . governor bores, semifinish and bore mains, idler, and center, and rear cam bores.	Rockford horizontal boring machine	8.7	8.30

Table 22. Cylinder block-crankcase for reported 4-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Con.

Operation	Machinery	Standard man-hours per 100 cylinder blocks	Setup man-hours
11. Move block across aisle, disassemble bearing caps and return to bench, operation No. 9 drill 3 holes and remove chips.	2 Avey drill presses	8.7	8.50
12. Drill and end mill push rod holes, drill balance of holes omitted in two-way and drill 2 oil relief holes, multidrill 4, 5/8" cam bores to oil gallery.	2 Natco vertical multidrill presses	8.7	13.20
13. Spotface, chamfer, and ream push rod holes, brush cam bore, chamfer 2 locating holes, spotface fuel pump hole, ream flange holes and load cam bar.	Barnes drill press	8.7	1.50
14. Load buggy, drill remaining 4 oil lines in main bearing bores, drill 3 angle oil lines from side of block, load cam bar.	Baush multidrill press	8.7	2.75
15. Drill, bore, face, and ream oil pump hole and flycut hour meter hole.	American radial drill press	8.7	2.75
16. Drill and tap oil pump lock screw hole, drill idler oil relief hole and drill, spotface and ream oil relief hole, drill and ream to depth and tap oil line hole and 1 oil relief.	Hammond radial drill press	8.7	2.75

Table 22. Cylinder block-crankcase for reported 4-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Con.

Operation	Machinery	Standard man-hours per 100 cylinder blocks	Setup man-hours
17. Tap 2 pipe tap holes and drill, and tap 2 distributor mounting holes, spotface, chamfer, and tap generator bracket boss.	Hammond radial drill press	8.7	2.75
18. Counterbore and ream cam bore, rough drill distributor hole, unload side-over-side buggy and load end-over-end buggy, brush chips. .	Hammond radial drill press	8.7	2.75
19. Drill 3 drain holes to camshaft and one 3/16" water return hole and redrill 4 oil line holes for 1/4" pipe tap. . .	Hammond radial drill press	8.7	2.75
20. Tap 5, 1/4" pipe tap and hand drill 1 oil hole to idler hole, drive cam bushing and hoist block, ream 5/8" oil gallery one end. .	Hammond radial drill press	8.7	2.75
21. Drill lock slots and 4 connecting rod oil spray lines, assemble bushing to next machine, secure block, load flycutter, and start . .	Avey drill press	8.7	.75
22. Semifinish and finish bore distributor holes, line ream distributor and pump holes, finish ream sleeve clearance, and wash block. . .	2 Barnes drill presses	8.7	1.95
23. Watertest for leaks, turn block and hoist for next operation. . . .	—	8.7	3.00

Table 22. Cylinder block-crankcase for reported 4-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953—Con.

Operation	Machinery	Standard man-hours per 100 cylinder blocks	Setup man-hours
24. Assemble and torque bearing caps, chamfer and drive governor bushing, and record block number. . .	—	8.7	0.75
25. Semifinish bore main bearings. ream 4 dowel holes, face front cam and finish bore governor and idler bores. .	Natco horizontal 1-way boring machine	8.7	2.00
26. Finish mill top of block and line ream cams and brush chips from main bores. . .	Sundstrand rigid mill	8.7	4.80
27. Semifinish bore all counter-bores. . .	Barnes drill press	8.7	1.50
28. Finish seat counterbores (indicate 6 counterbores every block).	—	8.7	.50
29. Single lip ream bearing and straddle face thrust bearing. . .	Barnes horizontal boring machine	8.7	1.25
30. Drill and tap 4 hour meter pad holes, drill 1 oil filter pad hole through and spot drill 2d hole. .	Hammond radial drill press	8.7	.75
31. Ream 2 holes, chamfer all tapped holes top of block, drill 7 protector screws, file top of block to burr, record block number, and hand drill 1 hole in oil filter pad. . . .	Rockford drill press	8.7	—
32. Brush, wash, and airblast block complete. . . .	—	8.7	—

Table 22. Cylinder block-crankcase for reported 4-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Con.

Operation	Machinery	Standard man-hours per 100 cylinder blocks	Setup man-hours
33. Burr idler hole, miscellaneous repair, stamp caps and letter "A" on block and burr center bearing faces and stamp.	--	1/ 8.7 2/ 8.7	--
Total man-hours, all operations	. . . .	304.5	178.92

1/ Machine operator's time.
2/ Helper's time.

Table 23. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953

Operation	Machinery	Standard man-hours per 100 cylinder blocks
1. Drill and ream locating holes in top and bottom of block.	American radial drill press	22.0
2. Mill pan contact face and main bearing shim face.	Ingersoll vertical mill	36.0
Drill oil gallery	Avery horizontal deep-hole driller	
3. Rough mill cylinder head face compressor pad, water cross-over pad.	Stoker unit horizontal mill	1/31.0
Straddle mill both ends of block.	Ingersol Tri-plex mill	2/31.0
4. Mill clearance at rear end of block and assist in loading and unloading mill used in next operation.	Milwaukee horizontal mill.	31.0

See footnotes at end of table.

Table 23. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Con.

Operation	Machinery	Standard man-hours per 100 cylinder blocks
5. Mill water pump mounting face . .	Milwaukee horizontal mill	31.0
Mill oil cooler pad	Milwaukee vertical mill	
6. Drill top and bottom of block . .	Defiance horizontal, 2-way driller	25.0
Drill both ends of block	Greenlee horizontal, 2-way driller	
7. Drill both sides of block	Barnes horizontal, 2-way driller	12.0
Tap both sides of block	Barnes horizontal, 2-way tapper	
8. Counterbore cylinder head and main bearing stud holes and drill lock slot holes at main bearings. . .	Hammond radial drill press	20.0
9. Tap top and bottom of block . . .	Barnes horizontal, 2-way tapper	27.0
Straddle mill main bearings . . .	Newton straddle mill	
10. Drill and ream 14 bearing cap dowel holes . . .	American radial drill press	19.0
11. Chamfer bearing cap dowel holes and air blast; wipe off shim faces; install dowels; assemble and secure caps; ready caps and bolts; remove caps and dowel on finished block; load caps in pan. . . .	--	31.0
12. Drill and redrill 2 long oil holes and drill one, 1" water circulating hole. (Also assists on next machine). . .	American radial drill press	31.0
13. Rough bore main cap, magneto, water pump bores and idler bore. .	Rockford horizontal boring machine	31.0

Table 23. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Con.

Operation	Machinery	Standard man-hours per 100 cylinder blocks
14. Semifinish bore main, water- . . pump mounting bore; finish bore cam; bore and semifinish face and turn magneto housing.	Rockford horizontal boring machine	31.0
15. Drill angle oil lines side of. . block; drill angle oil lines main to cam bearings; wipe off pan rail and bar for next operation; load buggy while drilling.	Natco multidrill press	31.0
16. Drill, endmill, ream, face . . . and chamfer oil pump hole, bore, face, and tap oil filler hole and face cross arm pad.	American radial drill press	31.0
17. Spotface and drill 2 pump . . . . mounting screw holes; counterbore for expansion plug; drill magneto oil line to cam bore; drill 3 cross oil lines part way; drill, pull face, and ream oil gage holes.	American radial drill press	31.0
18. Spotface oil cooler line hole,. . relief valve boss; drill and tap water drain hole, drill, endmill, pull face, counterbore, and ream distributor hole and drill and tap 3/4" pipe tap hole.	American radial drill press	31.0
19. Drill angle oil line in . . . . . water pump bore; drill 3 cross oil lines, other side; redrill 1 cross oil line; tap 2,1/4" pipe tap holes, 2, 1/8" pipe tap holes and 1, 3/8" pipe tap hole; drill spotface and	Hammond radial drill press	31.0

Table 23. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Con.

Operation	Machinery	Standard man-hours per 100 cylinder blocks
19. (Continued) tap distributor hold down holes, 1 hole to pump bore; redrill and tap; drill and tap distributor lock screw hole; redrill 1 cross oil line hole.		
20. Drill and rough seat relief . . . valve hole; tap relief valve hole; tap 2, 1/4" pipe tap holes; tap 2, 1/8" pipe tap holes, cross oil lines; tap 3, 1/8" pipe tap holes and 3, 1/8" side angle oil lines; tap 2 pump mounting screw holes; drill idler stud oil line hole; drill 1/4" hole, bottom of magneto housing and endmill oil hole in main bearing.	Hammond radial drill press	31.0
21. Load block to turn over and . . . index; index, turn over operation 11, remove fixture, operation 20; remove cam; bar hoist block across line.	--	31.0
22. Tap 2, 5/8"-11 holes, 1, 3/8" . . pipe tap hole, spotface fan bracket bosses; pull face idler stud holes; spotface magneto bore; drive bushing in magneto bore and face. (Assist loading next operation).	American radial drill press	31.0
23. Drill, endmill, and ream push . . rod holes; move block to cam idler.	Natco multidrill press	31.0
24. Chamfer bottom of push rod . . . holes; ream push rod holes; bore relief for oil pump.	Carlton radial drill press	31.0

Table 23. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Con.

Operation	Machinery	Standard man-hours per 100 cylinder blocks
25. Hand ream oil pump hole and . . . chip fins from main bearings; finish seat oil relief hole and rough wash and air blast complete.	--	31.0
26. Drive cam bushing in place . . . and drive 1 angle oil hole; file main bearing faces of block; drive dowel pins and oil cam bearings.	--	31.0
27. Drive studs; assemble caps . . . to block and tighten; index and move out on line.	--	1/31.0 2/31.0
28. Finish bore cam, crank, ... magneto, and water pump mounting bores; finish face and counterbore magneto face.	Natco horizontal boring machine	31.0
29. Finish mill top of block and . . chamfer push rod holes.	Beeman and Smith vertical mill.	31.0
30. Rough and finish bore cylinder. . sleeve.	Moline hole hog	31.0
Bore and finish counterbore . . . and chamfer sleeve bores.	Moline hole hog	
31. Finish bore and seat cylinder . . sleeve; counterbore file burr on cylinder head face; hand seat cylinder sleeve, 2 passes; load block on machine for next operation.	Colburn single-spindle drill press	31.0

See footnotes at end of table.

Table 23. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953—Con.

Operation	Machinery	Standard man-hours per 100 cylinder blocks
32. Drill 1, 1-1/16" hole in compressor pad; drill and tap 1, 1/8" pipe tap, 1, 1/4" pipe tap holes in magneto bore; blow out block; load block to fixture and watertest. . .	Carlton radial drill press	31.0
33. Rough and finish ream main bearing bore; stamp block; remove plugs and clamps and remove block from watertest. . . .	Rockford horizontal boring machine	31.0
34. Tap 8, 7/16" -14 holes, 4, 5/8" -11 holes, 1, 3/8" pipe tap, 6, 3/8"-16 holes and 3, 1/2"-13 fan bracket holes, front end of block; tap 8, 1/2"-13 and 6, 3/8"-16 holes, rear end of block and drill and ream 2 governor dowel holes.	Hammond radial drill press	31.0
35. Drill 12 oiler holes in push rod bosses. . .	Hammond radial drill press	31.0
36. Face for thrust, grind side water pad and grind rod clearance. . . .	Rockford horizontal boring machine.	31.0
37. Wash and airblast block complete	—	31.0
38. Miscellaneous repair	—	31.0
Total man-hours, all operations	. . . .	1,184.0

1/ Machine operator's time.

2/ Helper's time.

Table 24. Cylinder head for reported 4-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953

Operation	Machinery	Standard man-hours per 100 cylinder heads	Setup man-hours
1. Mill top and manifold face . . . and counterbore for expansion plugs.	American radial drill Sundstrand Tri-plex rigid mill	5.70	(1/)
2. Mill cylinder face and drill . . top, bottom and valve guide holes, spotface spring seat and bore valve throats.	Newton vertical rotary driller Barnes vertical 2-way driller	7.70	12.00
3. Drill and ream 2 dowel holes . . and drive 3 expansion plugs.	Delta drill press	5.40	2.00
4. Finish mill bottom	Newton vertical mill	6.60	--
5. Drill push rod holes, endmill . guide holes, rough bore for inserts, rough bore combustion chambers, drill combustion chamber hold down holes and drill manifold stud holes, drill 3 water circulating holes.	Barnes vertical multidrill (2 machines)	10.70	11.25
6. Finish bore combustion chamber . and nozzle holes.	Cincinnati-Bickford radial drill	13.00	2.50
7. Tap combustion chamber stud . . holes, tap top, tap manifold side and chamfer valve guide holes.	Hammond radial drill	10.50	1.00
8. Ream valve guide holes	Hammond radial drill	2.60	.50
9. Drill and ream 4 combustion . . chamber lock pin holes.	Hammond radial drill	7.00	1.00
10. Layout, center punch, and drill. . 2 water circulating holes and spotface 5 stud bosses.	Hammond radial drill	9.10	--

See footnote at end of table.

Table 24. Cylinder head for reported 4-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operations, plant B, U. S. A., selected period, 1953--Continued

Operation	Machinery	Standard man-hours per 100 cylinder heads	Setup man-hours
11. Shake chips from head and watertest.	--	2/ 7.80 3/ 7.80	1.50
12. Press in and ream valve guides.	Hannifin hydraulic press.	5.30	.75
13. Finish counterbore for inserts. drive inserts, and burnish. .	Avey drill press	15.00	1.50
14. File inserts flush, weld head, file edges of nozzle holes, and grind burrs in valve throats.	--	8.10	.50
15. Grind all valve seats	--	35.00	2.00
16. Grind burrs, wash, and airblast. .	--	9.70	--
17. Drive 4 combustion cup dowels . .	--	3.80	--
Total man-hours, all operations	. . . .	170.80	36.50

1/ Not timed.
2/ Machine operator's time.
3/ Helper's time.

Table 25. Cylinder head for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953

Operation	Machinery	Standard man-hours per 100 cylinder heads
1. Mill top and intake pad; . . . . drill and tap 3, 1/2" pipe plug holes and 3, 3/4" pipe plug holes.	Ingersoll vertical mill American radial drill press	14.0
2. Mill bottom; . . . . drill top and bottom.	Newton vertical mill Natco 2-way driller	13.0
3. Drill and ream 2 dowel holes . . mill 3 exhaust manifold pads.	Delta drill press Sundstrand vertical mill	10.0
4. Buttface spring seats	Moline hole hog	6.2
5. Drill 12 combustion chamber . . hold down holes.	Natco multidrill press	11.0
6. Drill exhaust and intake . . . . manifold pads; endmill valve guide holes; bore valve throats and rough and semifinish bore for inserts.	Natco multidrill press Natco multidrill press	12.0
7. Rough and semifinish . . . . . combination bore and finish bore nozzle holes and tap combustion chamber hold down holes.	Natco multidrill press American radial drill press	14.0
8. Tap holes on both sides, ... ream valve guide holes and drill 3 water holes.	Hammond radial drill press	17.3
9. Drill and ream 3 combustion . . chamber lock dowel holes	Hammond radial drill press	14.0
10. Counterbore 2 oil lines; . . . . ream 3 holes for tubes; pull face 3 holes; air blast water jacket and drive 5 pipe plugs.	Barnes drill press	20.0

Table 25. Cylinder head for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Continued

Operation	Machinery	Standard man-hours per 100 cylinder heads
11. Grind cylinder block contact face . .	Thompson surface grinder	10.5
12. Finish bore combustion chambers	Fosdick radial drill press	14.0
13. Watertest, shake chips, grind burrs from spring seats and assemble 1 pipe plug.	—	23.0
14. Press in and ream valve guides .	Hannifin hydraulic press Barnes drill press	8.4
15. Semifinish and finish bore for inserts, drive inserts, and roll edges. .	Barnes drill press	25.0
16. Grind burrs from throats, fill edges of nozzle holes and form radius at back pin holes. . . .	—	14.0
17. Rough, semifinish, and finish grind valve seats.	—	28.5
18. Grind burrs around stud holes and wash, steam, and airblast.	—	14.0
19. Assemble and drive 3 combustion chamber dowels and 3 tubes.	—	5.3
Total man-hours, all operations	. . . .	274.2

Table 26. Connecting rod for reported 4-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953

Operation	Machinery	Standard man-hours per 100 connecting rods	Setup man-hours
1. Snag bolt bosses for drill . . .	Yukon grinding wheel	0.23	--
2. Rough drill bearing end	Rockford vertical boring machine	1.00	4.50
3. Rough and finish bore pin end. . chamfer one side pin and bearing end to burr and plug gage.	Horizontal boring machine	1.90	3.20
4. Straddle mill locating spots . . bearing end and pin end, chamfer both sides.	Sundstrand horizontal hydraulic rigid mill	1.20	1.75
5. Drill and countersink squirt . . holes, complete teream to burr.	Avey drill press	1.70	.45
6. Drill, ream, and counterbore . . bolt holes.	Natco multidrill press	1.05	7.00
7. Split rod and cap, mill bolt . . seat and stamp.	Milwaukee horizontal mill	1.40	2.90
8. Spotface nut seat on cap	Avey drill press	1.90	.40
9. Chamfer bolt holes in cap . . . and rod, both sides.	--	.70	--
10. Drill lock slots, cap and rod .	Cincinnati drill press	.90	1.50
11. Snag grind all burrs	--	1.10	--
12. Burr 2 oil holes at bolt seat. .	--	.47	--
13. Disc grind shim faces and . . . wash rods and cap.	Gardner disc grinder	.94	--

Table 26. Connecting rod for reported 4-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Continued

Operation	Machinery	Standard man-hours per 100 connecting rods	Setup man-hours
14. Assemble cap to rod with bolts and nuts, file 1 side of crank end, and pile on conveyor.	--	1.74	--
15. Grind both sides of crank boss .	Blanchard surface grinder	2.10	4.00
16. Rough and finish bore crank end and chamfer one side.	Ex-Cell-O 6-spindle boring machine	1.30	6.40
17. Burr lock slots and oil holes. bearing end (rotary file) and wash in soluble water.	--	1.15	--
18. Finish grind bearing end and air check size.	Heald Sizematic internal grinder	1.99	2.00
19. Radius bearing end, both sides .	Avey drill press	.78	.50
20. Wash in gas, remove chips, press in bushings, and burnish.	Atlas power-driven press	1.80	.80
21. Chamfer bushing, both sides . .	--	.33	--
22. Diamond bore hole	Rockford diamond boring machine.	1.00	3.00
23. Check rod for burrs, burr lock slots and oil hole, pin end.	--	.90	--
24. Wash rods in gasoline and airblast	--	.50	--
25. Weigh rods in sets and mark . .	--	.53	--
26. Dip in oil and set on platform in sets.	--	.13	--
Total man-hours, all operations	. . . .	28.74	38.40

Table 27. Connecting rod for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953

Operation	Machinery	Standard man-hours per 100 connecting rods	Setup man-hours
1. Mill bearing end on both sides (leave .012" on each side).	Milwaukee vertical mill	6.30	--
2. Straddle mill pin end, straighten and file burrs.	Milwaukee horizontal mill	3.40	--
3. Mill sides of bearing ends for locating spots. . . .	Milwaukee horizontal mill	2.90	2.25
4. Rough bore bearing and pin ends, file locating face, bearing end, and chamfer 2 sides of pin end. . . .	Moline hole hog	8.40	(1/)
5. Diamond bore pin end	Barnes horizontal boring machine	8.30	1.85
6. Drill and ream bolt holes . . .	Natco multidrill press	4.30	(1/)
7. Saw off cap, mill bolt seat, stamp and file burrs. . .	Milwaukee horizontal mill	7.20	2.00
8. Disc grind shim face, rod and cap. . . .	Gardner disc grinder	3.60	.60
9. Spotface 4 holes in cap	Barnes drill press	4.90	.50
10. Drill long oil hole and chamfer holes, rod and cap; burr oil hole in pin end.	Leland-Gifford-Peck drill press	6.50	2/.75
11. Drill and ream dowel holes . . .	Fox multidrill press	3.00	6.60
12. Remove all burrs, file shim face, press in dowel pins, assemble cap to rod, chamfer and straighten. . .	--	9.50	--

1/ Time not available.
2/ Time per spindle.

