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Automation considerations for a manufacturing system

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AUTOMATION CONSIDERATIONS
FOR A MANUFACTURING SYSTEM

BY

MARVIN F. WANG

A THESIS
PRESENTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE
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APPROVAL OF THESIS

AUTOMATION CONSIDERATIONS
FOR A MANUFACTURING SYSTEM

BY

MARVIN F. WANG

FOR

DEPARTMENT OF INDUSTRIAL AND MANAGEMENT ENGINEERING

BY

FACULTY COMMITTEE

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NEWARK, NEW JERSEY

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ABSTRACT

This thesis examines the present manufacturing system of Apollo Valve Company, a solenoid control valves manufacturer. After analyzing the present system, the automation considerations and proposed new system were recommended.

Chapter 1 presents the background material of automation and manufacturing system. The development of the automated factory is also included. The plant layout, organization, and departments functions of the present system are briefly described in the Chapter 2. Analysis of the present manufacturing system - by the production volume, by the plant layout, and by the manufacturing operations, is discussed in the Chapter 3.

Proposed automation considerations and improvements, such as group technology (GT), computer-aided process planning (CAPP), computer-aided manufacturing (CAM), automatic assembly and testing, packaging, and flexible manufacturing system (FMS), are presented in the Chapter 4. The last chapter, the conclusions are discussed and the new manufacturing system is recommended.

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PREFACE

The topic was chosen for two basic reasons: (1) automation is the major key factor of American industries to deal with foreign competition. (2) the author intended to demonstrate the interaction of theoretical and practical methods to develop a workable program for job shop automation. It is hoped that the proposed improvements and recommendations may in some way assist others who face similar problem of job shop automation.

Thanks are due to my advisor, Dr. Stan S. Thomas, who directed my efforts and made valuable suggestions.

My wife, Ruth, also deserves appreciation for contributions in preparing and typing this thesis.

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CHAPTER 1

INTRODUCTION

This chapter presents the background material for this thesis with a brief history of automation from its beginning during the Industrial Revolution to the present. The development of the automated factory is also included.

THE DEVELOPMENT OF AUTOMATION

'If you attempt to analyze the current technological trends in manufacturing, and to forecast the future social, economical and political environment in which manufacturing will take place, it is possible to construct a vision of the modern automated factory of the year 2000.'¹ Automation is the major key factor of American industries to deal with foreign competition in the years ahead. This is the main reason why the author has chosen this thesis subject.

1 GROOVER, M.P., and ZIMMERS, E.W., "Energy Constraints and Computer Power Will Greatly Impact Automated Factories In The Year 2000," Industrial Engineering, November, 1980, p. 34.

Definition of Automation

'The word automation is a contraction of the words automatic operation. It implies the process of doing things automatically.'² We will limit this thesis to the automation of a manufacturing system, in which many processes of production, and movement of materials and parts are automatically performed or controlled by self-operating machinery, electronic devices.

"Automation is the technology concerned with the application of complex mechanical, electronic, and computer-based systems in the operation and control of production."³ This technology includes:

Automatic machine tools for processing workparts.

Automatic materials handling systems.

Automatic assembly machines for assembling components into products.

Continuous-flow processes.

Feedback control systems.

2 LUKE, H.D., "Automation For Productivity," John Wiley and Sons, New York, 1972, p. 2.

3 GROOVER, M.P., "Automation, Production Systems, And Computer-Aided-Manufacturing," Prentice-Hall, Englewood Cliffs, New Jersey, 1980, p. 3.

Computer process control systems.

Computerized system for data collection, planning, and decision making to support manufacturing activities.

We will discuss these technologies in Chapter 4.

Development of Automation

The techniques of manufacturing were developed concurrently with the growth of the Industrial Revolution (around the year 1770) when machines took over the work previously performed by manual labor. The evolution of industry from the 'domestic system' to the 'factory system' brought an increasing need for those activities which are known as manufacturing system.

Manufacturing was generally carried on in the home, prior to the Industrial Revolution. The manufacturing tools were inexpensive, and were usually muscle-powered and required a high degree of skill and experience. This was the 'domestic system' and the worker was the major element of the manufacturing process. However, this system could not meet the increasing demand for goods in the second half of the eighteenth century.

The 'factory system,' the workers congregate in a central place and use tools owned by the factory, increased the productivity. This change was advanced by manufacturing machinery, steam power, and the capitalistic system.

Mechanization and mass production technique lowered the skill level of the individual worker. Skilled craftsman yielded to semi-skilled workers. Under the factory system, manufacturing control was not completed during the nineteenth century.

The factories were small and there were still many skilled workers who were responsible for a product from beginning to finish, a trend which subordinated the worker to his machine. These workers could understand other operations in the factory and they still were able to have sufficient interest in their work to associate efforts with the objectives of the company.