Table 27. Connecting rod for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953--Continued

Operation	Machinery	Standard man-hours per 100 connecting rods	Setup man-hours
13. Semifinish and finish bore . . . bearing end, chamfer bearing end on 2 sides and file burrs, mill locating spot on pin end.	Ex-Cell-O 6-spindle vertical boring machine	5.30	9.00
14. Mill 3, 1/2" diameter slots in . rod and cap.	Milwaukee horizontal mill	2.80	1.00
15. Grind bearing end to size, . . . both sides.	Blanchard surface grinder	4.00	3.00
16. Burr tube, hole pin end, and . . torque tighten connecting rod bolts.	—	1.10	—
17. Grind bearing end to size . . . chamfer both sides, wash and clean out hole.	Heald Sizematic internal grinder	5.50	3.50
18. Press in wrist pin bushing, . . burnish and chamfer pin ends, both sides.	Hannifin hydraulic press	3.10	.60
19. Diamond bore bushing pin end . .	Heald diamond boring machine	3.30	5.00
20. Mill 2, 1/8" oil grooves in . . bearing end.	Bristol horizontal mill	1.70	1.00
21. Drill and tap piston oil . . . . tube hole.	Delta drill press	3.90	.60
22. Airblast and assemble piston . . oil tube; wire brush oil line; file burrs on locating spots; bolt slots, bearing end faces; burr lock slots, oil groove and 1/8" slots.	—	8.40	—

Table 27. Connecting rod for reported 6-cylinder diesel engine: Machinery used and man-hours required per 100 units, by manufacturing operation, plant B, U. S. A., selected period, 1953—Continued

Operation	Machinery	Standard man-hours per 100 connecting rods	Setup man-hours
23. Spotweld tube to rod in 2 places . . .	—	1.00	—
24. Dress weld	—	.50	—
25. Wash in gas and airblast . . .	—	.70	—
26. Weigh, mark, and sort in sets .	—	.50	—
27. Dip in oil and pile on truck. .	—	.40	—
Total man-hours, all operations .	. . . .	110.50	38.25

CASE STUDY, PLANT C

SPECIFIED PRODUCT

This plant reported data on a standard 6-cylinder diesel engine designed for industrial applications. Both the exhaust valve seats and the wet cylinder sleeves are removable to facilitate maintenance. Major specifications of the engine are shown in table 28.

Table 28. Specifications 1/ of reported 6-cylinder diesel engine, plant C, U. S. A., 1953

Item	Specification
Cycle	4
Horsepower (continuous)	215
Revolutions per minute	2,000
Bore (inches)	5-1/4
Stroke (inches)	6-1/2
Length, front of fan to rear of flywheel (inches)	59
Width, maximum (inches)	28
Height, maximum (inches)	35
Piston displacement (cubic inches)	844
Weight, less accessories (pounds)	2,550

1/ Specifications of some items are shown as approximations to avoid disclosure of confidential plant information.

GENERAL PLANT INFORMATION

This plant is housed in a series of 20 buildings with a total floor area of 750,000 square feet. It is located in a suburb of a large city thereby availing itself of the labor supply and transportation facilities of the city while taking advantage of an adequate supply of relatively inexpensive land.

The buildings are primarily machine shops and assembly areas, but there are facilities for heat treating forgings and other processing operations not usually found in machine shops.

This is a medium size plant employing a total of 1,800 workers.

OPERATING PRACTICES

Unionization

The production workers in this plant are represented by the United Steelworkers of America (CIO).

Office workers, sales personnel, supervisors, and custodial employees are not represented by any union.

Employment

At the time of this study the plant employed approximately 1,000 production workers. In addition, there were about 800 nonproduction workers in the office, including technical, sales, administrative, and clerical workers.

Hours and Wages

At the time of this survey, the plant was operating on a 2-shift basis for the factory workers. The first or day shift is normally 8 hours per day and 40 hours per week. The second or evening shift works the same number of hours but the workers receive an 8 cent hourly premium. Work in excess of the regularly scheduled workweek and Saturday work is compensated at 1-1/2 times the regular hourly rates. Work done on Sundays is paid for at twice the regular hourly rate.

The plant formerly operated on an individual piece-rate system for production workers but was in the process of changing over to a standard hour system, which both the union and management felt would eliminate some inequalities under the present system.

Fringe Benefits

Employees receive 6-1/2 paid holidays annually and are paid their regular pay for time worked during holidays in addition to the pay received for the holiday. The half holiday is granted the day before Christmas, when the plant closes at noon. In the event the holiday falls on Sunday, the following day is considered a holiday. Persons employed at this plant with 1 to 5 years' service are entitled to 1 week's vacation, those with 5 to 15 years' service to 2 weeks' vacation, and over 15 years' to 3 weeks' vacation. There is no formal provision for sick leave but pay for such absence is covered by an insurance plan. Premiums are paid by the company.

Production and Variety of Products

Total sales for a recent year were slightly less than $30 million, of which over 50 percent were accounted for by sales of diesel engines and replacement parts. Other products include gasoline engines and gas burning engines, industrial trucks (including some fork lift trucks), railway supplies, lifting jacks, and earth drills.

Recent changes were made in the production of these items to reduce manufacturing costs. These include a reduction in the number of different models manufactured and a standardization of remaining models so as to permit use of interchangeable parts. This has resulted in larger production runs and lower inventories of parts.

Professional and Engineering Services

Despite recent trends toward the reduction in the variety of models, this plant still produces a wide variety of items within each product class. As a result this plant employs a relatively large staff of engineers including a staff of 40 in product design, 50 in production engineering, and 25 in methods and time study work.

Integration

The plant purchases rough castings and forgings, and performs all subsequent operations including the finishing foundry operations, machining, and all assembly operations. Hardware and standard industrial parts are purchased, whereas parts especially designed for the product are manufactured within the plant.

Production Control

This plant has a production control and planning division. Its function is to devise systems for planning, checking on materials, methods, tooling, and operation times; handling of order routing; scheduling and dispatching; and coordination with labor. It is also responsible for machine utilization and related activities of factory departments. Every effort is made to bring about the highest production efficiency by manufacturing the proper quantities of products and parts to meet customers' needs.

Table 29. Man-hours required to manufacture and assemble the reported 6-cylinder diesel engine, plant C, U. S. A., selected period, 1953

Item	Man-hours per engine
Manufacturing:	
Direct labor:	
Cylinder block	4.63
Cylinder heads (2)	11.67
Connecting rods (6)	3.46
Other parts	56.83
Total	76.59
Assembling:	3.41
Direct labor	80.00
Indirect labor assigned 1/	68.00
Total	148.00

1/ Assigned on a plantwide ratio of indirect to direct man-hours. Indirect man-hours are 85 percent of direct man-hours.

MANUFACTURING PRACTICES

Direct man-hours shown in this case study are standard hours adjusted to the current operating efficiency of the plant. Indirect man-hours are based on a plantwide ratio of indirect to direct labor. Direct labor includes work performed directly on a given product such as machining the crank shaft or inserting the piston into the sleeve. Indirect labor includes all other types of factory labor such as supervision, maintenance or repair of equipment, factory clerical work, trucking, and other work not directly applied to a particular item but essential to the operation of the plant. Table 29 shows the man-hours required to manufacture and assemble the reported diesel engine.

The operation of this plant does not differ materially from other plants manufacturing diesel engines. Major parts are received as rough castings and forgings, and all machine shop and assembly operations are performed at the plant. All parts are inspected, the assembly thoroughly tested, and deficiencies corrected; the engine is then prepared for shipment.

Jigs and Fixtures

Since World War II, this plant has gradually installed control systems to enable it to determine the savings that can be realized from the installation of new jigs and fixtures. Savings are based on direct labor costs, changes in output, and costs of raw materials. A continuous time study is made of operations, and, in many instances, new time measurement techniques are developed to help justify the cost of jigs and fixtures used in various manufacturing operations. The plant is particularly alert to the development of economical operations, but management is careful not to invest substantial sums of money in jigs and fixtures that may show a considerable saving if used but which are seldom used.

MANUFACTURING OPERATIONS

In the following series of tables covering manufacturing operations for three components of the reported diesel engine, each manufacturing operation, the machines used, and the man-hours required are shown. Only three of the many parts made in the plant for the complete engine are studied in this report. These parts are the cylinder block-crankcase, cylinder head, and connecting rod. A description of the assembly operations for the complete engine is also provided.

Cylinder block-crankcase

The cylinder blocks are received as rough castings and machined into final form. The reported 6-cylinder diesel engine has a 1-piece cylinder block with integral crankcase. Manufacturing operations, machinery used, and man-hour requirements for each operation are shown in table 30.

Cylinder Head

Each 6-cylinder diesel engine of the reported type has 2 cylinder heads.

These are received as rough castings and machined to final form. Included as raw materials for this operation are valve stem bushings. Details on manufacturing operations, machines used, set-up time, and man-hour requirements for each manufacturing operation are shown in table 31.

Connecting Rod

Each engine has six connecting rods which are received as rough forgings and machined to finished dimensions. Other materials used in the manufacture of these rods are pin bushings for the wrist-pin end of the connecting rod and a bearing for the crankshaft end of the rod. Manufacturing operations, machines used, setup time required, and man-hour requirements for each manufacturing operation are shown in table 32.

Assembly Operations

Final assembly operations for the reported engine take place at a series of 11 assembly stations. At each station there are from 1 to 3 men who attach the various parts to the cylinder block to complete the engine. Some operations require 2 men working together. In other operations 2 or 3 men may work simultaneously on opposite sides of the engine, independently of each other. The individual operations at each station and the number of men required to perform them are shown in table 33.

Distribution of Costs

Cost of materials is the major cost involved in manufacturing diesel engines. This amounted to more than two-thirds of all factory costs in plant C. Labor costs accounted for approximately one-fourth of the total, (table 34).

Selling cost amounted to 3.3 percent of total sales. The distribution of these costs is shown in table 35.

Marketing

Plant C has a few company-owned outlets located strategically in major cities in the United States. These serve as distributing points for the privately owned retail outlets located in all parts of the United States. Engines and other products are also sold and distributed in practically every country in the world.

Table 30. **Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-hours required per 100 units, by manufacturing operation, plant C, U. S. A., selected period, 1953**

Operation	Machinery and equipment	Man-hours per 100 cylinder blocks
1. Clean out molding sand and wires . .	---	4.76
2. Move cylinder block to paint . . . . booth, spray paint	Paint sprayer (air)	11.90
3. Load on skids and move to . . . . . machine shop	---	4.33
4. Mill top and bottom. Rough mill . . bearing cap seat. Mill oil pump mounting	Fitchburg milling machine	
Drill and ream 2 locating holes . .	Avery vertical 2 spindle drill	
Straddle mill main bearings		
Mill front and rear ends of . . . . cylinder block	Fitchburg duplex milling machine	
Mill manifold face and . . . . . . lifter bracket cover	Fitchburg horizontal milling machine	
Mill bearing cap seat	Fitchburg vertical milling machine	
Mill lifter bracket bosses, ... fuel pump pad, fuel pump mounting bosses, water pipe pads and 6 pads on pan rail. Mill oil cover pad for clearance	Fitchburg milling machine	
Drill on top, deck, and exhaust side. 26 cylinder head stud holes, 1-1/2" deep 6 cylinder head stud holes, 1-3/16" deep 5 water circulator holes 1 rocker arm oil hole, 10-1/4" deep 8 manifold stud holes 3 drain holes		

Table 30. **Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-hours required per 100 units, by manufacturing operation, plant C, U. S. A., selected period, 1953--Continued**

Operation	Machinery and equipment	Man-hours per 100 cylinder blocks
Operation No. 4. -- Continued		
3 oil cooler bypass valve holes, 1-1/16" deep		
3 stud holes, 1-1/6" deep for mounting waterpipe		
3 stud holes, 1-1/16" deep for mounting generator		
1 stud hole, 1-1/2" deep for idler lockscrew		
7 oil line holes, 9-1/2" deep . . .	Natco multiple drill	
1 oil line hole, 6" deep from oil galley to center main bearing riser line		
Drill on top, bell housing and on gear case side: 10 stud holes, 1-1/16" deep for gear cover		
2-27/64" cam shaft washer holes 1-16" deep		
1 idler gear stud hole, 2-1/2" deep, counter sink to 1-13/32" deep		60.56
1 oil relief, hole 1" deep		
10 stud holes, 1-1/16" deep for bell housing		
4 rear oil seal studs, 1-1/16" deep		
27 water circulating holes		
2 stud holes, topside, 1-1/2" deep		
2 stud holes, 1-3/16" deep		
Drill main bearing stud holes and pan contacts.		
12 main bearing studs, 3" deep		
6 main bearing oil lines, 3-3/4" deep		
1 center main bearing oil line, 7-5/8" deep		
4 center main bearing stud holes, 3" deep		
1 oil hole, 6-5/8" deep to meet main oil galley line		

Table 30. **Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-hours required per 100 units, by manufacturing operation, plant C, U. S. A., selected period, 1953--Continued**

Operation	Machinery and equipment	Man-hours per 100 cylinder blocks
Operation No. 4. -- Continued		
Drill holes in bottom and side of cylinder block. 28 oil pan contact holes 7 main bearing lockscrew holes, 1" deep 2 oil pan contact holes 4 fuel pump pad holes, counter-bore 2 holes 6 push rod cover boss holes 4 step tool		
5. Counterbore holes in valve . . . . bracket bosses. 4 oil filter pad holes 1 oil inlet hole 2 oil filter holes 2 fuel oil filter boss holes 2 rocker arm oil line holes 1 oil galley line hole for rocker arm	Natco multiple drill	16.59
6. Counterbore: 16 main bearing . . . holes, 1/8" deep 36 cylinder head stud holes Chamfer: 28 oil pan contact holes	Black and Decker air-motor drill	10.20
7. Tap the following. . . . . 26 pan rail holes 2 oil line bracket holes 20 holes on cluster, bracket side 2 holes on gas pump pad 3 holes on pipe cluster on bracket side 12 main bearing, stud holes 4 center main bearing stud holes	Natco multiple tapper	
14 flange holes on bell . . . . . housing 12 holes gear case end of cylinder block	Natco horizontal tapper	

Table 30. **Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-hours required per 100 units, by manufacturing operation, plant C, U. S. A., selected period, 1953--Continued**

Operation	Machinery and equipment	Man-hours per 100 cylinder blocks
Operation No. 7. -- Continued		
32 cylinder head stud holes . . . 1 hole for pipe connection, top side of cylinder block Drill 1 oil gage hole Tap: 8 holes for manifold studs 7 holes for standard pipe oil line 3 holes for standard pipe drain 1 hole for idler gear lock screw 3 holes in oil filter pad 6 bracket holes on side of pan rail	Natco multiple tapper	37.41
Rough and finish bore. . . . . . 6 barrels for cylinder sleeves 5-7/8" diameter Chamfer bottom bore 10° 7/32" deep. Counterbore top	Moline vertical boring bar	
Studder drive. 12 main bearing studs 4 center main bearing studs 12 main bearing nuts		
8. Assembly. . . . . 6 main bearing caps 1 center main cap Tighten. 12 main bearing nuts 4 center main bearing nuts 3 main bearing studs 1 center main bearing stud Blow out main bearing stud hole	Conveyor and hand tools	65.52
9. Rough and finish bore main bearing . . . . Rough and finish bore cam bearing Drill main oil gallery line	Natco boring bar	34.50

Table 30. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-hours required per 100 units, by manufacturing operation, plant C, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Man-hours per 100 cylinder blocks
Operation No. 9. -- Continued		
Counterbore 4 dowel holes Drill oil line Ream 1 idler gear bearing		
10. Stamp and drill name plates . . . . Hand tap 2 pipe holes in main oil line Burr 6 holes Hand tap 2 dowel holes Hand ream 2 holes for 1/2" tap	Conveyor and hand tool	15.92
11. Straddle-face center main bearing	Rock bar machine	9.60
12. Remove center main bearing . . . . Bore and ream oil pump hole Surface bottom of oil pump Drill 1 hole to oil pump Tap 1 oil pump hole Clean out oil lines, replace center main bearing Surface 1 idler stud Counterbore 4 cluster brackets Drill 1 oil relief Drill and ream 1 ball seat hole Surface ball seat hole Tap ball seat hole Hand ream oil pressure hole Drill 1 hole through Tap 1 standard pipe hole	American radial drill	55.95
13. Grind sleeve clearance . . . . . . Check with master sleeve Grind cluster bracket clearance Check with master bracket Clean out oil lines Grind remove symbol number and stamp parts identification number	Conveyor and hand tools	27.88

Table 30. **Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and man-hours required per 100 units, by manufacturing operation, plant C, U. S. A., selected period, 1953--Continued**

Operation	Machinery and equipment	Man-hours per 100 cylinder blocks
14. Finish mill top surface	Fitchburg vertical drill	
Finish counterbore 6 barrels . . for sleeve fit Drill 2 oil line holes Tap 2 stud holes	Radial drill	
Blow out cylinder block Insert adapter before washing Wash cylinder block Clean out oil line Burr and blow off cylinder block after washing		46.65
Stamp identification numbers . . on bearing caps, pan rails, and side of cylinder block, to insure that cap will be identified with a given bearing	Conveyor and hand tools	
15. File burrs off 7 bearing caps . and blow off chips. Remove caps, clean oil lines, and reassemble center main bearing. Load cylinder block on conveyor. Clean dowel hole and threads. Inspect	Conveyor and hand tools	60.97
Total all operations		462.74