As manufacturing became more complex and the workers grew more specialized, the production control system changed too. In early factories the chain of command was usually organized as follows: The general manager, the superintendent, the foreman, and the workers. When an order was

received, the salesman would tell the superintendent who, in turn told the foremen and gave them their instructions. Each foreman instructed his workers and often assigned a job to the worker who had done a similar job previously. The foreman and worker also had to select and choose the necessary tools and materials, and they decided on the best manufacturing method together.

However the factory system was not to remain quite so simple. The insatiable demand for more production and lower unit costs by the early twentieth century resulted in more mechanization, assembly-line techniques, and further dilution in skills. The highly trained artisan gave way to lower-paid and less-skilled machine and assembly-line operators, each one performing only one or two operations on a component part or subassembly of the product.

Today manufacturing system has become much too complex for the ordinary mechanic or foreman to manage. A formal system of manufacturing process has developed to meet the increasing demand for more production and lower cost.

'Productivity is the name of game.' In recent years

there have been several trends in automation.⁴

1. The trend is to envision the separate machine tools, part transfer devices, and human operators as components of integrated manufacturing systems.
2. Another trend, based on the production systems concept noted above, is to attempt to achieve the best features of fixed automation and flexible automation in one highly automated system. The name given to this type of automation is "flexible manufacturing system," and we will be discussing this type of system in Chapter 4.
3. A third trend in manufacturing automation is the tremendous increase in the use of digital computers to control production equipment. Related to this, computerized manufacturing data bases and information systems are being developed for overall planning, scheduling, and coordination of plant operations.

These trends lead us to the conclusion that we will see, probably by the year 2000, the computer-integrated automatic factory.

AUTOMATION OF MANUFACTURING SYSTEM

⁴ Ibid. 3 p. 5.

Hand methods fail to fulfill manufacturing requirements because of economics, market demand, speed, quality and other factors. The solution has been provided to manufacturing engineering by automation.

Fundamental Manufacturing Processes and Operations⁵

The fundamental operations and processes of manufacturing together with several examples are:

1. Material Handling:

a. Manual effort: lift, carry, push, pull, wheelbarrow, hand trucks, chutes, slides, roller conveyors, etc.

b. Mechanized effort: belt conveyor, industrial track, hopper feed, bucket conveyor, transfer shuttle, power and free conveyor, Archimedes screw, endless chain, pneumatic tubes, etc.

2. Part Manufacturing: Turning, grinding, milling; stamping, spinning, bending; welding, riveting; polishing, plating, paint-

⁵ AMBER, G.H. and AMBER, P.S., "Anatomy of Automation," Prentice-Hall, Englewood Cliffs, New Jersey, 1962, p. 40.

ing; annealing, degreasing, baking, etc.

3. Inspecting Templates: Go-not go gages, thread gages, air gages; magnaflux, X ray; optical comparators; micrometers, surface plate layout; laboratory analysis; photoelectric sorting, segregating; ultra-sonic probing, computerized automatic inspection, etc.
4. Assembling: Putting together an engine, typewriter, automobile, fuel pump, solenoid valve, etc.
5. Testing: Functional testing of engine idling speed, transistor characteristics, generator loading, solenoid valve performance, dynamometer response. Also pressure, leakage, hardness, rupture testing, etc.
6. Packaging: Cement in bags; bearings in wraps; appliances in crates; wire in spools; solenoid valves in packs, cartons and shipping cartons; etc.
7. Storage: Raw material, work in process, semi-finished good, and finished good; to store at work station, stock room, warehouse.
8. Shipping: Delivery material, parts, goods to customer.

The typical operation model includes five functions;⁶ storage, transport, delay, work operation and inspection. Transports, unavoidable delays, and occasional inspections all represent events that take time but do not add value to the workpart.

Most manufacturing operations require five inputs:

1. Raw materials.
2. Equipment (machine tool).
3. Tooling and fixtures.
4. Energy (electrical energy).
5. Labor.

The manufacturing process produces three outputs:

1. The completed workpiece.
2. Spare parts.
3. Scrap and waste.

Manufacturing System

Establishing systems engineering with systems responsibility, it is possible to properly integrate the performance of all units in a system and consider of the overall

6 BARNES, R.M., "Motion and Time Study, Design and Measurement of Work," John Wiley and Sons, New York, 1968, p. 65.

influencing factors, resulting in superior performance.

Therefore, the greatest benefit will be achieved, by design an integrated manufacturing system which includes the eight stages of fundamental manufacturing processes, as mentioned in the previous section. The basic characteristics of systems engineering are:

1. Analysis - Concept.

2. Synthesis - Sources:

Equipment

Personnel

Facilities

Support

3. Install Prototype and Evaluate - Economic justification

4. Decision - Specifications

5. Reinstallation

Manufacturing engineering functions are to provide advice to the product design department for produceability; assist process planning groups to prepare route sheet and specify process sequence, production operations and associated machine tools for each workpart; and aid tool engineering group in providing the specification and design of tools, jigs, and fixtures used to produce the product.

Types of Control. There are four fundamental types of control - analog, digital, logic, and mathematical. We will discuss in the following paragraphs.