Table 31. Cylinder head for reported 6-cylinder diesel engine: Machinery and man-hours required per 100 units, by manufacturing operation, plant C, U. S. A., selected period, 1953

Operation	Machinery and equipment	Set-up man-hours	Man-hours per 100 cylinder heads
1. Normalize	Strong, Carlisle, and Hammond - hardening and drawing furnace		15.08
2. Sandblast, clean, agitate, and blow	Shot blast, (Make not reported). Binks air-operated agitator		7.33
3. Spray paint sealer	Paint sprayer (air)		3.15
4. Mill top and bottom	Fitchburg-spindle duplex milling machine		27.85
5. Stamp symbol	Power press (make not reported)		1.98
6. Mill exhaust and intake manifold sides . .	Fitchburg-spindle duplex milling machine		15.28
7. Drill holes in top and bottom . .	Natco horizontal multiple drill		
8. Ream 2 holes .590" diameter	Avey 2 - spindle vertical head speed drill		
9. Drill exhaust and unit manifold stud holes	Natco vertical multiple drill		6.86
10. Drill and semifinish valve guide holes . . .	Radial drill (make not reported)	1.65	30.61
11. Machine exhaust chambers and install inserts	Radial drill (make not reported)	1.85	75.24

Table 31. Cylinder head for reported 6-cylinder diesel engine: Machinery and man-hours required per 100 units, by manufacturing operation, plant C, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Set-up man-hours	Man-hours per 100 cylinder heads
12. Machine intake combustion chambers, install inserts, and form radius of exhaust chamfer bore	Radial drill (make not reported)	1.14	41.92
13. Rough and finish bore nozzle holes . .	Radial drill (make not reported)	--	52.24
14. Counter drill bottom drill holes, ream 3-12/16" holes, drive bushing . .	2 radial drills (make not reported)	1.51	32.97
15. Rough and finish drill. .	2 radial drills (make not reported)	--	51.31
16. Counterbore 6 spring seats, chamfer and tap 12, 3/8" holes. Counter drill 2, 41/64" end holes, tap 2, 1/2" holes . .	American 3-hole wizard radial drill	--	34.20
17. Drill; tap, bore, counter drill, and counterbore 24 holes. File to remove burrs	Combination drill	--	35.37
18. Gage cylinder head and mill ends to meet required specifications . . .	Heady Norton drill		
19. Ram out core and pins . .	Bench		
20. Counter drill 6 push rod holes. Drill 8 water holes, ream 7 water holes. Chamfer bottom of 6 valve . .	American radial drill	--	39.90

Table 31. Cylinder head for reported 6-cylinder diesel engine: Machinery and man-hours required per 100 units, by manufacturing operation, plant C, U. S. A., selected period, 1953--Continued

Operation	Machinery and equipment	Set-up man-hours	Man-hours per 100 cylinder heads
Operation No. 20. -- Continued			
grind holes. Counter drill 1, 1-1/16" hole and 1, 3/4" hole through bottom deck to water jacket. Turn cylinder head over, counter drill 3 push rod holes			
21. Check oil lines for leaks .	--	--	10.95
22. Counter drill 2, 6/16" . . holes, tap 3 holes; insert, tighten, and surface 2 pipe plugs, drill 2 holes 3-7/8" deep. Chamfer and tap 12 stud holes. Counter drill and tap for 3 pipe plugs	American radial drill 3-arm	--	41.69
Blend 1/16" rear and . . . 1/8" head at contact surface of combustion chambers	Kearney and Treaker profiling mill	--	
Finish mill cylinder . . . block contact surface	Fitchburg	--	
23. Blow chips from all . . . . holes to passage; clean out oil lines, polish 3 combustion chambers. Bump, wash, and air blast. Assemble 3 pipe plugs. Water test for leaks. Air blast and load to skids	Bumping machine	--	62.58
Total all operations			583.51
Total, all operations for 100 engines (2 cylinder heads per engine)			1,167.02

Table 32. **Connecting rod for reported 6-cylinder diesel engine: Machinery and man-hours required for production, by manufacturing operation, plant C, U. S. A., selected period, 1953**

Operation	Machinery	Man-hours per 100 connecting rods
Blacksmith department:		
1. Straighten	Morse power press	1.59
2. Grind shaft end and pin . . end	Blanchard grinder	2.29
3. Drill and bore piston pin . hole (reset locks)	Vertical drill	2.37
4. Chamfer both sides of pin . hole. Diamond bore pin end	Straiter post drill Ex-Cell-O wet horizontal boring machine	.68
5. Mill 2 sides, locate . . . . bosses and stamp rod and cap	Cincinnati mill	1.30
6. Rough bore crankshaft . . . end and chamfer. (Change quills)	Multiple drill	1.56
7. Broach cap from rod . . . . (reset rails)	Broaching machine	1.86
8. Grind mating face of . . . . cap and rod	Grinders	1.87
9. Drill, semifinish ream, . . and finish ream bolt holes in cap and rod	Multiple drill	1.92
10. Spotface cap for nut seat ,	Cincinnati drill press	1.04
11. Spotface rod for bolt . . . head seat	Cincinnati drill press	1.67
12. Mill bearing lock in . . . . rod and cap	Milling machine	2.30
13. Mill bolt lock in rod . . .	Milling machine	.95

Table 32. **Connecting rod for reported 6-cylinder diesel engine: Machinery and man-hours required for production, by manufacturing operation, plant C, U. S. A., selected period, 1953--Continued**

Operation	Machinery	Man-hours per 100 connecting rods
Blacksmith department -- Continued		
14. Drill long oil hole in rod (service drive) . .	Drill press	3.79
15. Chamfer 1/64" 45° on mating faces of cap and rod bolt holes . . .	Drill press	1.51
16. Clear drill chips from oil hole. File burrs on rod on cap compartment. Wash assembly, dowel bolts, caps, and nuts. Chamfer oil line hole in pin end of rod . .	Bench	6.33
17. Finish grind both ends . .	Blanchard grinder	3.03
18. Rough bore crankshaft hole . . .	Drill press	2.87
19. Semifinish bore shaft end and clean out (by means of a rod) oil hole . . .	Natco steel drill	1.52
20. Chamfer both sides of crankshaft end 1/8" at 45° and insert pin bushings . . .	Baker drill and air press	1.82
21. File crankshaft end, face and bore pin-end bushings . . .	Boring machine	1.60
22. Finish grind shaft, bore to size	Drill press, 4-spindle Heald-Sizematic	1.80
23. Remove burrs from oil line hole (both ends). Clean out oil hole . . .	--	1.85

Table 32. **Connecting rod for reported 6-cylinder diesel engine: Machinery and man-hours required for production, by manufacturing operation, plant C, U. S. A., selected period, 1953--Continued**

Operation	Machinery	Man-hours per 100 connecting rods
Blacksmith department: -- Continued		
24. Weigh for balance and mark notch in and stamp weight code	--	1.38
25. Remove cap, chamfer oil line and shaft end and reassemble cap for service	--	6.07
Total, all operations		57.76
Total, all operations for 100 engines (6 connecting rods per engine)		346.56

Table 33. **Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953**

Station and operation	Direct man-hours per 100 engines
Station No. 1. (1 operator):	
1. Load 4 wheel dolly on assembly track	.79
2. Pick up cylinder block with crane and position the cylinder block to dowels on dolly and attach securely	2.50
3. Install drain petcock; install 10 pipe plugs	5.60
4. Clean out 8 stud holes (side), white lead, 8 side and 36 (top-side) stud holes and drive studs	6.62
5. Insert 6 sleeves into sleeve dowels - (2 rubber rings per sleeve)	8.03
6. Stamp serial number on cylinder block; remove from dolly, return dolly to work area	1.11
Total, station No. 1	24.65

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued

Station and operation	Direct man-hours per 100 engines
Station No. 2. (2 operators):	
1. Move cylinder block to station No. 2; mount block on fixture in inverted position	1.86
2. Remove bearing cap nuts and bearing caps from 7 bearings. Remove burrs from oil grooves; wipe, clean, bearing babbits (cap and block sides) . . .	7.03
3. Stamp bearing caps	.71
4. Set bearing babbits into shell	1.11
5. Oil bearing	.32
6. Crane hoist cylinder block to machine; procure and drive woodruff key to crankshaft	2.10
7. White lead crankshaft; position and secure timing gear on crankshaft, clean flanges, bolt gear onto crankshaft at flanges	2.42
8. Clean oil lines in crankshaft; clean all journals and oil all bearings	3.37
9. Lower crankshaft onto block; remove crane	1.19
10. Oil 7 crankshaft journals	.24
11. Set 2 thrust half rings on center main bearing, position 7 bearing caps, 14 lock washers, and 16 nuts, tighten all nuts by hand	6.04
12. Check end-play of crankshaft with magnet base. Record. Bend up lock washer leg	3.41
13. Load piston and rod assemblies from rack to bench; stamp rod and cap with matching numbers; remove nuts and rod caps; wipe bearing seat; procure and clean bearing babbit and set babbits in rods and caps . . .	4.74
14. Position cylinder block in "roll over" fixture and set for connecting rod and piston assemblies (135°)	.71
15. Wipe sleeve with naphtha, dry, and oil	1.82
16. Prepare rod and piston assemblies including caps, nuts and washers. Set each of the 6 piston assemblies in sleeves, adjust compression rings, and push through cylinder block	4.69
17. Receive rod through sleeve, oil journals, assemble cap and 2 nuts by hand	3.58
18. Rotate cylinder block, placing crankshaft up. Change torque wrench extension; tighten nuts; insert and spread cotter pin	6.97
19. Rotate crankshaft, check rod clearance	1.72

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued

Station and operation	Direct man-hours per 100 engines
Station No. 2.--Continued	
20. Remove cylinder block from "turnover" fixture ready for station No. 3	.32
Total, station No. 2	54.35
Station No. 3. (1 operator):	
1. Move cylinder block to station No. 3; attach to "rollover" fixture and turn right side up	.45
2. Apply a tight seal to 1/8" L plug and assemble to side of cylinder block	.56
3. Apply tight seal to breather hole cover; assemble gasket to cover and bolt onto cylinder block . . .	.98
4. Bolt fuel pump bracket onto cylinder block with cap screw and lock washer	1.29
5. Assemble 2 dowels into end of the cylinder block. White lead 6 stud holes and 1 plug hole. Assemble pipe plug and studs (for water pump) into cylinder block	3.25
6. Shellac gasket surface area of gear case and apply gasket	.64
7. Clean gear case at idler stud area, set, and drive roller stud into gear case	.87
8. Clean pin hole of idler stud and assemble idler stud onto gear case	1.03
9. Oil the pressure relief valve on gear case; mount gear case on dowels at end of cylinder block and secure with 8 cap screws and lock washers	4.16
10. Procure, wipe, and assemble idler gear and washer to stud; set idler gear. Drive stud retaining pin. Assemble thrust plate, allen screw, and washer - inspect for clearance	1.94
11. Oil the pressure valve assembly and by-pass assembly, 2 end plugs and copper-asbestos washers	2.14
12. Procure gasket cap screws and washers, oil cooler housings and oil cooler, and gasket. Position oil cooler and gasket; set to housing	1.63
13. Procure and set 12 cap screws and lock washers to oil cooler. Remove 2 plugs from cooler. Procure and position gasket to oil cooler	2.12

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued

Station and operation	Direct man-hours per 100 engines
Station No. 3. -- Continued	
14. Procure and position oil cooler by-pass line assembly 4 cap screws and nuts on housing. Mount cooler assembly to cylinder block together with 4 gaskets and 8 cap screws. Tighten cap screws . .	4.33
15. Record and remove to station No. 4	.48
Total, station No. 3	25.87
Station No. 4:	
1. Bring cylinder block to station No. 4	.24
2. Move cylinder block to roll-over fixture; position camshaft, peen keyway, wipe and assemble camshaft, thrust plate to camshaft	1.63
3. Press cam gear on camshaft	1.11
4. Rotate cylinder block in fixture to 45° angle, wipe cam bearings and assemble camshaft and gear to cylinder block	1.98
5. Assemble 2 cap screws and lock washers through cam gear to camshaft thrust plate	1.45
6. Assemble end slotted camshaft screw plug, prick-punch countersunk head plug, and assemble retaining snap spring to camshaft	.95
7. Inspect and check end plug with magnet base indicator	1.43
8. Select and load 2 valve tappet brackets onto bench	.24
9. Penn 4 dowel holes and set 4 dowels in 2 valve tappet brackets	.60
10. Oil and assemble 12 push rod sleeves to 2 valve tappet brackets. Procure and assemble 4 cap screws and lock washer together for valve tappet brackets	.92
11. Set valve tappet brackets to cylinder block, tighten cap screws by hand and by wrench	1.54
12. Procure 2 valve tappet covers, shellac, and position gaskets on covers	1.19
13. Procure and assemble 6 cap screws and copper asbestos washers for valve tappet brackets. Position valve covers onto cylinder block and tighten cap screw by hand and by speed-wrench . .	2.17

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953—Continued

Station and operation	Direct man-hours per 100 engines
Station No. 4.--Continued	
14. Procure and assemble water pump, gasket and water pump to studs	.64
15. Procure and tighten by hand and wrench, lock washer and nut to stud	4.28
16. Rotate cylinder block in roll-over fixture to 180°, paint the camshaft with red lead, weld plug-seal; paint seal	1.29
17. Record and send cylinder block to station No. 5 .	.71
Total, station No. 4	22.37
Station No. 5:	
1. Block up cylinder block with wooden blocks	.20
2. Set pistons in position for timing	1.27
3. Procure accessory drive; position and stick gasket to drive	.67
4. Check, set key gage in keyslot	.24
5. Set accessory drive to cylinder block; position and tighten 8 cap screws and lockwashers	4.07
6. Check clearance, remove protective plug	.22
7. Assemble T plug to accessory drive, assemble oil line 1 to form oil line against cylinder block . .	1.71
8. Line up fuel pump on accessory drive shaft, tighten to pump bracket and check	1.39
9. Assemble Woodruff key of accessory drive shaft, assemble fuel pump coupling to accessory drive shaft over Woodruff key; tighten fuel pump coupling locking cap screw	1.67
10. Procure fuel pump, trim gasket and position on bracket; secure with 6 cap screws and washers; tighten	1.71
11. Adjust fuel pump coupling for a .006" clearance, tighten cap screw and coupling. Set fuel pump coupling to timing mark	2.86
12. Assemble oil cup to accessory drive, check clearance of fuel pump to side of engine, procure gear cover, secure oil seal to cover	2.26
13. Procure, set, and drive 2 dowels	.44

Table 33. **Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued**

Station and operation	Direct man-hours per 100 engines
Station No. 5. -- Continued	
14. Shellac gasket and position gasket on cover	1.15
15. Procure 14 cap screws and washers; set cover to cylinder block on dowels	2.10
16. Set cap screws and washers to cylinder block; tighten	3.25
17. Procure jaw-spacer sleeve and driver; set sleeve and assemble starting-crank jaw	.71
18. Remove wood blocks from cylinder block and send to assembly station No. 6	.44
Total, station No. 5	26.36
Station No. 6:	
1. Move cylinder block to work station and block into position	.87
2. Procure and position 2 cylinder head gaskets . . .	.49
3. Load 2 cylinder heads to cylinder block assembly via crane; set cylinder head on studs; remove crane .	6.55
4. Procure and place 36 flat washers on studs.	1.00
5. Procure and position nuts on studs	3.43
6. Line up heads, tighten 5/8" nuts with stud driver .	3.27
7. Hand drive 1/2" nut	1.59
8. Procure torque wrench; tighten nuts 5/8" - 160 lb.; 1/2" 90-100 lb..	2.69
9. Procure from stock and set 2 hose clamps to hose; set cast iron elbow to hose	1.11
10. Assemble elbow with gasket to water pump; tighten hose clamps	3.57
11. Procure and hand-tighten pipe plug into cast iron elbow	.56
12. Procure and hand-tighten pipe plug in oil cooler .	.63
13. Tighten cap screws on oil cooler and manifold and by-pass line	2.36
14. Procure and set push-rod tubes	.62
15. Procure 2 rocker arm assemblies; set to cylinder head	1.68
16. Procure and set lock washer and nuts to rocker arm assembly; tighten	3.19

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued

Station and operation	Direct man-hours per 100 engines
Station No. 6.--Continued	
17. Procure and set 6 brass fuel injection pipe assemblies to nozzle and tighten connection on L and T plugs .	5.14
18. Aline pipe after assembly to connections	.29
19. Procure blow out and set fuel injection lines for clamps	1.31
20. Procure and assemble slot clamps, cap screws, lock washers and nuts to each of 6 fuel lines	2.62
21. Position fuel injection lines to injection nozzles .	1.15
22. Position fuel injection line nuts to fuel pump nozzle	1.15
23. Tighten lines	2.30
24. Tighten cap screw and lock washer nuts on clamps . .	1.59
25. Tighten fuel pump nozzles	1.10
26. Procure injection nozzles	.29
27. Remove nozzle dust guards and loosen nozzle on dust guard	1.29
28. Remove injection nozzle dust guard, dust guard plugs, end covers and copper asbestos covers	1.21
29. Assemble L and T fittings of nozzles	1.48
30. Set mica gasket to nozzles and nozzles to cylinder head	.71
31. Place lock washers to studs; set nuts to T studs . .	1.56
32. Tighten nuts (with speed and box wrenches)	1.86
33. Remove dust guards, nuts and washers from nozzle end	1.19
34. Tighten and position L and T fittings for injection lines to nozzle	.95
35. Record, remove blocks from assembly and move cylinder block to station No. 7	1.59
Total, station No. 6	62.39
Station No. 7:	
1. Block cylinder block into position	.44
Exhaust Side:	
2. Position cylinder head gasket for water intake pipes	.20

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued

Station and operation	Direct man-hours per 100 engines
Station No. 7.--Continued	
Exhaust Side--Continued	
3. Position cylinder head water inlet pipe to cylinder head. Secure with cap screw and lock washer; tighten with box wrench	5.07
4. Position and secure 1, 1/2" and 1, 3/4" pipe plug in exhaust pipe	1.51
5. Procure rear water intake pipe; assemble hose to pipe, loosely fasten hose with 2 clamps	2.06
6. Secure rear water intake pipe to cylinder head with hose over exhaust	4.76
7. Tighten hose clamps	.16
8. Secure heat guard for hose to rear water inlet pipe with 2 cap screws and eye washers	.52
9. Position asbestos gasket to studs on cylinder heads; position exhaust manifold to studs; position expansion rings over manifold	2.26
10. Position 12 flat washers and 12 brass nuts on studs; tighten	5.14
Intake Side:	
11. Remove 2 dust guards from fuel pump	.32
12. Change plug in fuel pump	.24
13. Assemble 1 L pipe to left end of fuel pump and 1 L pipe to bottom of fuel pump	1.07
14. Straighten fuel lines at filter area; procure and place filter on 2 studs	.13
15. Position and tighten lockwasher and nuts in air cleaner	1.65
16. Assemble L connection to left side of filter; assemble reducer to right side of filter	1.43
17. Assemble L connection to right side of reducer . . .	.48
18. Assemble 2 weather-head lines from fuel pump to left side of filter	1.19
19. Connect 1/4" hose from bottom of fuel pump to right side of filter	.71
20. Procure split clamp, cap screw, nut, and lockwasher. Assemble split clamps on weather-head lines	.99
21. Connect nozzle drip line to T-pipe on nozzle to L on fuel pump	.91

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953—Continued

Station and operation	Direct man-hours per 100 engines
Station No. 7.—Continued	
<u>Intake Side</u>—Continued	
22. Procure and place 6 intake gaskets on 12 cylinder head studs (1 gasket for each cylinder)	.55
23. Procure air intake manifold; inspect and blow out	.71
24. Assemble air screen, insert in manifold	.40
25. Procure air heater element. Assemble to 2 adapter studs (electric terminals)	.89
26. Crimp ribbon wires to adapter studs	.40
27. Assemble 2 copper asbestos washers and 2 mica washers to air intake manifold	.55
28. Assemble 2 mica bushings, 2 mica washers, and 2 copper asbestos washers. Thread die over 2 studs .	.72
29. Position 2 brass nuts over stud, hand tighten . . .	1.47
30. Position manifold to studs; position 2 lock washers and nuts by hand and tighten with open end wrench .	1.86
31. Position and tighten 10 lock washers and nuts to studs	3.52
32. Final tighten 2 nuts (see step 30)	.24
33. Record, remove blocks and send assembly to station No. 8	1.39
Total, station No. 7	43.94
Station No. 8:	
1. Procure and position oil breather gasket to 2 studs	.16
2. Procure and position oil filter gasket to 4 studs .	.16
3. Procure oil filter, wipe base, position on 4 studs	.29
4. Procure 4 lock washers and nuts; position on studs and tighten	3.11
5. Assemble and secure air magazine to oil breather casting	1.27
6. Assemble oil breather casting assembly to studs; fasten with 2 lock washers and nuts	.83
7. Inspect	.16
8. Procure, set, and tighten 5 thermo-housing to stud .	2.68

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued

Station and operation	Direct man-hours per 100 engines
Station No. 8.--Continued	
9. Check height of studs; assemble gasket; assemble thermos to cylinder head and thermo-housing to stud . . .	.79
10. Procure and position nuts and lock washer on thermo-housing studs . . .	1.31
11. Send assembly to station No. 9 . . .	.64
Total, station No. 8 . . .	11.40
Station No. 9:	
Subassembly oil pan and oil pump:	
1. Load oil pan to work area; procure 2 gaskets and 2 hand-hole cover plates. Set in position . . .	.56
2. Position cap screws and lock washers on each of hole cover plates; tighten . . .	2.57
3. Turn pan, procure and wet a set of gaskets . . .	.32
4. Shellac end of pan, position and stick gasket . . .	.24
5. Shellac 2 half-sides of pan, position and stick 2 gaskets . . .	.49
6. Shellac 2 half-sides and short end of pan; position and stick 2 half-side gaskets and 2 short end gaskets . . .	.89
7. Move to next pan and put shellac away . . .	.12
8. Move cylinder block to roll-over fixture. Index roll-over . . .	.44
9. Set 2 pan rail guide studs and clean gasket surface . . .	.79
10. Procure oil pump, pipe, and screen; shellac and stick gasket to pump . . .	.24
11. Position pipe on pump loosely with 2 cap screws and lock washers . . .	.32
12. Position screen and gasket to pump, fasten loosely with 2 cap screws and lock washers; tighten . . .	.71
13. Position oil pump assembly on pan rail of motor; loosely fasten with 1 cap screw and lock washer . .	.52
14. Position gasket and 2 cap screws, and lock washer to pan rail, tighten cap screws; position in steps 11 13, and 14 . . .	1.51

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued

Station and operation	Direct man-hours per 100 engines
Station No. 9. -- Continued	
Subassembly oil pan and oil pump:--Continued	
15. Check pump to camshaft and adjust crankshaft for lag	.59
16. Load oil pan to 2 guide studs and pan rail, position and tighten cap screws, trim gaskets, and remove guide studs	3.70
17. Set 30 cap screws and tighten	4.64
18. Tighten 16 cap screws in handhole cover	.63
19. Record actions in log and move cylinder block assembly to next station	.67
Total, station No. 9	19.95
Station No. 10:	
1. Move cylinder block to station No. 10	.24
2. Position 4 dowels to cylinder block, position oil gage adaptor bushing to cylinder block and oil stick to adaptor	.71
3. Position oil seal to oil seal housing	.36
4. Shellac, position, and stick gasket to housing	.28
5. Graphite the lower half of gasket; position cap screw and lock washer to oil seal housing	.40
6. Position and secure oil seal housing to cylinder block with 4 cap screws and lock washers; tighten	.87
7. Secure oil pan to oil seal housing and 4 cap screws	2.22
8. Remove cap from oil pump, fill pump with 2 quarts oil, and replace cover	1.19
9. Adjust the position of crankshaft and adjust 2 rocker arms to .02" clearance from each of 6 cylinders	4.36
10. Procure and assemble front support to timing gear cover	.40
11. Procure fan bracket and secure to gear cover with 4 cap screws; tighten	1.19
12. Position gasket on air intake port on cylinder block assembly; procure and fasten elbow on air intake port; tighten 4 cap screws	1.31
13. Fasten 2 cylinder head covers over rocker arm bracket assembly	.32
14. Move cylinder block to end of line and to work station	.71

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued

Station and operation	Direct man-hours per 100 engines
Station No. 10. -- Continued	
15. Remove air cell clamps and air cell, insert a lead for reading	.16
16. Tighten water pump coupling nut; secure with cotter pin	.91
17. Remove wood protector from generator, assemble and secure couple with key	.26
18. Position and secure nut and washer on generator coupling, and position rubber spider to water pump coupling	.57
19. Position and fasten generator bracket to motor . . .	.82
20. Position generator to bracket; engage water pump and generator spiders; fasten generator to bracket with 4 cap screws and lock washers	1.56
21. Check line-up of couplings of water pump and generator, secure generator brackets to cylinder block and bracket to generator	1.13
22. Position 3/8" pipe plug in water inlet elbow	.12
23. Position elbow and gaskets to water pump. Tighten .	1.13
24. Tighten 3/8" pipe plug in elbow	.20
25. Position gasket to thermo housing, position gasket and inlet elbow to housing, secure with 4 cap screws and lock washers	1.40
26. Record work done in log, remove lead (see step 15). Attach lead to log sheet and send report to foreman	.93
Total, station No. 10	23.75
Station No. 11:	
1. Loosen 2 lifter nut wheels off dolly	.28
2. Bring lifter bar block with crane, remove crane to bell housing	.61
3. Attach 2 lifter bolts to bell housing	.40
4. Hitch to crane, loosen 2 wheel nuts	.38
5. Lift and move bell housing to engine with crane . .	2.75
6. Procure crane hook and secure to flywheel	.34
7. Remove dolly	.40
8. Attach crane to flywheel and move to cylinder block	.75

Table 33. Man-hours required to assemble 100 reported model, 6-cylinder diesel engines, by operation and by station, plant C, U. S. A., selected period, 1953--Continued

Station and operation	Direct man-hours per 100 engines
Station No. 11.--Continued	
9. Procure and position 10 cap screws and lock washers, crane adjust bell housing, hand tighten cap screws	2.48
10. Adjust crankshaft; position flywheel on crankshaft, wait for partner to tighten cap screws to bell housing	1.41
11. Lock crankshaft into position with special wrench	.18
12. Unhitch crane from bell housing, attach to lifter bar on engine	.34
13. Secure flywheel to crankshaft with 8 nuts and lock washers, tighten 4 nuts with torque wrench	2.25
14. Search flywheel for indicator, set 1 cap screw in indicator	2.68
15. Turn crankshaft and check flywheel indicator . . .	1.00
16. Reset flywheel indicator to different flywheel surfaces	.65
17. Turn crankshaft and record	.84
18. Remove flywheel indicator, note results	.44
19. Tighten 4 nuts (see step 13)	1.96
20. Final tighten 12 air cell nuts on cylinder heads .	1.19
21. Move crane hoist to engine	.28
22. Remove wheel on carrier used in cylinder block; put wheels on truck spud	.84
23. Secure oil pan spud	.12
24. Secure water inlet — pipe drain petcock	.13
25. Bring dolly into position, load engine to dolly and remove crane	1.07
26. Remove crane lifter bolts and move engine on dolly to test room	1.46
27. Bring next engine to work area	.48
Total, station No. 11	25.71
Total, all operations	340.70

Table 34. Percent distribution of factory costs, plant C, U. S. A., 1953

Item	Percent
Factory labor 1/	25.5
Direct materials	67.2
Other factory costs	7.3
Total	100.0

1/ Includes items such as social security payments, workmen's compensation, and fringe benefits.

Table 35. Percent distribution of selling costs, plant C, U. S. A., 1953

Item	Percent
Advertising	39.4
Salesmen's salaries and commissions . . .	36.4
Other (sales promotion, conferences, and training)	24.2
Total	100.0

CASE STUDY, PLANT D

PRODUCTS AND VOLUME OF PRODUCTION

Plant D produces 4-cycle, heavy-duty diesel engines for industrial applications for electric power generation, and for marine service. The engines are adaptable for most stationary and portable uses and have been used in a wide range of industries. Some of the engines are installed in various types of stationary and mobile machinery. Plant D claims to have made many outstanding contributions in the improvement of the diesel engine over a period of years.

About 25 different models are manufactured by this plant, including 4- and 6-cylinder engines ranging from 90 to 240 horsepower. All of these models are of similar design. The crankcase and cylinder block are cast as an integral unit. Dual overhead camshafts are used on all of the engines. Superchargers and other equipment are provided according to customer specifications. A more detailed description of the engine and parts covered in this case study is provided on page 131. Specifications of the reported engine are shown in table 36. Horsepower rating shown in table 36 is based on radiator cooling; if a heat exchanger is used the horsepower rating is increased almost 10 percent.

During the reported period a total of 1,100 4- and 6-cylinder diesel engines of comparable design were manufactured. Of this total, 738 were 6-cylinder engines. This case study is based on the production of the 6-cylinder engines.

Table 36. Specifications of reported 6-cylinder diesel engine, plant D, U. S. A., 1953

Item	Specification 6-cylinder model
Cycle	4
Horsepower, continuous rating at 1,200 r.p.m. (radiator cooled)	150
Bore, inches	5.75
Stroke, inches	6.5
Piston speed at 1,200 r.p.m. (feet per minute)	1,300
Piston displacement, (cubic inches)	1,013
Length, flywheel to fan, (inches)	76
Height (inches)	44
Width (inches)	38
Weight, less radiator (pounds)	4,700

Plant D is currently producing 1 engine a day of the reported model series. At capacity, the plant could produce approximately 12 engines per day on a 3-shift basis (22-1/2 hours per day). Plant D does not operate a mass production shop because of the number of models and types of engines built. However, certain mass production techniques are used and batch quantities are produced whenever production schedules permit.

GENERAL PLANT DESCRIPTION

Building and Site

Most of the plant is housed in one building which includes factory, office, and warehousing space. This building, which is approximately 30 years old, has been enlarged from time to time with the growth in the firm's business. The plant has a floor area of about 45,000 square feet. Plant D's property, consisting of factory, warehousing space, administrative offices, production office, receiving and shipping dock, railroad siding, and yard, covers an area of approximately one acre. This plant has excellent transportation facilities and is located close to important sales markets and sources of raw materials.

The 1 large building in which plant D is housed, is a 1-story, concrete structure, about 20 feet high, with steel reinforced concrete floors. Concrete exterior walls carry their own weight and part of the floor weight. Welded steel trusses support the roof. Adequate daylight is admitted by numerous and relatively large windows. Both lighting and ventilation are good in this building. Inasmuch as stair and elevator wells and ramps are unnecessary considerable plant space is saved. Internally, the building is divided into large workrooms separated by brick fire walls and heavy fire-resistant doors. An overhead sprinkler system provides further fire protection. Costs of moving materials in plant D are low since vertical movement is not required.

Machinery

Both general purpose and special purpose machines are widely used in plant D. Management has become increasingly willing to purchase special purpose machines when the cost of such machines can be amortized quickly; thus, the trend toward greater utilization of highly automatic special purpose machines. Although special purpose machines are usually larger than general purpose machines, they require less floor space since their greater productivity permits use of fewer machines.

General purpose machines are usually slower than special purpose machines. At the same time labor is much more expensive. Operators must be skilled and more supervision and inspection are needed. These general purpose machines do, however, provide greater flexibility and make it easier to keep production capacities in balance.

Materials Handling

A wide range of parts must be handled in the manufacture of diesel engines. When these parts are small, they are moved in boxes from operation to operation. Wherever machines performing succeeding operations are near each other, these boxes are carried by hand from one group of machines to the other, but where machines are more widely separated, the tote boxes are carried on powered industrial trucks. Large or heavy parts, particularly when the rate of production is high, are moved by specially designed conveyor systems from machine to machine as well as from department to department. Considerable use is made of portable power lifting and handling devices provided at individual machines to lift heavy parts into position and to remove them when the work is completed. Cranes, overhead rail hoists, and horizontal roller conveyors are used on line operations and are generally applied in the manufacture and assembly of large engine parts, such as cylinder blocks.

Employment

At the time of this survey, plant D employed about 170 production and office workers; about 10 percent of these were office employees. No women were employed in the plant, although there were 6 in the office.

Operating Practices

Production variations exist in this plant as they do in the diesel engine industry as a whole. Management's policy has been to maintain a plant large enough to handle peak orders and to vary the work force according to production demands. Production schedules are based on both sales orders and sales expectations, and are prepared regularly since this plant is basically a job-lot shop making products to customer order.

Unionization

Production and maintenance workers are represented by the International Association of Machinists (AFL). This union is the sole bargaining agent for production workers but not for office workers, foremen and higher supervisory personnel, the chief inspector, engineering department employees, tool design engineers, and plant guards. As a condition of employment, new employees, in occupations covered by the agreement, must become members of the union within 30 days after the date on which they were hired. Members of the union may individually authorize the company to make payroll deductions from their earnings for payment of union dues and initiation fees.

Hours and Wage Practices

Hours. The normal workweek for both production workers and office employees in this establishment is 40 hours. The workweek consists of five 8-hour days, Monday through Friday. Two 8-hour shifts are worked each day.

Wage Practices. Production workers are on an incentive wage system. This is a straight piece rate with guaranteed minimum hourly earnings but with no limit to the maximum that an individual may earn. Each worker has a basic guaranteed hourly pay rate. All pay rates, such as straight-time hourly rates, piece rates, overtime rates, week-end and holiday rates, and shift differentials are determined by agreement between the union and company. An employee retains the higher basic hourly pay when shifted temporarily to a lower paying job. On any day that a plant worker is required to report for work, he is guaranteed minimum earnings for that day equal to 4 hours' work at his basic pay rate.

Overtime. Time worked in excess of 40 hours during a single week or 8 hours in 1 day is compensated for at one and one-half times the worker's basic hourly pay rate.

Weekend and Holiday Pay. Work performed on Saturdays, Sundays, and holidays is also compensated at premium rates: one and one-half times the employee's basic hourly pay rate for Saturday work and two times his basic hourly pay rate for work performed on Sundays and holidays. Plant B provides 6 paid holidays.

Shift Differential Pay. A premium of 10 cents per hour is paid to workers on the second (evening) shift in addition to their basic hourly wage and the incentive piece-rate pay.

Fringe Benefits

Vacations. Vacation provisions are the same for both plant and office workers. After 1 year of service, an employee receives 1 week's vacation with pay. Workers with less than 1 year's service on June 1 of each year receive a benefit payment in lieu of actual vacation based on the length of time that the individual has been employed by the firm. Workers with 5 or more years' service receive 2 weeks' vacation with pay, the maximum granted by the company. Employees with 1 to 5 years' service receive 1 week's paid vacation plus prorated pay reflecting the length of service they have had between 1 year and 5.

Insurance. After 3 months' continuous service all employees are eligible for various insurance benefits: life insurance, accident and sickness insurance (weekly benefits), and insurance to cover hospitalization, medical, and surgical costs. The company pays the entire cost of these benefits.

Pensions. This firm provides a pension plan which is supported by contributions from both the employees and the company. Payments are made to the employee or his beneficiaries upon his retirement, when he reaches the retirement age or when he is retired because of disability. Each employee has an individual account. The amount he or his beneficiaries draw upon his retirement or death depends in part upon his length of service with the company.

Other Fringe Benefits. Among other benefits provided by the company are a 10-minute rest period during the first half of each workday and a Christmas bonus to each employee ranging from $10 to $35, depending on length of service with the company.

Standardization

All of the diesel engine models produced in plant D are similar in design and construction and use many interchangeable parts. Wherever possible, machined parts have been designed so that they can be readily adapted with a minimum of machining for use in models of different sizes. Additional improvements have been made by applying standardization to materials, processes, specifications, machinery, tools, jigs and fixtures, and engine test practice.

Engineering and Research

One department employs 7 persons engaged in production engineering, methods and time study, and product design. Market analysis is performed informally by the head of the sales department. The research division concentrates on research and tests from which information is obtained for process and product development.

Purchasing Pattern

Over 1,800 parts are assembled in the reported basic 6-cylinder diesel engine. About 900 of these parts are purchased in finished or rough condition from suppliers; the remaining 900 parts are manufactured in the plant. Flywheels, crankcases, cylinder heads, connecting rods, and sumps are purchased as rough castings or steel forgings. Oil coolers are purchased semifinished and machined at the plant. Crankshafts, camshafts, and radiators are purchased in finished condition.

Production Control

Production control at plant D is relatively simple and paper work is kept to a minimum. One form, a daily report from the plant keeps management informed on the progress of customer orders. Another, the shop order form, accompanies each order through the plant. The latter lists various operations and specifications. A setup card is also provided for each machine and operation.

Production of diesel engines is scheduled by setting starting dates for the assembly operation. Usually, the rate of assembly and approximate date for assembly of the last engine on the order are shown. The assembly starting date is set in accordance with the existing workload, provided that necessary parts are available or can be processed in the intervening period. The date is advanced if the customer is eager to get early delivery. In this case, both parts production and assembly may be speeded up by giving the "rush" order priority over less urgent orders. Individual department heads have complete responsibility and authority in their spheres of operations. They select and train their own men; plan and schedule work, and set quality and production standards. However, each department must perform its work on schedule so that succeeding operations are not delayed.