Analog Control:

Control based on information and action which is proportional to the dimension and function it represents, not on pulses or counts, or numbers. Analog control uses models, either mechanical or electronic, of the problem or system being considered.

While general purpose computers (analog or digital) are capable of solving diverse problems, limited purpose computers (programmable controllers) are intended for specific machine or process control or instrumentation. Analog control readily performs mathematical operations and is naturally suited to analog signals from proportional (analog) transducers.

Digital Control:

Control based on manipulation of information in the form of numbers. These numbers represent the characteristics of the problem of interest. Digital control is based on rules of logic. Analog and digital control each have their particular features and characteristics and should be selected according to the application, as for example choice between

AC, or DC, hydraulic or pneumatic. Often, the most effective control system uses both analog and digital techniques.

Digital control, also known as numerical control, is particularly suited for handling numerical data (data processing), as in sales records, inventory control, and numerical control of machines from punched paper tapes or cards. Arithmetic and engineering type problems can also be programmed. However use for proportional control or response to equations requires input and output apparatus for analog-digital conversion, as the transducers (sensors) and actuators are generally analog.

Logic Control:

Control based on the operations of logic: and, or, negate. Actions (decisions) depend on occurrence or non-occurrence and sequence of required previous conditions. Information exists in simple two state forms, as yes - no; true - not true; in position - not in position. Logic control, operated on the "either - or" principle, eliminates intermediate values of information and is digital as the information is two state, like binary numbers. The logic operations are performed by storage (memory) and gate (action) devices. The decision to act is the make - or - break of an electrical circuit in response to information from two - state (flip -

flop) storage devices and from feelers (on - off signals).

Most machine control (control panels) consists of logic operations. Latching relays and contactors are the storage devices and gates. Limit switches on the machine frame signal information. Delay timers are used both to hold an action (time) and to delay an operation (sequence). Interconnection of relay and switch contacts makes up a programmed sequence of machine operations. Typical actuation in the energization of motor starters or valve solenoids.

Mathematical Control:

Control operations which take place, usually simultaneously, based on interrelated process factors, by means of computer type devices. Mathematical operations for control are analog in form, and deal with algebraic equations rather than arithmetic. In order to automatically control a complex process, it is necessary that the process variable be predictable and expressible mathematically. Automatic solution of this process equation, taking into account the values of the terms of the equation from instrumentation, makes possible continuous control of the process.

This is the foundation of control by programmable controller (limited purpose computers). Automatic optimizing, machinability, interpolation, proportioning, analysis, and

simulation, depend on relationships of mathematical equations.

There are specific fundamental control elements in an automatic control system. They are: (1) Variable - such as temperature, pressure, voltage, etc. (2) Measuring element - such as thermocouple, pressure gage, voltmeter, etc. (3) Final control element - such as actuator, hydraulic cylinder, toggle switch, etc.

The principal features of control theory involved:

Open loop control Whereby an input signal is applied and amplified, and an output is obtained. Nonfeedback; assumes that a system is always satisfactory and suffers no lapse of performance, so that constant "checking up" on the system is not needed (this is also known as open-end control). The assumption that system performance will be correct and that the probability of malfunctions is negligible is entirely justified in the greatest number of cases. Even in highly automatic feedback controlled machines, many elements of the process, both control and operational, operate on an open-loop basis. Automatic screw machine, automatic stamping, spot welding, are as examples.

Closed loop (Feedback) control - Actual output is measured and a signal is sent back to the input station for

comparison with some set goal. Negative feedback causes a system (machine or process) to respond to the difference (error) between a standard value and the output of the system, continuously "checking up" to ascertain that system performance is satisfactory. Accidental positive feedback will cause system oscillations or "hunting," and must be avoided. Only the key variables of any process need to be regulated or controlled by feedback. Feedback control makes possible great system stability, as many disturbances can be compensated automatically. All self-adjusting devices, thermostat control of furnace or refrigerator, steam engine governor, etc., are considered as feedback control. Semi-feedback is defined as automatic measuring with simplified readout, so that an operator can readily make corrections.

There are recognized engineering activities that support manufacturing automation:

Industrial Engineering

Concerns itself with manufacturing, the production of goods. Typical activity includes plant layout, arranging an automatic warehouse; designing an automatic machine or process; studies of costs, efficiencies and materials; value analysis of production methods; also specialties as methods

engineering, plant engineering and manufacturing engineering.

Production Planning and Control

Concerns itself with the most effective methods and arrangement for the production of goods, measuring effectiveness of manufacturing process; scheduling machining operations, determining optimum machine loading. Improving efficiency and productivity of existing and contemplated production systems.

Tool Engineering

Concerns itself mainly with the tools dies, jigs, and fixtures; for cutting and forming the workpiece, guiding the tool, and for holding the workpiece. Machinability evaluations; determines of rates and feeds for optimum removal of metal, when to replace tools and deciding the best method for removing metal.

Materials Handling Activities

Concerns itself with the task of moving materials at the proper time, place, and position, developing automatic stock room and inventory control plan.