MANUFACTURING PRACTICES

This plant operates on a custom basis. Although some machinery is laid out in production lines, in most cases, machines are grouped around an operator. Although the basic engines have been largely standardized, customer specifications require many variations in manufacturing operations. The company, therefore, processes a wide variety of special flywheels, housings, and mountings. Effective utilization of labor has a considerable influence on shop layout. If the cycle of time of a machine permits the operator to undertake a further task, an additional machine may be placed near him.

Machines doing similar work are usually grouped together, resulting in labor economies. This type of layout is flexible. Products requiring diverse operations can easily follow diverse paths through the plant. Both the cylinder block and the cylinder head used on the reported 6-cylinder diesel engine are machined on a line basis. Other parts are generally machined where the machine tools are grouped together. Both general purpose machines and highly specialized automatic machines are used. The trend in the plant has been towards a greater utilization of automatic machinery. The general purpose machinery usually requires more skilled workers and more supervision, whereas automatic machinery frequently requires little of the operator's time except for loading and unloading, thus permitting him to tend more than one machine.

When the engines are of relatively standard design, they are assembled by line production methods. The products move down a conveyor line from one work station to another as the subassemblies and parts are attached to the cylinder block. Nonstandard engines are assembled in one location. The parts and subassemblies are brought to this central location for assembly to the engine block. The specific engine reported on in this study is assembled on a conveyor line.

Derivation of Man-Hours

Production of the reported 6-cylinder engine requires utilization of 263 man-hours, 75 percent of which are direct man-hours as shown below.

Direct and indirect man-hours per reported 6-cylinder diesel engines, plant D, U. S. A., selected period, 1953

Model	Man-hours per engine		
	Total	Direct	Indirect
6-cylinder	263	200	63

It should be noted that interplant comparisons of man-hour totals of similar engines is misleading unless account is taken of many variables such as differences in the proportions of purchased components, finished or rough. A plant which is primarily an assembler of purchased parts will have total man-hours per engine significantly lower than a plant manufacturing a larger percentage of its parts. Direct man-hours for each engine were derived from time cards and payroll summary sheets. Indirect man-hours were arbitrarily assigned to each engine from a plantwide ratio of direct to indirect labor.

Direct man-hour requirements, by operation, to produce cylinder blocks and cylinder heads are shown in tables 37 and 38. Data on man-hour requirements for assembling the engine selected for this study or for the production of connecting rods were not provided by plant D.

Table 37. Cylinder block-crankcase for reported 6-cylinder diesel engine: Man-hours per 100 cylinder blocks required for production, by manufacturing operation, plant D, U. S. A., selected period, 1953

Operations	Direct man-hours per 100 units
Mill top and bottom	188.7
Drill, ream, and spotface	166.7
Mill ends	55.6
Mill pads	76.9
Machine oil groove	13.9
Bore, counterbore, and bore half hole	283.3
Drill, chamfer, tap, and drive studs	365.0
Total	1,150.0

Table 38. Cylinder head for reported 6-cylinder diesel engine: Man-hours per 100 cylinder heads required for production, by manufacturing operation, plant D, U. S. A., selected period, 1953

Operation	Direct man-hours per 100 units
Mill first side of manifold	40.0
Mill bottom	40.0
Mill top	37.0
Mill second side of manifold	32.3
Mill end	10.0
Drill, counterbore, ream, and groove	450.5
Bore, counterbore, and chamfer 3-1/2 inch hole	50.0
Drill, chamfer, and tap both ends	30.8
Drill, counterbore, chamfer, and tap	173.0
Total	863.5

Detailed Engine Description

A 6-cylinder, 4-cycle engine was reported on for purpose of this study. General specifications for this engine are shown in table 36. This engine's cylinder block and crankcase are cast as a single unit and symmetrically designed to maintain alinement. One casting forms the cylinder head for all six cylinders. Both cylinder block and head are drilled to provide a water jacket for the engine.

Separate wet type cylinder liners of alloy cast iron are used. No pre-combustion chamber is employed. Fuel is injected directly into a plain, open combustion chamber.

Two exhaust and two intake alloy steel valves are provided for each cylinder. These, the manufacturer states, permit greater breathing capacity and consequently higher power output than engines employing only two valves per cylinder.

Two drop-forged overhead camshafts with integral cams provide a short drive to valves and fuel injectors. These are rifle-drilled for pressure lubrication to bearings, journals, and cams. Valve operation is direct from the camshafts through rocker arms. The camshaft drive is taken from the crankshaft at the flywheel end through ball bearing mounted bevel gears and worm gears. Full pressure lubrication is provided.

The crankshaft is drop-forged, heat-treated steel. Its hardened journals are drilled for connecting rod lubrication and piston cooling. Seven steel backed bearings of copper, lead, and nickel are used. They are lead-tin plated.

Full force feed oil pressure lubrication is used to all parts of the engine. A gear type oil pump and an oil filter are used. If the oil pressure falls below a safe minimum the engine stops automatically.

An in-line, high flow capacity, absorbent type, fuel filter is used. The gear type fuel pump is driven from the generator shaft.

Piston castings are oil cooled, heat treated, and tin plated. Piston pins are full floating and pressure lubricated.

Each cylinder is equipped with a fuel injector, which combines fuel pump, metering control, and spray nozzle as a single unit. These injectors are driven by roller bearings from the overhead camshafts. High pressure fuel lines are unnecessary.

The engines are equipped with a wide variety of accessories. Variable speed, hydraulic, servo-type governors and oil bath air cleaners are standard on the reported engine. A 24-volt starting motor is geared directly to the ring gear on the flywheel. Cooling water is delivered to the engine by a centrifugal pump. Engines are either radiator or heat exchanger cooled.

Manufacturing Process

Cylinder Block-Crankcase. The cylinder block and crankcase of the reported engine are cast as an integral unit. Drum mills are used for milling parallel faces of cylinder blocks. The work is clamped to the continuously rotating drum. The process is continuous. One man constantly loads and unloads the machine. Several cutters are employed making it possible to both rough and finish mill. Heavier maintenance is involved when drum mills are used. This is offset, however, because it is possible to secure higher productivity than when using duplex or planer type millers.

Planer-type milling machines are used on some cylinder blocks, particularly those with step-up faces and those too big for drum millers. This is in contrast to planers used by the company for special orders, and where the number of units made of any one kind is small. In appearance the planer-type milling machine resembles a large planer. The table is at a fixed height and moves back and forth under the cutters. Nine cutters, working on three sides, rough and finish mill at one pass of the table.

A listing of manufacturing operations and direct man-hours required in producing 100 cylinder blocks is shown in table 37.

Cylinder Head. A one-piece heat treated gray iron alloy casting serves as the cylinder head for the entire engine. Each cylinder has two intake and two exhaust valves arranged symmetrically around a fuel injector in the center of the cylinder. Water flows through the entire length of the cylinder head and also flows up from the block into the head under the intake and exhaust sections of each cylinder.

Direct man-hours required to produce 100 cylinder heads, by broad operational grouping, are shown in table 38. More detailed data were not provided by the plant.

Connecting Rod. The diesel engine reported on in this study is equipped with safety interlocking connecting rods, which are interlocked by means of transverse serrations on the mating surfaces of the bearing cap and rod. These serrated mating parts are held together by four high-alloy, heat-treated bolts. This construction relieves the bolts of 70 percent of the separating forces and is designed to reduce the possibility of failure from fatigue. The connecting rods are made from heat-treated, drop-forged steel. A hole is drilled the full length of the connecting rod so that the steel-backed, bronze-lined piston pin bushings can be pressure lubricated from the crankshaft end of the connecting rod.

Data on direct man-hour requirements for producing connecting rods were not provided by the plant.

Assembly

Plant D was unable to provide separate data on man-hour requirements to assemble the engine. The complete fabrication and assembly of the reported diesel engine, including all necessary subassemblies, required 200 direct man-hours. Assembly operations are performed on conveyor lines consisting of moving belts at floor level. The engines are placed in cradles which rest on the conveyor lines. These cradles are used also as test mountings. From 9 to 12 assemblers usually work on an assembly line during one shift. At the time of the study, Four production workers on the first shift and three on the second shift operated the assembly line for the series of engines which included the reported model.

A line method of assembly was adopted because it was economical to employ a line layout for most of the engines. This decision was made even though other parts of the plant are arranged on a functional basis. This method of operation was adopted after consideration had been given to the cost factors involved such as the capital required for investment in special machines, tools, floor space, handling equipment, and employee training. These considerations indicated that reductions in cost made this method of operation more economical than other methods of production.

When engines are assembled an adequate supply of subassemblies and parts is kept at appropriate places, or they are produced at a rate matching their use. Much of the work on these lines is done by men with portable power tools.

Since the supply of parts and subassemblies is small, their rates of use and replenishment are maintained at the same rate. To do this, physical counts of the quantities are sometimes made hourly with most of these checked at least once each shift. When items are either running low or accumulating, steps are taken immediately to correct the situation. Parts manufacturing lines send in frequent regular reports of their output and also report immediately when any interruption occurs which will cause them to fall behind in production or when the inspector has rejected an unusually large quantity of parts. Stock supply men, who take parts to the final assembly line from purchased parts storage or from parts production lines, also check the quantities remaining.

Costs of manufacturing by the line method are reduced by using subassemblies wherever possible. The design engineers determine which parts can be put together as subassemblies.

Production on subassembly lines is greater than that of the final assembly lines since some subassemblies are sold for replacement purposes. The production control department determines the total need for each kind of subassembly, sees that they are made, and also sees that they are furnished to the final assembly line at the proper rate. This company manufactures at least half of the parts used in their engines.

Production control is simple for parts which can be produced steadily and at a rate close to the rate of use. A production line is set up for these parts so that they progress directly from operation to operation. The production control department furnishes statements of the quantities wanted each day. When a parts production line produces parts a little more rapidly than the assembly lines can use the parts, the parts line is operated fewer hours. When the flow of parts falls below their rate of use by the assembly lines the parts production line operates longer hours until an inventory is built up for the assembly lines. Most of the parts, however, are produced in successive lots with intervening time intervals, during which the assembly line uses the accumulated supply.

Great care is taken to insure cleanliness during assembly. All parts are washed carefully before use, twice if necessary. Housekeeping in this plant is excellent. The use of individual oil cans for lubrication purposes is banned. Oil is piped to wherever it is needed; the ends of the pipe are flexible with gun-type fittings. All manifolds and other holes are immediately sealed with tape to prevent the entrance of dirt.

It is not necessary for valves to be lapped in their seats at assembly because they are made sufficiently accurate. The seats are ground with a truncated conical grinding wheel, guided by a spindle extension in the valve guide.

Selective assembly is used for pistons in cylinders, steps of 0.0004 inch being used. Cylinder liners are marked with their inside diameter and pistons are marked with their outside diameter. They are selected for assembly provided the difference in their diameters is 0.0004 inch or less. The Works Manager said this allows wider manufacturing tolerances both on pistons and cylinders. Connecting rods and pistons are carefully matched for weight in the machine shop, as a means of rigidly controlling dynamic balance of the rotating parts of the engine.

A method has been developed for salvaging oversized tapped holes. A heli-coil spring when inserted brings tapped holes to original size. These springs are available commercially for standard thread sizes in the United States.

All machines on production lines are linked by roller conveyors with such facilities as turnover sections, turntables, and sidings for storage where required. Machines are laid out to reduce to a minimum the distance traveled by material between successive operations. After complete assembly of the engine, it is sent to the testing floor.

Inspection

In this plant there is an average of 1 inspector for every 10 workers. Inspection is involved in the entire manufacturing process of the diesel engine from the time the raw material enters the plant to the point of final assembly or shipping. During production certain standards of quality must be met, such as the following:

Raw materials from which parts are fabricated are checked for correct size and suitable chemical, physical, and mechanical properties.

Parts and components used in production are inspected for proper dimensions, finishing, and for damage.

Magnetic crack detection is used on such items as crankshafts, camshafts, pistons, and liners. These components travel through a magnetising coil on a conveyor and then drenched with a fluid. They are then inspected by ultra-violet light which shows the cracks plainly.

Completed diesel engines are given a comprehensive final inspection and assembly check or proof test.

Shop gages have a well-finished appearance to encourage the users to take good care of them. Pneumatic gages are used for pistons, connecting rod bores, and for other gaging purposes. The plant maintains a separate repair department for clock-gages and micrometers and keeps a large supply of repair parts on hand. All micrometers are tested at the end of each 8-hour shift.

Testing

Testing is performed for the purpose of determining whether completely assembled end products, generally engines, conform to standards established by the plant for its products. The inspection procedure includes testing.

This firm has recently built new facilities for testing equipment. Engines are tested in sound-proofed cells, two engines to a cell, at right angles to a central gangway. On the gangway side, the cells are open. An opening in the ceiling above the test beds, permits an overhead gantry crane to lower and raise engines from the cells as needed.

Engines are tested at the end of the production line and again after the customer's modifications have been made. An external oil supply is used for the first run of a new engine. The drain plug is removed and the oil is returned to a centrifuge through channels under the floor. This is done as a further precaution to insure a clean engine. An engine's oil system is normally tested on the last test run.

Painting

Painting takes place over a grille in the floor in conventional water-backed spray booths. Powerful fans create a down-draught, thus making screens unnecessary. The spray is caught up in a stream of water flowing almost 5 feet under the grille and is washed away. Precautions against fire hazards have been made as required by building codes and fire protection equipment is provided.

Housekeeping

Cleanliness is given considerable attention in this plant. All parts are cleaned carefully before machining and doors are always provided for storage bins to exclude dust. General factory cleaning is also performed. Floors are cleaned with electric brushes and vacuum cleaners. All corners in the factory are enameled white so that dirt will show up quickly.

Maintenance and Repairs

This establishment has a force of skilled mechanics for maintaining production equipment in good working condition. These workers are provided with machines, cutting tools, work-holding devices, and gages for checking wear and service. Department foremen are responsible for reporting equipment needing repair and manufacturing equipment requiring adjustment. The responsibility for these repairs rests with the Production Department. Because emergencies frequently arise at inopportune moments, the company maintains an emergency toolroom which is an integral part of the Production Department.

Productivity Factors

The Works Manager attributes the high productivity level to better plant layout. He states that increased productivity per man-hour has permitted higher wages and lowered unit costs. It is his belief that greater productivity may be attained with less arduous work by better application of plant layout engineering principles.

In order to increase productivity, a basic change was recently made on an experimental basis with respect to plant layout. Machines formerly laid out in lines are now grouped around an operator. When the cycle time of a machine permits the operator to undertake a further task, the appropriated machine is placed near him. In order to provide flexibility of layout machines are not bolted to the floor unless absolutely necessary.

Changes are constantly being made to improve efficiency and reduce costs. One major change has been the installation of more automatic equipment such as automatic screw machines and automatic chucking lathes. Another recent change has been the adoption of a systematized tooling program.

Essential features of this tooling program are:

Tools which have to be especially made for specific jobs are designed by the plant's new tool design section.

Tools needed for each operation are specified.

Tools are standardized wherever possible and practical.

Records are kept showing tool performance and costs.

A perpetual inventory of tools is kept.

Establishment of organized tool control, as noted above, has resulted in many advantages: For example, less capital is invested in inventory, tool stocks are kept consistent with production requirements, and the better tool control resulting helps to eliminate unnecessary duplication of tools and provides better control in disposing of obsolete tools. Production costs are reduced also since work is now done in less time with less scrap and spoilage. Finally, production control is aided by this program. Standard stock tools are available and new or special tools are procured before production begins and planning can be done with assurance that schedules will be met.

Examples of changes in machining operations and assembly practices which have contributed to higher productivity and at the same time made the work less arduous are provided below. The labor time saved by each of these operations ranges from 0.15 to 0.40 man-hours. In the opinion of the firm's president, the cost of these changes in machines and tools have usually been recouped through increased productivity in about 2 years.

Recently, the firm installed a shaving cutter, mounted after the milling cutters on a planer-milling machine, which shaves the crankcase on the return stroke of the table. This is adjusted to remove about 0.003 inch of metal, leaving the faces square, and free from milling marks.

Crankshaft and camshaft bearing supports in the crankcase are machined by a multitool boring bar with the tools remaining fixed. The crankcases are held in an elevator fixture so that the boring bar is withdrawn when the crankcase is lowered. The crankcase is supported in the fixture by its engine-mounting brackets.

Improvements were made also by the installation of a simple and speedy method of balancing small flywheels. The flywheel is supported on a mandrel, resting on rollers. A horizontal drill is provided at "bottom dead center," so that the heavy part of a flywheel can be lightened quickly by removing a small amount of metal.

Cylinder blocks are carefully washed in a variety of washing machines. Some travel through on a conveyor and are washed by jets of solution. Others are lowered into an agitated caustic bath, and some are steam cleaned and explored with magnetic rods and remove tramp iron.

Improvements have been made with regard to hardening camshafts. The company purchased an automatic induction machine designed to harden the camshafts progressively in a vertical position. A traveling induction block is used to avoid a possible soft spot at the inductor block joint. The shafts are revolved continuously during the hardening operation.

Productivity has been increased considerably through improving the design of jigs and fixtures. During the past 5 years, plant officials estimate that man-hours per engine produced have been decreased 2 hours. Considerable importance is attached to interchangeability of fixtures used on machine tools.

Elements on machine tools which affect the interchangeability of cutting tools are also being standardized. Previously, the plant's practice was to make a set of tools for each component diesel part made on screw machines. When not in use, the complete set of tools was stored in special boxes, marked with a part number. After this practice was followed for many years, the space required to store the tools began to approximate that required for the screw machines themselves. Moreover, the amount of money invested in tools, many of them duplicates, became excessive. Standardization of this equipment eliminated most of the duplication, and substantially reduced the amount of storage space.

Some examples of jig and fixture parts standardized include jig bushings, locking latches, handles, thumb screws, locating studs or seats, feet for jigs, die sets, and suppressed die frames. The company has also designed special tote boxes and racks for holding the work between operations.

Productivity has been increased by a constant expansion of standardization practices on a broad front. This has included the standardization of engine parts and surfaces, materials, processes, specifications, machinery, tools, jigs and fixtures, and of engine test practices.

Plant officials also emphasized production control as another factor which has been important in promoting higher productivity in this plant. Efficient production control methods are considered of prime importance in the smooth functioning of the plant.

Cost Distribution

Because of a variation in the operations required for the different models, the company has a job-lot cost system. Each job is given a number to identify it (the same number used by the production control department) and an account is set up in the cost accounting department for the job. As requisitions for materials and worker job tickets come in, showing costs of materials and labor, the amounts are recorded in this account. Later, overhead costs are also charged to the order, usually according to the amount of direct labor the job required. The amounts for materials, labor, and overhead are added together to obtain total manufacturing cost.

Manufacturing costs of the reported engines were approximately 62 percent for direct materials costs, 20 percent for labor costs, and 18 percent for other factory costs. Maintenance of equipment and supplies are the largest items classified as other factory costs.

Selling expense generally averages 3 percent of total sales. Sixty-five percent of selling expense is salesmen's salaries and commissions; 14 percent is advertising costs, and 17 percent represents the selling costs of company retail outlets.

CASE STUDY PLANT E

PRODUCTS AND VOLUME OF PRODUCTION

Plant E manufactures diesel engines exclusively. In 1952, shipments of diesel engines and parts from this plant totaled approximately $55 million. These shipments included automotive, industrial, and marine diesels, ranging in size from 60 to 600 horsepower. Nearly all of the engines were 4, 6, and 12 cylinder models. They were light weight, high speed, heavy duty diesels and included mobile, portable, and stationary types.

An automotive diesel engine was selected from plant E's production for use in this case study. It is widely used for diesel trucks, and buses and is also used for off-highway purposes. The particular model selected is a full-diesel, 4-cycle, 6-cylinder high speed engine. Further description of the engine is provided on page

General specifications of the engine are shown in table 39.

Table 39. Specifications of the reported 6-cylinder diesel engine, plant E, U. S. A., 1953

Item	Specification 6-cylinder model
Cycle	4
Horsepower, continuous rating at 2,100 r.p.m.	200
Bore (inches)	5.125
Stroke (inches)	6
Piston displacement (cubic inches)	743
Compression ratio	15.5:1
Length (inches)	61
Height (inches)	49
Width (inches)	29
Weight, with standard accessories (pounds)	2480
Weight per horsepower (pounds)	12.4

GENERAL PLANT DESCRIPTION

Buildings and Site

Plant E covers an area of about 40 acres. Although it contains a number of large buildings, a substantial part of the property is allocated to parking space. Most of the buildings are 1- or 2-story and constructed of steel and masonry. Total floor space is close to one-half million square feet.

Nearly all of the buildings were constructed solely for the purpose of producing diesel engines and parts. Receiving, storing, and shipping activities are consolidated in one large building. A railroad spur passes through the center of the property.

Machinery and Equipment

For the past several years, this plant has been undergoing a program of expansion and improvement, including the construction of new buildings and the purchase of new machinery and equipment. These additional facilities are expected to increase the plant's capacity more than 50 percent.

Conveyor type assembly lines are used for assembling engines and for subassemblies. The entire factory is arranged in such a manner that cylinder blocks, cylinder heads, and other major engine components are fed directly to the engine assembly line.

Machinery and equipment in this plant are typical of that found in most engine manufacturing plants in the United States. It consists chiefly of a wide assortment of machine tools and associated equipment. These machine tools and other items of equipment include both standard tools and specially designed tools and equipment made for specific operations in this particular plant. A wide variety of jigs, fixtures, and other attachments are used. These form an important part of the plant's equipment from the standpoint of improving efficiency. Such equipment is constantly undergoing improvement and change.

In addition, the plant has a large amount of equipment for inspection and testing purposes, including inspection and testing of incoming materials and parts, testing engines after assembly, and checking tolerances and other standards of parts and subassemblies during manufacturing operations. A modern research center, containing a considerable amount of costly equipment, is also maintained. Other plant equipment includes heating plant and power equipment, and equipment for moving materials, such as overhead and floor conveyors, mobile and overhead cranes, hoists, tow trucks, and fork lift trucks.

Employment

During the last 3 years, employment at this plant has ranged between 2,000 and 3,000 workers. About 85 percent of the work force are production workers and 15 percent are office employees. More than 60 percent of the office workers are women. Women comprise about 4 percent of the production workers. At the time of this survey 71 percent of the plant workers were employed on the day shift; 28 percent on the evening shift; and about 1 percent on the night shift. Night shift workers were mostly custodial employees. Employees engaged in engineering and research activities comprised 5.4 percent of the plant's total employment.

OPERATING PRACTICES

Owing to fluctuations in the level of diesel engine sales, the level of operations at the plant varies from time to time. This causes some fluctuations in employment. Whenever possible, workers are moved from the production of one model to another as demands change.

A major part of the plant's production is done in job lots, based on actual orders received by the firm. Normally, diesel engines are not produced for stock. However, several engine models produced by this plant are so standard, particularly truck and bus diesels, that some advance planning of production is possible; many parts can thus be ordered or produced in advance of actual orders. To some extent, this permits plant operations to be maintained at a relatively stable level.

Most assembly (including subassemblies) is on a conveyor line basis. In a few cases, where the number of engines on order of a certain type or model may be very small, other assembly methods may be used. However, such methods are expensive. Major components are usually produced on production lines. Smaller components may be produced in areas with machines of a similar function grouped together.

Standardization often determines applicable production methods. It may be impossible to machine nonstandard parts on highly automatic specialized machines or to assemble nonstandard engines on specialized assembly lines.

Unionization

A majority of the plant workers are covered by a collective bargaining agreement with a local independent union. Most wage and labor practices of the firm are the result of agreement with this union. The office clerical staff is represented by a committee of office workers.

Hours and Wage Practices

Hours. The normal workday is 8 hours, except for employees on the evening and night shifts who work 7-1/2 hours including a paid 1/2-hour lunch period.

Wage Practice. Employees are paid either a salary or a straight hourly wage, and overtime and shift pay differentials where applicable. Incentive pay methods and bonuses are not used.

Overtime. Pay equal to one and one-half times the employee's regular hourly rate is paid for all work over 8 hours in any 1 day or for all work over 40 hours performed during a single workweek. Time and a half is also paid for work performed on holidays. Work performed on Sundays is compensated at double time rates.

Shift Pay Differentials. At the time of this survey, plant E was working two shifts; it had a few workers on the third (night) shift. Workers on the evening and night shifts received a "shift differential" payment of 8 cents an hour in addition to their regular hourly rates.

Fringe Benefits

Vacation and Sick Leave. Paid vacations and sick leave benefits are provided by the company. Details concerning these provisions were not furnished by the company.

Insurance and Hospitalization. All employees in both plant and office, including salaried workers, are covered by the firm's life insurance and hospitalization program. The costs of this program are borne by the company.

Pensions. Retirement pay is provided through a company financed pension plan which supplements pension benefits provided under the Federal Social Security law (see Chapter III). Data on the extent of coverage and the level of benefits provided by the company plan were not supplied.

Standardization

About 80 models of diesel engines are manufactured by this plant, although the basic design features of these engines are the same. The engines manufactured by plant E are all 4-cycle full diesels. Wherever practical, this plant standardizes tools, jigs and fixtures, materials and methods, as well as engine design.

Engineering and Research

Approximately 5 percent of the employees at plant E are engaged full time in engineering and research. Fifty-four of these workers (41 percent of those in engineering and research) were employed in production engineering. Another 16 workers (12 percent) were in methods and time study, and product design employed 59 workers (45 percent). Two employees were engaged in market research.

Emphasis in this plant's current research program is being placed on studying the practicability of higher rotating speeds, turbocharging, and certain improvements to the fuel injection system. Over the long run the firm has been attempting to lower operating costs of the engines and at the same time to decrease their size and weight.

Production Control

This plant produces diesel engines to order only. Complete engines are not stocked. Each order for engines has a separate set of specifications particularly for equipment attached to the engine block. Although these orders are for basic models shown in company catalogs, specifications are written up individually on each order and vary considerably from order to order. Company sales engineers often aid the buyer in preparing the specifications. Orders are developed into bills of materials, including all parts and subassemblies. A bill of materials report is used for basic materials planning and for shop planning.

Plans for supplies of common components and for optional equipment are made well in advance of production. Such plans are based on past experience and expected sales.

Derivation of Man-Hours

Standard man-hours as shown in this case study were established just prior to the end of 1953. These are considered by the firm to be reasonably accurate as compared with actual man-hours.

MANUFACTURING PRACTICES

Detailed Engine Description

The reported engine is a full-diesel, 4-cycle, 6-cylinder high speed engine. At 2,100 revolutions per minute, maximum continuous rating, the engine develops 200 horsepower. A more complete list of specifications is shown in table 39.

A low pressure fuel pump is used with a single metering pump and distributor which serve all cylinders. Mechanically operated injectors preheat and feed fuel into the cylinders. Water is circulated by a centrifugal pump driven by a belt and mounted on the gear-cover end of the engine. Standard equipment includes a 7-1/4 cubic foot air compressor and a 24 volt starting motor.

Cylinder Block-Crankcase

The crankcase and cylinder block are cast as a single unit from alloy steel. The upper part of the cylinder block serves as a water jacket and is equipped with removable wet type cylinder liners. These liners are of special alloy and are held in place by the cylinder heads. Valves and fuel injectors are operated by rockers and push rods from the camshaft located in the upper part of the crankcase and to one side of the block. Lubricating oil is forced to working parts of the engine through: an oil header, drilled the full length of the block; oil pipes leading to the upper rocker housings; and various oil lines drilled through the block, crankshaft, and rocker levers.

This engine has a compression release shaft located on the opposite side of the block from the camshaft. The fuel pump and filter are mounted on the camshaft side of the block. If the gear end of the block is divided by a perpendicular line, the lubrication pump and air compressor holes are on the camshaft and fuel pump side of the block; while the idler gear pin and the holes for the water pump and generator are on the relief shaft side of the block. Direct man-hour requirements, by operation, to produce 100 cylinder blocks are shown in table 40.

Cylinder Head

Cylinder heads on this model are cast in pairs; thus, each 6-cylinder engine requires 3 castings. The valves, made of heat-resistant alloy, are seated in the cylinder head. Each cylinder has dual intake and dual exhaust valves. Hence, the dual cylinder head contains 4 exhaust and 4 intake valves, 2 injectors, 2 injector rocker levers, 4 valve rocker levers, and 4 crosshead valves. Water circulates through the cylinder head and around the injector sleeves.

Direct man-hour requirements, by operation, to produce 100 cylinder heads, are shown in table 41.

Connecting Rods

Connecting rods are drop-forged and drilled for pressure lubrication to the piston pins from the crankshaft. Two bolts hold the rod and cap together. Direct man-hour data for producing connecting rods are shown in table 42.

Inspection and Quality Control

All materials are inspected prior to production. These inspection measures include testing and inspection for physical and chemical properties, for dimensions, and for finishes.

Methods of statistical quality control during the processes of production are utilized for maintaining high standards in critical machining operations such as in machining connecting rods, cylinder blocks, cylinder heads, fuel injectors, and fuel pumps. This program is largely accomplished by the use of charts located at the individual machines. The operator posts critical dimensions to a chart located at the machine that he operates. He is required to follow a specified method of sampling in checking and recording dimensions. Accuracy in manufacturing is of prime importance. Such parts as injector bodies and lubricating pump gears are finished to tolerances as close as ten-millionths of an inch.

Following assembly, each engine is adjusted and given a "break in" run lasting several hours. After this initial run, a thorough inspection of the engine is made. The engine is then given a final test-run on a dynamometer, during which it must develop a predetermined horsepower at a minimum fuel consumption rate. The engine is then ready for shipment.

Productivity Factors

Most of the factors that have promoted increased productivity in other American diesel engine plants have also been influential in raising productivity in this plant. Among the factors contributing to higher productivity in plant E, have been the development of standard engine models, simplification of engine design, and the employment of a staff of 4 persons engaged in production engineering, and in time and methods study. A well planned method of quality control has also lowered production costs and maintained high standards of precision.

All receiving, storing, and shipping activities, and many inspection functions are consolidated in one large 1-story building. Incoming parts and other materials to be used directly in production and incoming finished parts which will be shipped as repair parts are received, inspected, stored, and shipped from this building. Large semitrailer trucks pull into the building for loading and unloading.

A new conveyor-type engine assembly line has been installed. Almost all of the factory is arranged so that cylinder blocks, cylinder heads, and other major engine components are fed directly to the assembly line with a minimum movement of materials.

This plant, like others in the industry, lowers costs substantially through an aggressive program of jig and fixture development. Following are two typical examples of such savings:

A fixture to permit drilling 6 holes in a water header cover on a multiple drill press rather than on a single drill press, resulted in a savings of 0.1 of an hour per piece. Since this is a high production part, the overall savings were substantial.

A special fixture for drilling a hole at an angle in a governor housing resulted in a savings of about 0.5 hour per piece.

COSTS

Total costs amounted to 93 percent of net sales during 1952. Of this amount 86 percent represented the cost of goods sold and 14 percent represented selling costs, general and administrative costs, cost of services, and research and developmental expenses. Of the cost of goods sold 68 percent was for direct materials; the other 32 percent was for all other direct costs including labor.

MARKETING

This firm has three principal outlets for sales of diesel engines and parts: direct sales to manufacturers, sales through its dealers, and sales to the United States Government. Manufacturers of trucks, buses, construction machinery, industrial equipment, and boats buy a large part of the plant's output of diesel engines for incorporation into their own products. The second source of sales, of equal importance to sales to other manufacturers, is sales of diesel engines and parts to this firm's dealers throughout the United States and other countries. These dealers are independent firms which are authorized as outlets for the company's engines and parts and at the same time maintain factory approved repair services. Many of the diesel engines that they sell are replacements. The sale of parts by these dealers is also important. The third source of sales, less important than the two previously mentioned, are sales to the United States Government.

Table 40. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and direct man-hours per 100 cylinder blocks required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953

Operation	Machinery 1/	Direct man-hours per 100 units
1. Shot blast	Wheelabrator	18.34
2. Rough bore camshaft hole	Boring mill	11.87
3. Clean	Floor	114.92
4. Paint outside and inside	Paint booth	8.41
5. Straddle mill main bearing pads . . Drill and ream 2 holes through . . .	Milling machine Drill	39.57
6. Rough mill flywheel end and gear end . . . . Rough bore main bearing half holes	Milling machine Boring machine	26.74
7. Drill 2 holes through block	Drill	17.29
8. Mill camshaft side and generator side . . . . Rough and finish mill extruding pads	Milling machine	46.18
9. Rough and finish bore 7 camshaft holes	Boring mill	39.22
10. Rough and finish bore generator, fuel pump, and lube pump holes. Finish bore water pump hole	Drill	17.92
11. Counterbore generator, water pump, fuel pump, and lube pump holes . .	Boring mill	37.89
12. Rough and finish mill generator pads and hand hole pad. Mill 2 water connection pads	Milling machine	33.77
13. Rough bore, finish bore, counter-bore, and chamfer 6 linder holes	Boring machine	28.44
14. Face sides of main bearings	Milling machine	20.65

Table 40. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and direct man-hours per 100 cylinder blocks required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953 -- Continued

Operation	Machinery 1/	Direct man-hours per 100 units
15. Mill cam boss. Rough and finish mill idler pin bosses	Milling machine	20.43
16. Drill 41 holes and spot drill 3 holes on camshaft side	Drill	13.32
17. Water test oil line	Floor	8.05
18. Drill 28 holes on gear end. Drill 22 holes and ream 1 hole on flywheel end	Drill	13.10
19. Drill 24 holes, 24 holes through, and 3 starting holes in top . . .	Drill	11.47
20. Drill 28 holes through bottom flange	Drill	6.42
21. Drill 14 main bearing stud holes	Drill	23.82
22. Drill angle oil holes and angle holes to water jacket. Drill 1 hole through. Backface 2 holes. Drill 8 holes through to cam hole and idler hole	Drill	32.79
23. In relief side: Spotface 21 holes. Drill 3 holes into cam. Drill 3 holes through 2 walls. Counterbore 3 holes. Tap 29 holes. Backface 4 holes. Ream 3 holes .	Drill	43.02
24. In relief side: Chamfer 24 holes. Drill 2 holes. Tap 26 holes. Tap 1 hole through 1 wall	Drill	29.99
25. In camshaft side: Drill 7 holes through. Drill 18 holes. Ream 4 holes	Drill	37.27

Table 40. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and direct man-hours per 100 cylinder blocks required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953 -- Continued

Operation	Machinery 1/	Direct man-hours per 100 units
26. In camshaft side: Drill 9 holes. Tap 59 holes	Drill	35.87
27. In camshaft side: Drill 1 hole through. Drill 13 holes. Spot-face 3 holes. Chamfer 23 holes. Tap 36 holes. Ream 1 hole	Drill	49.99
28. In top of block: Drill 3 holes. Ream 27 holes. Counterbore 18 holes. Tap 18 holes	Drill	49.02
29. In generator side: Drill 25 holes. Drill 3 holes through. Tap 27 holes. Ream 6 holes . . .	Drill	45.18
30. In bottom: Ream 14 holes. Counterbore 21 holes. Rough tap 14 holes. Finish tap 14 holes.	Drill	48.84
31. Insert 1 plug. Wash block and blow out tapped holes. Drill 3 holes. Ream relief shaft holes. Assemble 6 water heater pipe plugs. Check water channels for wires and sand	Wash tank	33.92
32. Water test. Assemble 3 plates. Grind oil groove in 1 bearing . .	Water test	37.54
33. Ream and burr 7 cam holes	Floor	13.41
34. Check block and select caps. Stamp block and caps. Assemble 14 main bearing studs. Assemble number 7 bearing cap. Assemble numbers 2, 4, and 6 bearing caps. Assemble numbers 1, 3, and 5 bearing caps. Check to see if oil lines are open	Floor	24.41

See footnotes at end of table.

Table 40. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and direct man-hours per 100 cylinder blocks required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953 -- Continued

Operation	Machinery 1/	Direct man-hours per 100 units
35. Burr lock ring. Drill 2 holes through cam and into block. Ream 2 holes. Assemble 2 dowel pins. Countersink 2 holes. Finish tighten studs by hand. Lap face of caps. Check height of studs	Drill	38.15
36. Assist boring mills and get block ready to bore		8.34
37. Finish-face 1 main bearing (number 7). Finish-bore 7 main bearings	Drill	62.25
38. Burr and sand edge of bearings in block. Mill both ends square with main bearing bore. Burr 7 main bearing caps and sand	Milling machine	34.26
39. Finish-face and chamfer number 7 main bearing by hand. Burr bottom flange and file edges of parting face of main bearing bore. Burr liner holes and 3 oil holes on cam side. Burr main bearing on block	Floor	34.47
40. Finish-bore idler pin hole	Drill	15.18
41. Drill 2 holes through. Ream 2 holes through. Chamfer 3 oil holes	Drill	9.39
42. Drill 1 hole through. Counterbore 1 hole. Finish-counterbore 1 hole. Finish-chamfer at bottom of bore	Drill	9.99
43. Face cam bosses and idler pin bosses	Drill	13.04

See footnote at end of table.