Product Design and Engineering

The activity of designating by drawings and specifications, the details of a proposed product, process, and system. Concerns itself with product redesign and process design for automation.

Quality Activities

Measurements: the activity of determining the numerical value of a dimension. Usually the physical size of the workpiece, but the dimension being measured may be any process or product variable. Measures diameters, thickness of work pieces and process variables, such as temperatures, pressures, flow rates.

Inspection: the activity of comparing measurements or other attributes of quality to a standard to determine acceptance or rejection.

Quality Control: the activity of evaluating measurements and inspection information by statistical methods, determining variability and process capability; determining malfunction and out of control; evaluating by sampling.

New terms are arising constantly from work on automated factory concept. The new technologies are briefly described as follow.

"Group Technology" (GT), has as its basic principle, the grouping together of components of similar shape, dimensions and/or technology, and to form a group of machines on a flow line basis. Setting up a group technology system helps make better use of machine tools, reduce in-process inventory, shorten batch cycle times and, in general, increase productivity.

Process planning converts design data to work instructions, and is a basic step for economical production. A process planner defines what processes are required to make a component and determines which machines have the capacity and accuracy to achieve the desired results. Because modern manufacturing plants offer thousands of alternative process plans, Computer Aided Process Planning (CAPP) depends heavily on the idea of group technology.

Material requirement planning, MRP is a method for managing production inventories that takes into account the timing of the requirements. Its object is minimize inventory while still meeting a given production plan. MRP begins with a time phased, master production schedule for the items required. This leads to a schedule of material orders that make sure materials are available only when needed - not

before and not after.

(Flexible Manufacturing System (FMS), consists of a group of processing stations (usually NC machines), connected together by an automated workpart handling system. It operates as an integrated system under computer control."⁷ Flexible manufacturing systems incorporate many individual automation concepts and technologies into a single production system.)

(Utilizing computer-aided design (CAD) technology, a design engineer can define a part shape, analyze stresses and deflections, check its mechanical action, and automatically produce engineering drawings, all from the same graphics terminal of a CAD system.)

Under the concept of computer-aided manufacturing (CAM), manufacturing people can draw upon the geometric description provided by CAD as a starting point to create NC tapes, determine process plans, instruct robots, and manage plant operations with CAM system.

⁷ Ibid. 3 p. 564.

Automated factory is the integration of the group technology, computer aided process planning, automatic material handling system, flexible manufacturing system and CAD/CAM technologies. These technologies are now being combined into unified CAD/CAM systems, where a design is developed and the manufacturing process controlled from start to finish with a single system.

Automation Philosophy

"The philosophy of automation undertakes to organize all knowledge, developments, techniques, applications, and theories applicable to or resulting from automation."⁸ Man is limited by his brain and muscle. He alone cannot work with the strength, speed, and accuracy he desires, thus, he has always sought tools, methods, and machines to enable him to accomplish extraordinary tasks. Automation is not a specific discipline but a philosophy of doing things; attempts to reveal present and future applications of automatic techniques.

The principal rules of management philosophy are the

8 Ibid. 5 p. 185.

following:

The new technology will be accepted and used as a prerequisite for process. Continued research and development and innovation management will lead to a stable, long-range capital equipment program that will assure company competition well into the future. Effective communications will have been established with employees. They will be fully informed in matters that affect them, and will be given every opportunity to retain or advance their jobs with the company in the event of a major change in manufacturing methods. Workers morale, loyalty and productivity will improve. Existing employees will provide a pool from which to make long range manpower projections to match automation planning.

By arranging a continuing public information program, promote local community and industry understanding of your automation planning. And demonstrate how these policies are in the best interests of everybody concerned - management, employees, and the people of the surrounding community.

Management can more effectively utilize automation to improve productivity and combat rising costs in the years

ahead. Most significant, automation should make it possible for business and industry to focus a insight on the social and economic responsibilities implicit in management today.

Advantage of Automation. A number of economic and social factors provide the motivation for automation in manufacturing. These reasons for automating include the following:

Increased productivity. The amount of production for the manpower involved.

Reduced in-process inventory. The number of items within the process is reduced.

Reduced factory space. The production per square foot of factory is increased.

Reduced cost. The manufacturing costs per part will be greatly reduced for large volume production.

Improved product-quality. Machines are more consistent than men; less variation in output.

Improve safety. Removing the operator from hazardous locations; safe working conditions.

Increased production capacity. The number of hours per day which the machines can be used; the percentage of time each station is actually in use. The ability

to produce a large volume of goods.

Intangible benefits. Company image, competitive position, advertising/sales promotion, marketing and sales, design engineering, manufacturing, top management decision making, and new business opportunities, all these functions will be improved.

Disadvantage of Automation. There are questions and arguments whether automation was really worth its high investment cost. The arguments against automation include the following:

Capital costs. Automation requires a large capital expenditure, whether bought or designed, and built.

Reduced flexibility of operations. Orienting the production system around specific products limits use of the machines for other purposes. Automation demands long runs at full capacity for maximum benefits. Short production runs or frequent model change overs are very costly.

Reduced flexibility of product. Redesign of product requires rearrangement or design of the manufacturing process. Material must continue to come without variations in form, size, which limits sources for materials.

Adjustment problems. Having installed the automatic equipment, an adjustment and rebuild period may be necessary. The more complex a system, the more vulnerable is the whole to a sectional failure.

Today in 1983 it has become obvious that something must be done soon to reduce soaring production costs and to meet competition. Management should always make an objective automation feasibility study, that maximizing the ability of current computer technology requires development of a total systems approach - automation, to effect a new total solution to the productivity goal in mind.

CHAPTER 2

DESCRIPTION OF PRESENT MANUFACTURING SYSTEM

For the purpose of this chapter we shall assume the existence of a hypothetical company - the Apollo Valve Company, a solenoid valve manufacturing firm, established in 1880. This medium size company, with 1500 employees and fifteen foreign subsidiaries, has progressed rapidly in the recent years. With strong financial resources, experienced employees, and effective management technique, the business profit is continuously growing. The variety and complexity of the solenoid valves manufactured at Apollo Valve Company are examined as shown in the following pages.

General Description of Solenoid Control Valves

A solenoid control valve, an important part of modern automation control systems, is a combination of two basic functional units - (1) a solenoid (electro-magnet) with its plunger (or core); and (2) a valve containing an orifice in which a disc or plug is positioned to stop or allow flow. The valve is opened or closed by movement of the magnetic

plunger (or core) which is drawn into the solenoid when the coil is energized. A solenoid mounted directly on the valve body with the solenoid core attached to the valve stem. The core is enclosed and free to move in a permanently sealed tube inside the solenoid coil. This construction provides a compact, leaktight assembly. The exploded views of typical 2-Way and 3-Way valves are shown on Figures 2-1 and 2-2.

Solenoid control valves are available in thousands of varieties, each designed to meet specific requirements. Valve types fall into four basic groups:

1. Two-way valves One inlet and one outlet pipe connection. These valves are available in normally closed and normally open versions. The normally closed type is closed when its solenoid coil is de-energized; it is open when proper voltage is applied to the coil. Normally open valves are open when de-energized, and closed when energized.
2. Three-way valves Three pipe connections and two orifices that are alternately open or closed. These valves are offered in normally open, normally closed, and universal constructions. The universal type can be used as either normally open or normally closed. Three-way valves are generally used