Table 40. Cylinder block-crankcase for reported 6-cylinder diesel engine: Machinery and direct man-hours per 100 cylinder blocks required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953 -- Continued

Operation	Machinery 1/	Direct man-hours per 100 units
44. Finish-burr block	Floor	34.82
45. Wash block and cap. Assemble 7 cam shaft bushings as follows: numbers 3 and 5; number 1; numbers 2, 4, and 6; and number 7	Wash tank Bushing machine	28.87
46. Finish-hand-paint block. Drill 4 holes. Assemble stamping plate and 2 screws	Turn table	36.72
47. Assemble 18 cylinder-head studs. Check height of studs. Chamfer 18 water holes	Floor	34.79
48. Finish-counterbore 6 cylinder holes. Burr and sand 6 liner holes	Drill	18.82
49. Assemble 1 relief shaft and 3 oil pipes. Finish-wash and blow-off piece. Assemble 1 pipe plug. Check main bearing studs to see if nuts turn freely (2 men required)	Tank and floor	33.17
Total	. . . .	1,450.70

1/ The plant did not provide machinery manufacturers' names or other detailed data on the machinery used.

Table 41. Cylinder head 1/ for reported 6-cylinder diesel engine: Machinery and direct man-hours required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953

Operation	Machinery 2/	Direct man-hours per 100 units
1. Shot blast	Wheelabrator	1.18
2. Clean	Bench	14.86
3. Roll-out shot	Bench	4.11
4. Blow-out shot	Bench	5.43
5. Use wire wheel on 2 intake ports. Clean where necessary	Bench	4.61
6. Paint inside and outside	Booth	3.00
7. Mill manifold pads	Milling machine	4.96
8. Rough-mill bottom face	Milling machine	2.77
9. Grind top face	Grinder	4.76
10. Finish-grind bottom face	Grinder	1.51
11. Rough and finish-form injector holes	Drill	12.29
12. Mill injector pads, water manifold pads, and nut pads	Milling machine	9.21
13. In top face: Drill 43 holes. Counterdrill 9 holes. Ream 8 holes. Chamfer 17 holes	Drill	4.54
14. In bottom face: Drill 20 holes. Counterdrill 7 holes. Ream 2 holes. Bore valve throat clearance. Rough counterbore 4 exhaust holes. Rough bore 4 intake holes. Drill and chamfer 4 manifold stud holes	Drill	3.91
15. Counterbore 8 holes. Cut push-tube clearance	Drill	6.77

See footnotes at end of table.

Table 41. Cylinder head 1/ for reported 6-cylinder diesel engine: Machinery and direct man-hours required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953--Continued

Operation	Machinery 2/	Direct man-hours per 100 units
16. Finish-bore valve guide holes. Finish-counterbore 4 holes. Rough-face valve seats on intake . . .	Boring machine	15.62
17. Drill 6 holes. Spotface lifting lugs .	Drill	9.81
18. Drill 2 holes	Drill	5.57
19. Finish-spotface 2 nut pads. Burr 2 holes. Cut 4 water passages	Drill	7.87
20. Tap 3 holes. Ream crosshead guide holes	Drill	6.15
21. Counterdrill 2 holes. Tap 4 holes. Cut lifting lug clearance	Drill	7.74
22. Tap 12 holes	Drill	6.18
23. Tap 15 holes	Tapper	4.04
24. Drill and tap 1 hole	Drill	3.00
25. Wash cylinder head and blow dry	Tank	4.67
26. Burr and clean. Assemble 2 fuse plugs and 2 pipe plugs	Bench	19.82
27. Assemble 6 pipe plugs	Bench	3.86
28. Water test	Bench	3.19
29. Wipe clean	Bench	3.25
30. Peen 2 injector sleeves and roll-in . .	Drill	3.84
31. Face-off burr on piston side of injector sleeve and file smooth with casting .	Drill	2.34
32. Final water test	Bench	2.70

See footnotes at end of table.

Table 41. Cylinder head 1/ for reported 6-cylinder diesel engine: Machinery and direct man-hours required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953--Continued

Operation	Machinery 2/	Direct man-hours per 100 units
33. Cut injector seats	Drill	4.17
34. Assemble 8 valve guides and 4 valve crosshead guides	Press	4.42
35. Hone 8 valve guides	Hone	8.05
36. Wash cylinder head and blow dry	Revolving tank	2.64
37. Assemble 4 exhaust valve seat inserts. Tap threads in 4 holes. Plug-gage all valve crosshead guides. Hand-ream crosshead guides when necessary . . .	Bench	3.42
38. Grind 8 valve seats	Grinder	11.79
39. Assemble 4 intake valves, and 4 exhaust valves. Lap 8 valves into seats. 100 percent indicate valve seat with valve guide hole. 100 percent blue check on all seats	Bench	13.20
40. Remove, wash, oil, and replace 8 valves. Assemble 8 valve springs, 8 valve guides, and 16 collets	Tank and bench	5.22
41. Assemble and drive 4 injector studs and 7 rocker-arm housing studs	Bench	4.47
42. Tighten when necessary. Check rocker-arm housing for fit on studs. Check rocker-arm housing oil tube for clearance. Finish hand paint. Check valves for leakage	Bench	9.04
Total all operations		259.98
Total for 100 engines (3 cylinder heads per engine) . .		779.94

1/ 3 cylinder heads used for each 6-cylinder engine.
2/ Machinery details not reported by manufacturer.

Table 42. Connecting rods for reported 6-cylinder diesel engine: machinery and direct man-hours required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953

Operation	Machinery 1/	Direct man-hours per 100 units
1. Shot blast	Wheelabrator	0.38
2. Forging sent to inspection department for hardness test		Not included
3. Remove all burrs, sharp edges, and nicks	Grinding wheel	3.10
4. Straddle-mill crankshaft end and pin end	Milling machine	3.09
5. Burr rods	Lathe	3.29
6. Flat-bore pin end	Boring machine	4.89
7. Rough-bore crankshaft end and pin end. Remove burrs from crankshaft end	Drill	4.66
8. Mill locating pads. Bore and chamfer pin end	Milling machine Boring machine	4.89
9. Mill bolt and nut pads	Milling machine	3.04
10. Saw cap from rod	Saw	1.79
11. Rough-and-finish-broach crankshaft end and cap	Broach	1.74
12. Wash rods	Tank	.26
13. Wash caps	Tank	.13
14. Grind end of rod square	Grinder	1.90
15. Grind end-face of cap square	Grinder	2.10
16. Mill lock-slot in rod	Milling machine	.81
17. Mill lock-slot in cap	Milling machine	.78

See footnote at end of table.

Table 42. Connecting rods for reported 6-cylinder diesel engine: Machinery and direct man-hours required for production, by manufacturing operation, plant E, U. S. A., selected period, 1953 -- Continued

Operation	Machinery 1/	Direct man-hours per 100 units
18. Finish-burr bolt hole clearance in cap and demagnetize	Drill	.78
19. Finish-burr bolt hole clearance in rod and demagnetize bolt	Drill	0.90
20. Drill 2 bolt holes in cap and 2 bolt holes in rod	Drill	3.00
21. Finish-burr 2 bolt holes in cap . .	Drill	.35
22. Finish-burr 2 bolt holes in rod . .	Drill	.41
23. Drill long oil hole through. Chamfer pin end of oil hole	Drill	5.97
24. Lap connecting rod. Wash after lapping. Inspect face of rod and check for squareness	Lapper	3.61
25. Lap connecting rod cap. Wash after lapping. Inspect face of cap . . .	Lapper	3.61
26. Counterbore 2 holes in rod	Drill	2.25
27. Bore and countersink 2 holes in rod	Boring machine	2.07
28. Counterbore 2 holes in cap	Drill	2.20
29. Bore and countersink 2 holes in cap	Boring machine	2.12
30. Chamfer 2 bolt holes on cap	Drill	.46
31. Chamfer 2 bolt holes on rod	Drill	.46
32. Mill radius	Milling machine	4.64
Total for all operations		69.68
Total for 100 engines (6 connecting rods per engine) . .		418.08

1/ Machinery details not reported by the plant.

Case Study Data on
Productivity and Factory Performance

DIESEL ENGINES

CONTENTS

TABLES

ILLUSTRATION

TABLES

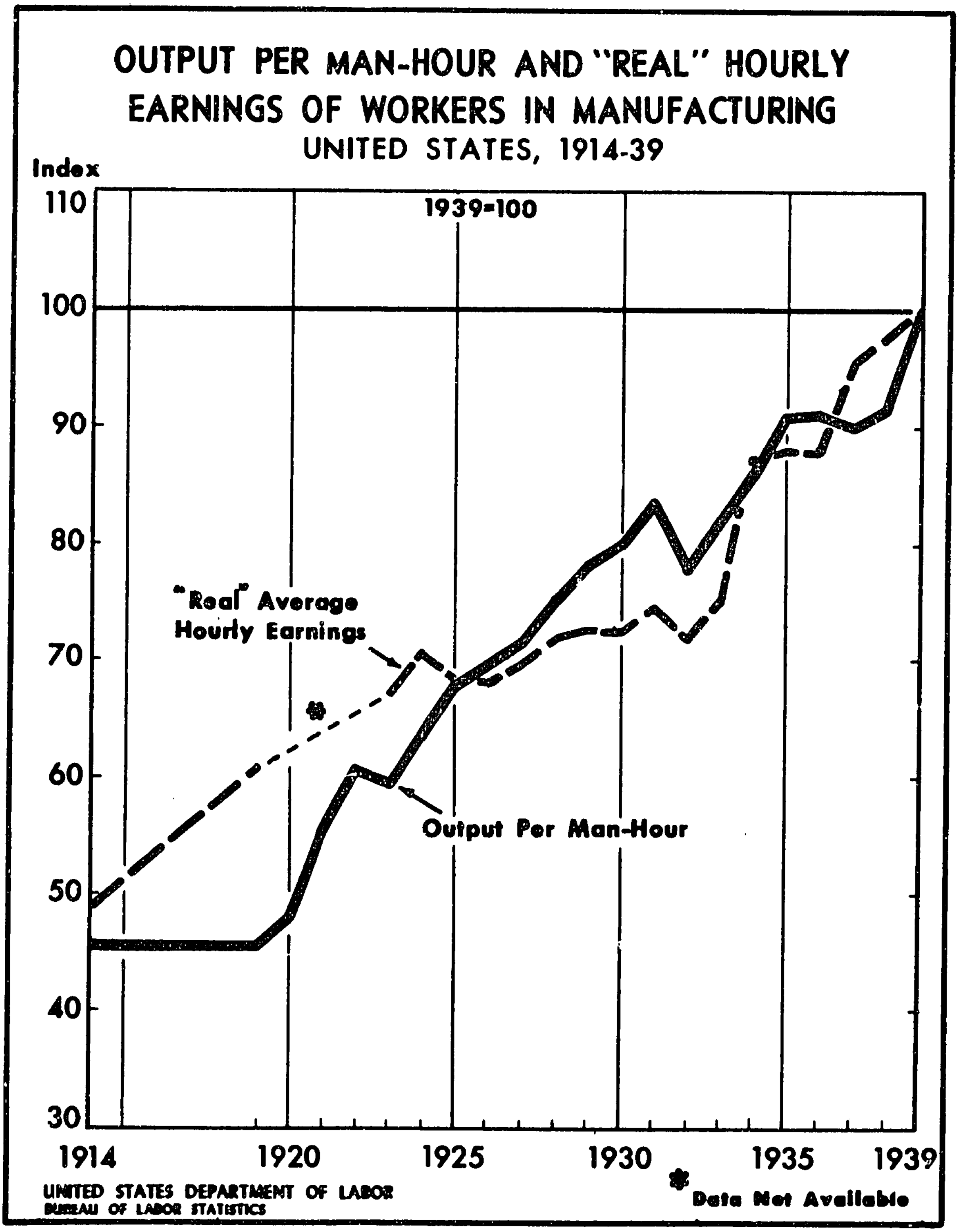

Figure 11 Output per man-hour and "real" hourly earnings, manufacturing, U. S. A., 1914-39

CHAPTER III: LABOR IN THE DIESEL ENGINE INDUSTRY

(NOTE: THIS CHAPTER IS NOT INTENDED TO BE A COMPLETE STUDY OF LABOR OR LABOR CONDITIONS IN THIS INDUSTRY. IT IS PRESENTED PRIMARILY TO ILLUSTRATE THAT THE UNITED STATES FACTORY WORKER HAS ACHIEVED A HIGH STANDARD OF LIVING IN HIS HIGHLY PRODUCTIVE ECONOMY.)

LABOR BACKGROUND

Factory worker's earnings together with the earnings of other groups in the United States, have increased in real as well as in monetary terms along with an almost continuous productivity improvement. Their average real weekly earnings increased about 140 percent between 1914 and 1953, whereas the scheduled workweek declined 22 percent during this same period. These substantial improvements in income could not have been achieved except for increased output per man-hour of work made possible by a constantly improving technology of production. Although all workers have benefited from greater productivity, workers in industries with strong unions have generally been in the forefront in obtaining a share of the gain from increased productivity. In addition to increased pay and shorter hours, workers have chosen to take some of the returns from greater productivity in the form of benefits such as paid holidays, vacations, and pensions.

Despite the advantages arising from technological change, and the fact that workers and unions in the United States have generally been well disposed toward accepting improvements in machinery and methods, there have been problems of adjustment. Both organized and unorganized labor have on some occasions resisted the introduction of new methods or machinery because of the threat of short-run unemployment and the natural human resentment to change. Management and labor have dealt successfully with many of these problems. Several general examples appear in appendix I.

Real average hourly earnings rose each year from 1951 through 1953 (table 43) for workers employed in diesel engine manufacturing plants. They received a higher average hourly earnings than the average for all manufacturing industries. Coupled with a longer average workweek this gave them substantially higher average weekly earnings. Although average weekly hours worked declined during 1951, 1952, and 1953 increased average hourly earnings in each of these years resulted in an increase in average weekly earnings in each year.

The cost of common commodities in terms of worktime required for the average production worker in all manufacturing industries and workers in diesel engine manufacturing to buy food and commodities in 1953 is shown in table 44.

Table 43. Consumer Price Index, gross average earnings and weekly hours of production workers in all manufacturing industries and in the diesel and other internal combustion engine industry, United States annual averages, 1951-53

Year	Consumer Price Index (1947-49=100)	All manufacturing industries			Diesel and other internal combustion engine industry except automotive and aircraft 1/		
		Average weekly earnings	Average weekly hours	Average hourly earnings	Average weekly earnings	Average weekly hours	Average hourly earnings
1951	111.0	$64.71	40.7	$1.59	$78.26	43.0	$1.82
1952	113.5	67.97	40.7	1.67	80.37	42.3	1.90
1953	114.4	71.69	40.5	1.77	82.41	41.0	2.01

1/ Separate hours and earnings statistics for diesel engine manufacturing are not available. About 42 percent of the dollar value of primary products for this industry classification were attributable to diesel engines in a recent year.

UNIONS

Production and related workers in 4 of the 5 plants studied were covered by collective bargaining agreements with various unions. These unions are named in each plant case study. Three of the leading unions in plants manufacturing diesel engines are the United Automobile, Aircraft and Agricultural Implement Workers of America (CIO); International Association of Machinists (AFL); and the United Steelworkers of America (CIO).

Collective bargaining agreements with diesel engine plants generally include provisions concerning hours of employment, pay rates, working conditions, grievances, seniority rights, paid vacation leave, holiday pay, overtime rates, and pay rates for Saturday and Sunday work, shift differentials, and sick leave. Job rate relationships are usually determined by agreement between the union and the management.

Some union contracts have provisions for pay increases or renegotiation of rates when increases in productivity occur or when new machinery or methods are introduced. Other contracts provide for pay rates which vary with changes in the "cost-of-living." The Consumer Price Index published by the United States Department of Labor's Bureau of Labor Statistics, is used as the basis for such adjustments.

Table 44. Worktime required of production workers to buy selected items of food and clothing, U. S. A., 1953

Item	Unit of measure	Production workers in all manufacturing industries 1/		Production workers in diesel engine manufacturing 1/	
		Hours	Minutes	Hours	Minutes
Food:					
Fresh milk	1 liter	--	8	--	7
Large eggs, grade A	10	--	22	--	19
Oranges	10	--	14	--	13
White flour	1 kilogram	--	8	--	7
White wheat bread. .	1 kilogram	--	12	--	11
Butter	1 kilogram	--	58	--	51
Potatoes	1 kilogram	--	3	--	3
Coffee	1 kilogram	1	8	1	0
Clothing: 2/					
Men's:					
Wool suit	1	35	52	31	36
Cotton work shirt .	1	--	54	--	47
Cotton socks	1 pair	--	17	--	15
Rayon socks	1 pair	--	17	--	15
Street shoes	1 pair	7	51	6	55
Work shoes	1 pair	4	14	3	44
Women's:					
Wool coat	1	16	55	14	54
Cotton housedress .	1	1	52	1	38
Nylon hose 3/	1 pair	--	49	--	43
Street shoes	1 pair	6	11	5	27

1/ Based on the 1953 average hourly earnings of production workers in all manufacturing industries and in the diesel and other internal combustion engine manufacturing industry, except automotive and aircraft engines.

2/ For clothing items, the average of the average prices collected monthly from five cities unweighted were used to represent typical prices. Those represent prices paid by all Americans rather than factory workers only.

3/ Only nationally advertised brands are included.

PAY PROVISIONS

Overtime Pay

Plants in most manufacturing industries in the United States, including those producing diesel engines, are required by Federal law to pay extra compensation for overtime, which is defined as work after 40 hours in a work-week. Overtime payments must be at the rate of not less than one and one-half times the regular rate at which the employee is actually employed and paid. Most plants also pay time and a half for work over 8 hours performed in 1 day. Employees who work on Saturday, Sunday, or holidays generally receive extra compensation. The Sunday work rate is usually double the regular rate. The pay rate for work performed on selected holidays is usually 2 or 3 times the regular rate. These provisions are frequontly determined through agreement with the unions.

Shift Differentials

A survey of plants in diesel and other internal combustion engine manufacturing, except automotive and aircraft, indicated that almost 70 percent of the workers in the plants surveyed were employed on the first (day) shift in January 1952. Over 23 percent were on the second (evening) shift and the remaining 7 percent worked a third (night) shift.

It is common practice in American industry to pay a premium for night or evening shift work. This generally takes the form of an addition of a specified number of cents or a percentage increase to the pay rate. The third shift frequently receives a higher premium than the second. A check of a sample of union agreements in 1952 indicated that the most prevalent premium rates for second shift work were an addition of from 4 to 6 cents an hour to the regular rate. The third shift differentials commonly vary from an addition of 6 to 10 cents to the regular hourly rate.

Incentive and other Payments

Incentive methods of pay that directly relate earnings to workers' output have a considerable effect on average wage rates in many American industries. There are two principal types of incentive pay: "piece rates" and production bonuses. In the case of "piece rates," earnings are related to the efforts of the individual, whereas production bonuses more frequently depend on group effort. Nonproduction bonuses are also common, such as profit-sharing plans and Christmas bonuses.

Four of the five plants in this report had an incentive wage system for their production workers. Exact details of the plans were not reported.