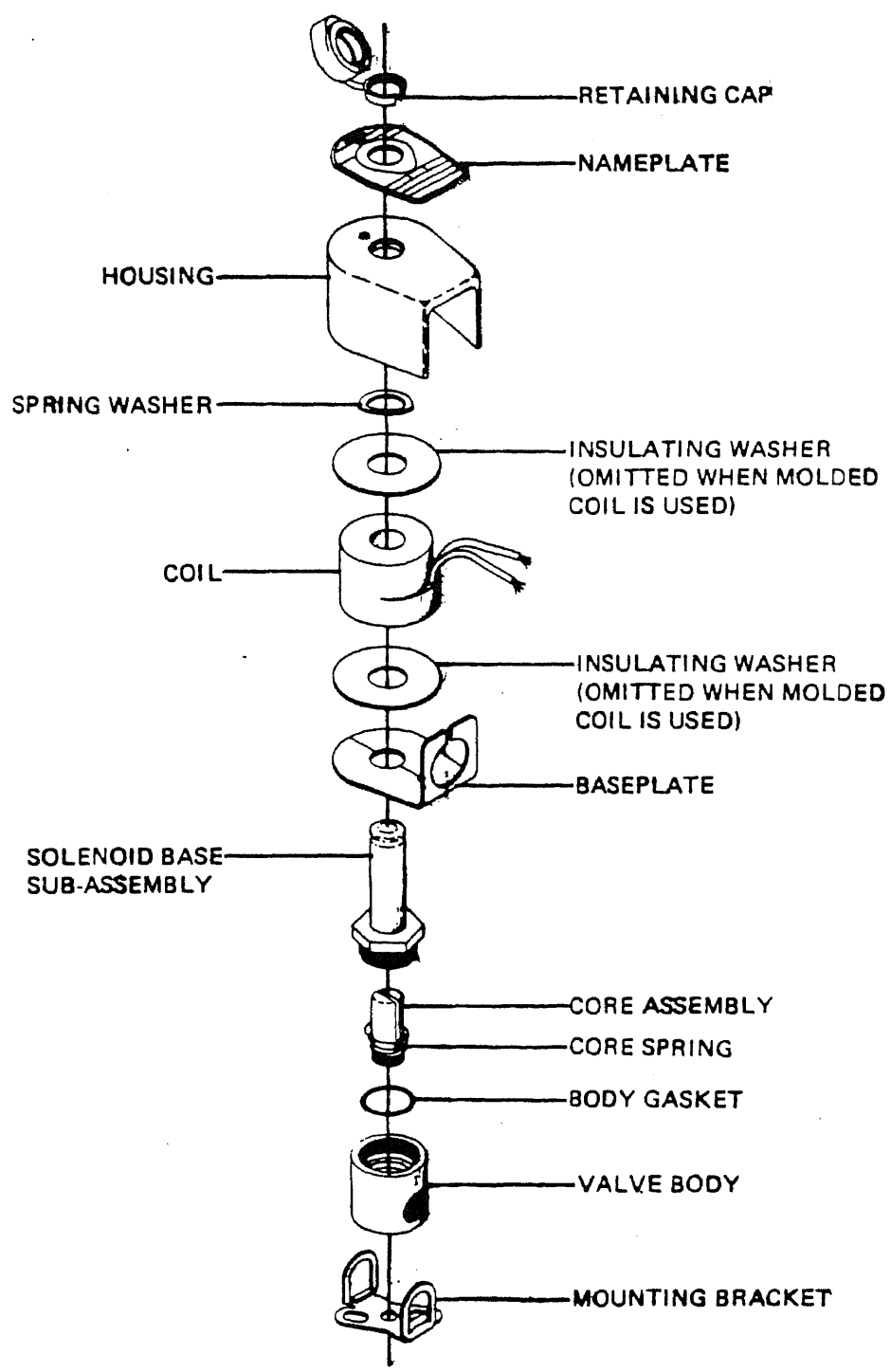


FIGURE 2-1 2-WAY SOLENOID VALVE

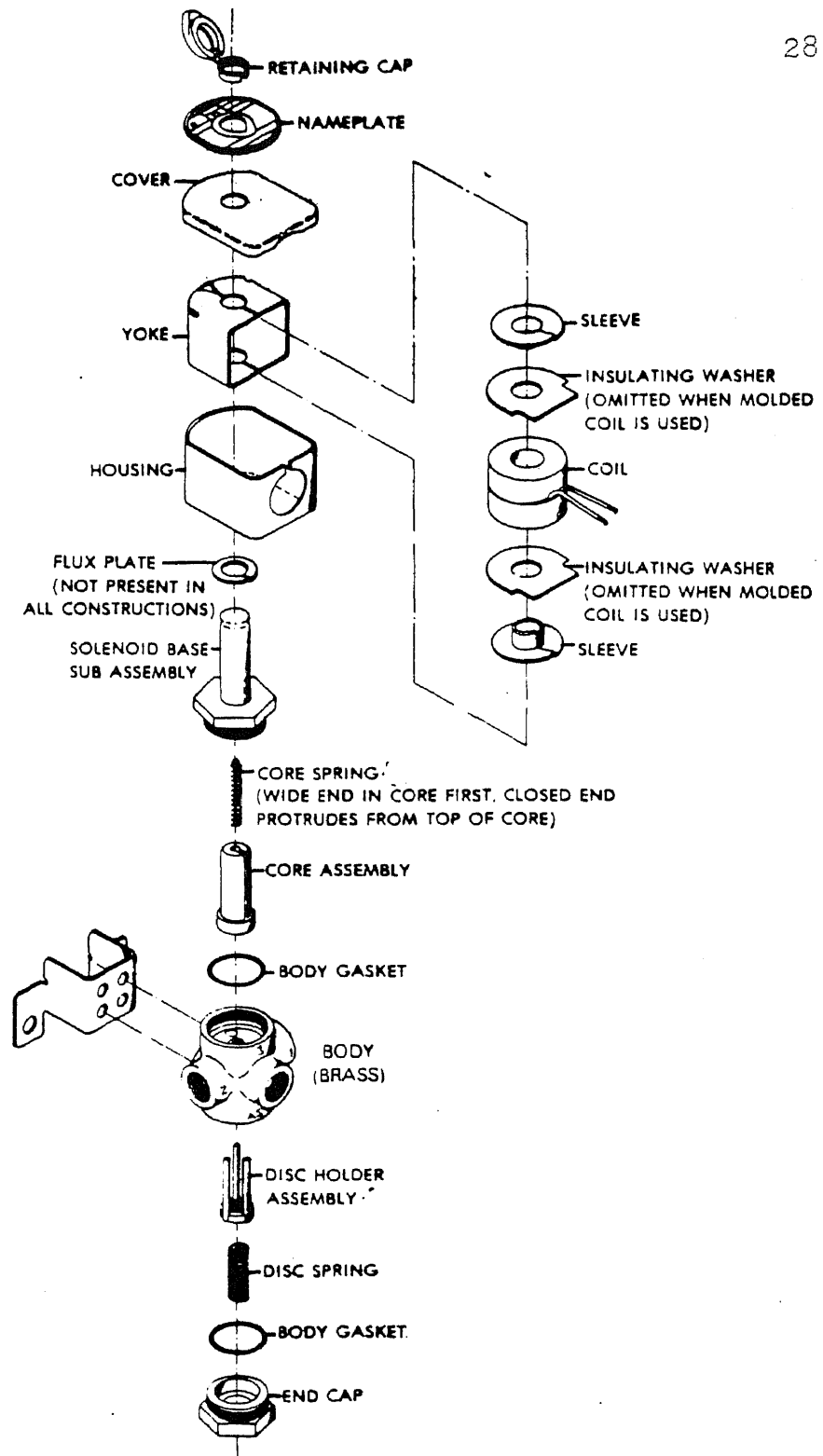


FIGURE 2-2 3-WAY SOLENOID VALVE

as pilots for larger control valves, or to actuate single acting power cylinders. They are also used to divert the flow of fluids.

3. Four-way valves Usually four pipe connections, one for pressure, two for cylinders, and one for exhaust. This type is generally used to operate double-acting cylinders or to pilot larger control valves.
4. Manually vs. electrically reset valves Typically, a manually reset valve can be opened or closed manually; it reverts to its original position when, depending on its construction, it is energized or de-energized. An electrically reset valve operates electrically in the same manner; this valve is reset by applying a separate electrical signal.

After the required basic valve type has been determined, pipe size, orifice size, flow rate, pressure rating, medium to be controlled, ambient and fluid temperatures, voltage, type of solenoid enclosure, cycling rate, and required life rating must be considered. These fundamental factors of solenoid control valves are discussed as follows:

Valve sizing. A number of factors influence the manner in which fluids flow through valves. Valve configur-

ation and orifice size, and viscosity, specific gravity, and temperature of the controlled medium will usually have the greatest influence on determination of proper valve size. All variables affecting selection of valve size, however, have been reduced to a single parameter known as the flow coefficient C_v , the most common method of determining fluid flow.

Pressure rating. Solenoid valves are manufactured in a variety of orifice sizes and pressure ratings. Orifice size and pressure rating are interrelated. For direct-acting valves (those that operate from zero pressure to maximum pressure), pressure rating decreases as orifice size increases. Large valves and those rated for high pressure are offered in pilot-operated versions. Such valves are equipped with a pilot and a bleed orifice and are usually of the diaphragm and piston type. The line pressure of the controlled fluid operates the valve. A minimum pressure differential (depending on construction) is required between inlet and exhaust ports for satisfactory operation. Pressure ratings should be as near as practiceable to the system pressure. Best results will be obtained by selecting a valve with a pressure rating above, but not significantly greater than, the system pressure.

Medium Compatibility. Valves are manufactured in materials and constructions that are compatible with a wide variety of

media - air, water, oil, steam, and corrosive and noncorrosive gases and liquids. It is essential that the valve be compatible with the controlled medium.

Cycling rate and estimated life. Special solenoid valve construction is usually required to obtain long valve life when the controlled medium is unlubricated air or a dry, inert gas. Selecting the solenoid valve to last as long as other parts of the system or equipment on which it is used allows the valve to be functioned during a normal system or equipment outage.

Solenoid coil insulation. Thermal degradation of coil insulation is a function of time at elevated temperatures. The coil is subjected to heat from surroundings, from high temperature fluids passing through the valve, and from the electrical energy spent in the coil. The temperature created by all heat sources will determine the required class of coil insulation (per Underwriters' Laboratories and/or military standards).

Coil operating voltage. Standard voltage ratings are 6, 12, 24, 120, 240, and 480 volts A-C and 6, 12, 24, 120, and 240 volts D-C. These coils are designed for industrial operating voltages and can be used on the specified voltages ranges. Also most manufacturers can supply coils in special voltage ratings to meet customer's requirement.

Solenoid enclosure. Solenoid valves are offered with a wide variety of enclosures, general purpose, rainproof, dust-tight, water-tight, submersible, hazardous locations, explosion-proof, corrosion resistant, and oiltight, etc. per National Electrical Manufacturers Association (NEMA) and National Electrical Code standards. The enclosure should be kept in place at all times, because with many types of solenoids, the enclosure is employed as part of the magnetic circuit.

Due to the multiplicity of basic valve types and the wide variety of design specifications, Apollo Valve Company, produces over 25,000 types of valves. It is therefore a challenge to survive profitably under the demands of business competition, market requirement, and the multitudinous varieties of demands for satisfaction of an endless number of needs.

DESCRIPTION OF THE PLANT

The main manufacturing facility of Apollo Valve Company is located in the New York metropolitan area, with a modern plant in suburban surroundings, an ideal plant site for the

company and its employees. In this section, we shall describe plant layout, firm organization, and departments function.

Plant layout

Plant layout is an important phase to be undertaken when planning a new industrial concern, and the building was selected to best suit the over-all requirements of the layout plan. The total plant area of Apollo Valve Company is approximately 410,000 square-feet; office and shop occupy 140,000 and 270,000 square-feet respectively. The detailed layout, shown on Figure 2-3, indicates the building is rectangular in shape and a single story, which is the most popular shape.