FRINGE BENEFITS 3/

Paid Vacations and Holidays

Paid vacations and holidays are common throughout industry and commerce in the United States. The number of paid vacation days usually varies with the worker's length of service with the firm. Administrative, professional, and office workers generally receive longer vacations. Vacation and holiday provisions are usually determined under agreement with the union, when the plants' workers are organized.

Insurance

Insurance plans are prevalent throughout most of American industry. In a recent survey of the machinery industries conducted by the United States Department of Labor's Bureau of Labor Statistics (October 1952 through February 1953) in 29 American cities, it was found that the percent of machinery manufacturing establishments providing life insurance coverage to their employees ranged from a low of 66 in one city to a high of 99 in another. Coverage in the median city was 90 percent.

The same survey indicated hospitalization insurance coverage ranging from 48 percent of machinery establishments in the lowest city to 98 percent in the highest, with 81 percent of machinery establishments covered in the median city. Sickness and accident insurance plans, though less common, were found in 76 percent of all machinery manufacturing plants in the median city. Specific engine data on fringe benefits provided by diesel engine manufacturing plants are not available.

Pensions

Virtually every worker in the United States employed by business or industrial firms, including the employees of the firms in this study, is eligible to receive a pension at the age of 65. The program is required by Federal law and is known as Old Age and Survivors Insurance. To finance the plan, employers are required to contribute periodically an amount equal to 2 percent of each employee's wages or salary, while the employee contributes an equal amount.

The benefits from this pension plan are distributed to the worker and his wife, or on his death, to his surviving wife and children, and range in amount from a minimum of $30 to a maximum of $200 per month. The amount of benefits depend upon the average wage received and the number of dependents. A worker who has averaged $71.69 per week during the last few years, which in 1953 was approximately the national average earnings for production workers, would be eligible at 65 for a pension for $100.63 a month, and his wife at age 65, would receive an additional $50.32 for a combined total of $150.95

3/ Includes nonwage benefits such as paid vacations, holidays, pensions, and health programs.

In addition to benefits under the Federal law, some States make extensive payments to aged workers that supplement the above amounts.

In addition to these legally required pension plans, some employers, often after negotiations with the unions in their plants, have set up pension funds to which the employers contribute all or part of the cost. In the event that all the cost is not paid by the employer, the employees contribute the remainder. In addition to the normal benefits, many company pension plans provide for permanent disability retirements and in some cases for early retirement on a lower benefit level, after completion of a stipulated number of years of service.

Other Fringe Benefits

Other fringe benefits provided in American industry vary widely by individual firm and industry. Paid lunch periods are uncommon but a few plants include the lunch period as part of the worktime. Paid sick leave is a relatively new benefit provided in some plants. Other benefits include free work clothing, availability of company nurses and physicians, rest periods, and recreational activities and facilities. Some plants foster employee operated loan associations.

SAFETY

Management, in recent years, has emphasized the importance of lower accident rates in industrial plants. Safety programs are instituted and vigorously maintained. In some instances safety engineers are hired as full-time members of the plant staff.

Injury rates in all manufacturing industries and in the engines and turbines manufacturing industry are shown in table 45.

Table 45. Injury rates for all manufacturing, and engines and turbines manufacturing, by type of injury, U. S. A., 1953

Industry	Injury - frequency rate 1/	Percent of disabling injuries resulting in		
		Death and permanent total disability	Permanent partial disability	Temporary total disability
All manufacturing . . .	13.4	0.4	5.4	94.2
Engines and turbines manufacturing	9.2	.6	5.2	94.2

1/ Average number of disabling work injuries for each 1,000,000 employee-hours worked.

ADJUSTMENTS TO TECHNOLOGICAL CHANGE

Labor and management in the United States have always been faced with problems arising from changes in processes and the introduction of new machinery. The problems generally include determination of earnings, workloads, work schedules, displacement of special skills by new machinery and methods and, in some cases, actual displacement of workers. Over the past 25 years, with the more rapid growth of labor unions, adjustments and solutions to these problems have been reached in many instances on a case-by-case basis as a result of negotiations between the two parties. The success of the solutions and adjustments has depended almost entirely on the attitudes and procedures with which labor and management approached each case and, only incidentally, on the technical details of the change itself.

Moreover, negotiations over technological change in many fields of manufacturing indicate that the experience gained from a case in one industry is applicable to problems of change in other industries. Consequently, the methods and ideas developed in negotiations over technological change are used in many industries besides the one in which a problem first appeared. Technical details concerning machines, processes, and conditions of employment still require agreement on a case basis within the framework of ideas and methods handed down from past experience.

Examples of adjustment to technological change appear in appendix I.

APPENDIX I: CASE STUDIES OF ADJUSTMENTS TO TECHNOLOGICAL CHANGE

(NOTE: THE CASE STUDIES USED TO ILLUSTRATE ADJUSTMENTS TO TECHNOLOGICAL CHANGE WERE NOT MADE IN THE DIESEL ENGINE INDUSTRY. THESE EXAMPLES WERE SELECTED BECAUSE OF THE TECHNIQUES AND PROCEDURES THEY DEMONSTRATE, WITHOUT REGARD TO THE INDUSTRY IN WHICH THEY OCCUR.)

Example A. 4/

"1. The company discusses with the union proposed changes in process and introduction of new machinery. The company must keep pace with and, if possible, lead the way in making changes in technology and processes which turn out cheaper and better glass. Accordingly, Libbey-Owens-Ford wants freedom to introduce new machines and processes, to shift work from less efficient to more efficient plants, and to make more products with less manpower. If it is unable to achieve these objectives at least in part, its very survival as a business is in jeopardy; the automobile manufacturers, which use a large amount of the glass produced by LOF, are 'tough customers.' The following case is an illustration of the union-management consultation which usually precedes any technological change.

"A conveyor system was to be installed in the laminated plant in Toledo. The local president was called in and told the company's plans. At first he hit the ceiling. After he had calmed down he gave a dozen and one reasons why the plan would not work. By the time a second meeting was held with full union committee, management had altered its plans to meet several of the objections raised by the local president and had answers ready for the others. Again the union representatives told management why their plans would never work, and again the company adopted some suggestions and set forth its reasons for insisting that the conveyor system be used. The conveyor system was then installed, but in a way which met many of the union's objections. The union's biggest fear was that earnings would be reduced, and in this respect the company was able to assure the men that they would keep up their bonus earnings on the new jobs. In this case the information-sharing process was used successfully as a means of implementing a management decision.

4/ The Libbey-Owens-Ford Glass Company and the Federation of Glass, Ceramic and Silica Sand Workers of America, Causes of Industrial Peace Under Collective Bargaining, Case Study No. 2, National Planning Association, Washington, D. C., November 1, 1948.

"2. Another time the company laid a scheduling problem out on the table for the union's consideration. Since the auto manufacturers were short of steel they could not use the glass they had ordered for the next nine-month period. The company had two alternatives. They could cut production drastically at once, lay off a large number of men, and then rehire later to bring production back up when the glass could be used at a faster rate. Or they could gamble on the total amount that would be needed for the entire nine months and schedule the glass at a constant rate, laying off a few workers at once but keeping all the remaining men at work over the entire nine-month period. The company told the union to make the decision, since it felt that the laying off and rehiring of men was the most important consideration involved. As one might expect, the union decided to cut down as much as necessary for the entire period. Probably the company wanted the same thing but recognized the advantage of having the union make the decision in a case of this kind."

Example B. 5/

"Technological changes involving displacement of workers have been handled with real care and with genuine concern for employee welfare. In 1945, a division of the company employing 76 people was moved from Cambridge to a new plant in another area in order to locate the manufacturing operation near the source of supply of raw materials. For six to eight months prior to the move, consideration was given to the placement of the employees affected. Some were transferred to other jobs as normal turnover created openings. A crew of 35 operators was required right up to the last moment in order to build up an inventory to supply customers during the transfer of heavy equipment to the new plant. These workers were given a guarantee of their regular hourly rates regardless of the job to which they might be transferred. The guarantee was based on length of service: One month for each year up to twelve months' guarantee. The length of service of these employees ranged from one year for two people to ten years or more for eight people. Practically all these employees were placed before their guarantees expired on jobs carrying rates at least as high as their former ones. None of the 76 was laid off, but two men and eight women resigned rather than accept transfers."

5/ The Dewey and Almy Chemical Company and the International Chemical Workers Union, Causes of Industrial Peace Under Collective Bargaining, Case Study No. 3, National Planning Association, Washington, D. C., December 17, 1948.

APPENDIX II: INDUSTRY STATISTICS

Diesel engines are used in practically every segment of industry and agriculture, plus many divisions of municipal and federal government agencies. There are literally thousands of different applications where diesel engines are used and consequently there is a great deal of overlapping between broad classes of use as shown in table IIa. This table does not separate diesel engines used by the army, navy or air force as individual users, however, they are included in such classes as truck and bus, or marine. "Municipal and Utility" includes such uses as electric power generation, and water and sewage pumping. In this table no attempt has been made to distinguish between types of engines such as large stationary or industrial high-speed types. Two categories, construction and agriculture, will account for 64 percent of all engines estimated to be produced in 1955, however, they total only 41 percent of the total estimated horsepower.

From 1950 through 1953 the production of diesel engines remained fairly constant, due principally to the effects of the hostilities in Korea (table IIb). The biggest decline in quantity has been in the field of agriculture which has shown a decrease of 35 percent from the number of engines built in 1950 to the estimated number to be built in 1955. With the exception of the railroads which have practically completed their dieselization program, all other categories have held fairly constant in the number of engines used per year.

Table IIa. Diesel engine production in terms of horsepower, by major use, U. S. A., 1955 1/

Use classification	Horsepower range	Estimated average horsepower per engine	1955 Projected engines	1955 Estimated total horsepower
Railroads	200 - 2,400	1,200	1,277	1,532,400
Truck and bus	120 - 200	140	16,400	2,296,000
Marine	165 - 4,800	400	2,290	916,000
Municipal and utility . .	200 - 3,600	1,250	443	553,750
General industry	60 - 3,600	300	12,800	3,840,000
Petroleum	60 - 2,400	300	4,530	1,359,000
Mining	60 - 550	150	3,295	494,250
Construction	60 - 550	150	27,800	4,155,000
Agriculture	30 - 180	75	46,000	3,450,000
Total			114,835	18,596,400

1/ Source: Diesel Power Magazine, January 1955, New York, N. Y., U. S. A.

Table IIb. Number of diesel engines produced in U. S. A., by major use, 1950-55 1/

Use classification	Year 1955 (estimate)	1954 (estimate)	1953	1952	1951	1950
Railroads	1,277	1,171	2,201	3,140	3,662	3,403
Trucks and bus . . .	16,400	15,430	16,390	17,837	21,765	17,029
Marine	2,290	2,225	2,119	1,966	2,162	1,869
Municipal and utilities	443	425	392	355	450	436
General industry . .	12,800	11,200	15,780	12,987	13,146	12,378
Petroleum	4,530	4,310	4,280	4,164	3,903	3,546
Mining	3,295	3,150	2,635	1,950	2,325	2,317
Construction	27,800	26,200	28,400	25,286	28,583	27,468
Agriculture	46,000	47,900	53,158	68,327	70,000	70,060
Total	114,835	112,011	125,353	136,012	145,996	138,506

1/ Source: Diesel Power Magazine, January 1955, New York, N. Y., U. S. A.

APPENDIX III: DATA COLLECTION

Data for this report were collected by representatives of the Bureau of Labor Statistics who personally visited each plant. A questionnaire was used to record the data and it is reproduced in this appendix. For reproduction purposes the length of the questionnaire was reduced by shortening the space allowed for answering some of the questions.

For many different reasons it was not possible to get answers to all the questions. However, all the principal questions were answered and these data were presented in this report.

It is suggested that this questionnaire be used if any individual plant measurements of productivity are to be made, so that results can be compared to those presented in this report.

UNITED STATES DEPARTMENT OF LABOR
Bureau of Labor Statistics
Washington 25, D. C.

CONFIDENTIAL

PRODUCTIVITY AND FACTORY PERFORMANCE

Name of Industry or Product Group ______________________________

Plant Name ____________________ Address ____________________

Parent Company ____________________ Address ____________________

Officials Interviewed: (Cross out "Co." or "Plant")

Name ______________ Title ____________________ (Co.) (Plant)

Name ______________ Title ____________________ (Co.) (Plant)

The data submitted on this questionnaire will be seen only by sworn employees of the Bureau of Labor Statistics. The data will not be released in any form which permits identification with any specific company, without written permission.

Survey made by ____________________ Date ____________________

Part A. GENERAL QUESTIONNAIRE

PRODUCT INFORMATION

1. List specifications of reported product(s): ____________________

PRODUCTION: MAN-HOURS

2. Production and man-hours for reported product:

   a. Select a recent period at least as long as the normal production cycle, but in no case shorter than one week, in which production operations were proceeding at an average level.

      Reported period begins ____________ and ends ______________

   b. Total production of reported product during this period (specify units) ______________________

   c. Total direct man-hours on reported product during this period ______

   d. Total indirect man-hours on reported product during this period _____

   e. Describe exactly the procedure used to derive direct and indirect man-hours in (c) and (d) above ________________________

PRODUCTION COMPOSITON

3. Composition of Production for Reporting Plant:

Enter the value of output (production or shipments) in 1953 for the reported product and for other product classes:

a. Reported product: Value of output $________ Percent of value of total output ________________

b. Product classes:

	Value of output	Percent of total value of output
(1) Product class including reported product	$	
(2) Other product classes - specify:		
(3) Miscellaneous		
Total	$	100.0

c. Data shown represent value of (check one): Production /__/

Shipments /__/

ANALYSIS OF INTEGRATION AND PARTS USED

4. List of parts, materials and components for reported product: (omit small hardware and findings)

Part name	Source of part (check)		Department and operation in which used	Approximate number and kind of other products in which part is used
	Made in plant	Made elsewhere		

ENGINEERING AND RESEARCH

5. Enter the number of persons employed in this establishment during the reported period that spent the major part of their time in the following activities:

Activity	Number of persons
Production engineering	______
Methods and time study engineering	______
Product design engineering	______
Market analysis	______

If plant obtains any of the above services from outside plant, note.

COSTS OF REPORTED PRODUCT

6. Manufacturing Cost Distribution:

   a. Enter the percent of total manufacturing cost of the following accounts for the reported product (or product class in which it is included) for a recent period:

   These ratios should generally reflect the conditions which existed during the period for which the unit man-hours were developed. Take from summary records of reporting period, nearest quarter or year.

   Period covered from ______________ to ______________

		Percent
(1) Labor Cost Accounts:		
(a) Monetary payments to all production and related workers plus plant supervisors and technicians.		______
(b) All other costs associated with these employees in this connection such as (OASI, workmen's compensation, pension plan costs, etc.)		______
(2) Direct Materials		______
(3) Other Factory Costs: (Total)		______
(a) Electricity	______	
(b) Fuel	______	
(c) Maintenance (supplies and equipment)	______	
(d) Miscellaneous factory cost	______	
Total Manufacturing Cost		100.0

b. Data in 6a relate to:

(Check one): Reported product ☐ Product class ☐

7. Selling Expense Distribution:

a. Enter percent of selling expenses to the total operating cost for the preceding year: ____________ percent

b. Breakdown of selling expense:

	Percent of total selling expense
(1) Advertising	________
(2) Salemen's salaries and commissions . . .	________
(3) Other (Specify) ____________________	________
______________________________	________
______________________________	________
Total Selling Expense	100.0

NARRATIVE QUESTIONS

8. Changes in Product or Operations:

What major changes have been made in the last 5 years to effect operation simplification, and/or product simplification, or to save materials: Describe one or more examples. Include also changes in product design in the interest of standardization.

9. Production Planning and Control:

Briefly describe the plant's production planning and control system.

10. Jigs and Fixtures:

Describe one or more examples of special jigs, fixtures, or attachments, which have been developed in last 5 years and have had a significant effect on unit man-hours; estimate effect.

11. Inspection:

Describe method of inspection used in the manufacture of the reported product. Include description of any statistical quality control system used in any of the manufacturing operations.

12. Plant Staffing Pattern:

Obtain plant staffing pattern and indicate occupations classed as direct and indirect labor.

13. Plant Layout:

a. Describe the plant layout, using diagrams wherever possible.

b. If plant was not originally constructed for its present use, describe outstanding changes made since its construction or acquisition to adapt the building to the production of the reported product.

14. Distribution Channels:

Describe the distribution channels for the product class which is represented by the reported product. State the percent of total sales of the product class to each type of outlet for the latest year available.

15. Productivity Factors:

Describe any other key factors which contributed to the present level of productivity in this plant.

EXHIBITS

Submit the following, if available:

16. Forms used in production control and scheduling.

17. Photographs of plant operations, equipment, and layout.

18. Catalog.

19. Exploded view of schematic drawing showing names of parts.
This will not be shown in published report without permission of plant.

ANALYSIS OF MANUFACTURING PROCESS

On the attached sheets, indicate operations in order of their actual sequence in each department engaged in the production of the reported product. Use separate sheet for each department or stage. Indicate nit man-hours per operation in every case.

20. ANALYSIS OF MANUFACTURING PROCESS

a. Operation, sequence, machinery, and time.

Name of plant __________ Parts, materials and components used 1/ __________

Department or stage __________

Part or product produced __________ Method of measuring man-hours 2/ __________

Step No.	Operation performed (nature of work done in each shop)	Machinery used 3/		No. of direct production workers		Materials-moving device	Direct unit man-hours per operation 2/
		Name, make, model, and type of drive 4/	No. of units	Total	Female only		

1/ If subassembly of previous operation is used, identify by department or stage from which it comes.

2/ Man-hours should be obtained in this order of preference: (a) Actual man-hours, (b) adjusted standard time, (c) standard time, or (d) foreman's best estimate. Indicate method used by (a), (b), (c), or (d) as appropriate.

3/ Note "L" if line drive, "U" if unit drive, or "G" if group drive.

4/ Include portable and power handtools. Also, if possible secure sketches, drawings, or pictures of specially designed machines, special jigs and fixtures and attach to operational sheet if plant will allow publication in our report.

20. ANALYSIS OF MANUFACTURING PROCESS--Continued

b. Departmental Summary -- Department or Stage ____________________

(1) Employment for Department or Stage

(a) Average total number of direct workers during the reported period ____________

(b) Average total number of indirect workers during the reported period ____________

(2) Staffing Pattern (For the Reported Product if possible) and Method of Payment

(a)

Direct Workers			Indirect Workers		
Job Title	Number of Workers	Method of Payment	Job Title	Number of Workers	Method of Payment
Total		XXXX	Total		XXXX

(b) If incentive system is used, describe ____________________

____

(3) Material Movement To and From Department

Material	Department		Distance Moved (ft.)	Method and Description of Equipment Used
	From	To		