There are three classical types of layouts. Most plants today are laid out using a combination of these classical layouts, but in their pure forms they are seldom seen. The three classical types are:

1. Product layout
2. Process layout
3. Fixed - position layout

It is best to plan the over-all layout and then to consider the detailed layout plan in support of the over-all

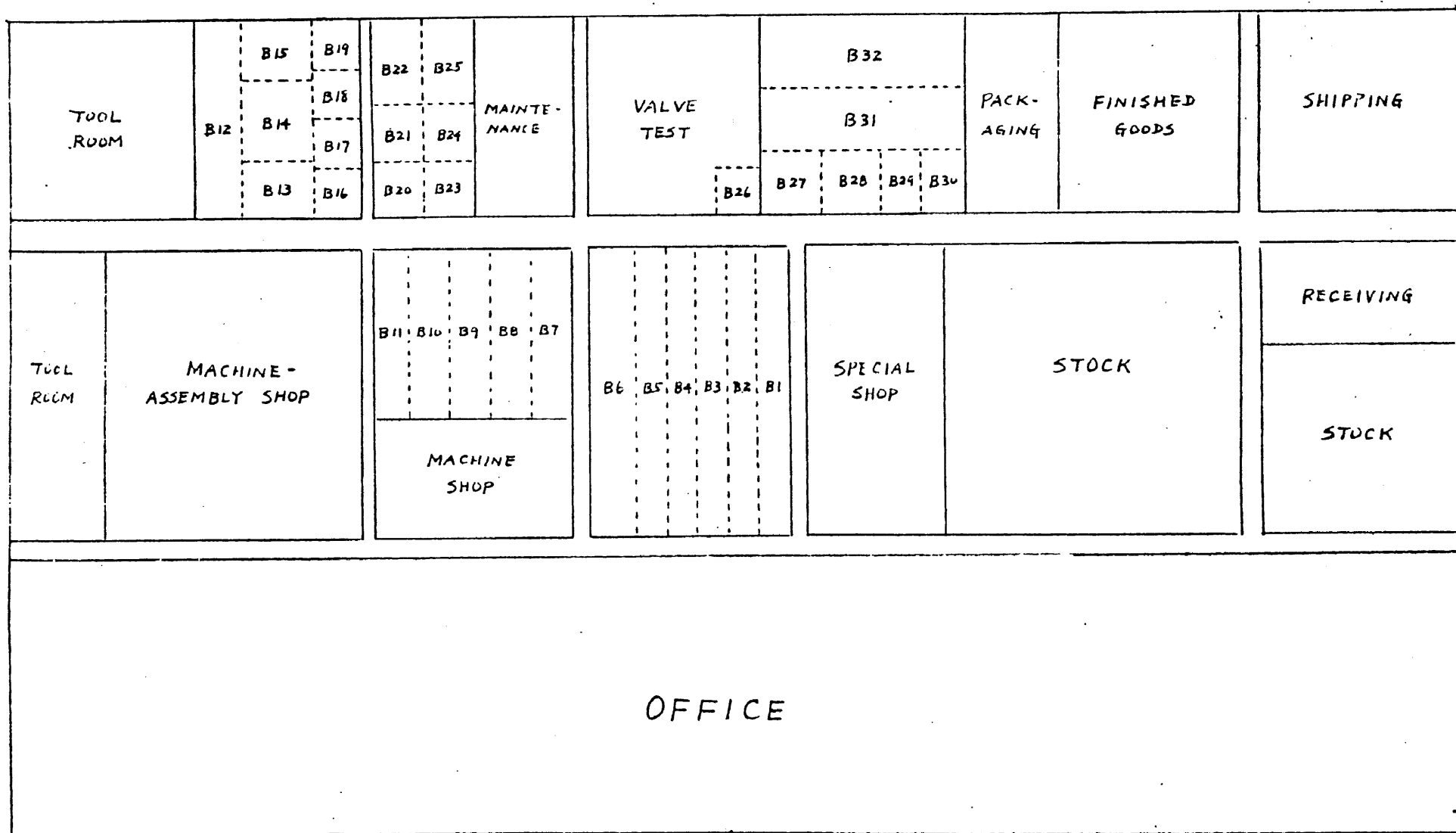


FIGURE 2-3 PLANT LAYOUT
 APOLLO VALVE COMPANY

NOTE: B1 - B32 ASSEMBLY BENCH NO.

plan. Therefore, by examination of the detailed layout (Figure 2-3), it is seen the Apollo Valve Company has adopted the combination of two classical layouts; Assembly Benches as the product layout, and for general operations, the process layout.

Firm Organization

In this section, we shall consider the organizational functions within the manufacturing firm classifying it as a fabricator. That is, it manufactures discrete components, assembles and tests those components into final products for sale to its customers. Many medium-size and large corporations fall into this category. For Apollo Valve Company, thousands of different products are manufactured. The task of organizing and coordinating the activities of the Company to perform its manufacturing function is complex.

The plant is administered by according to the President, organization chart is shown on Figure 2-4. The general production responsibilities of the related Departments are discussed in the following subsections:

Sales Receives customer's order and originates the

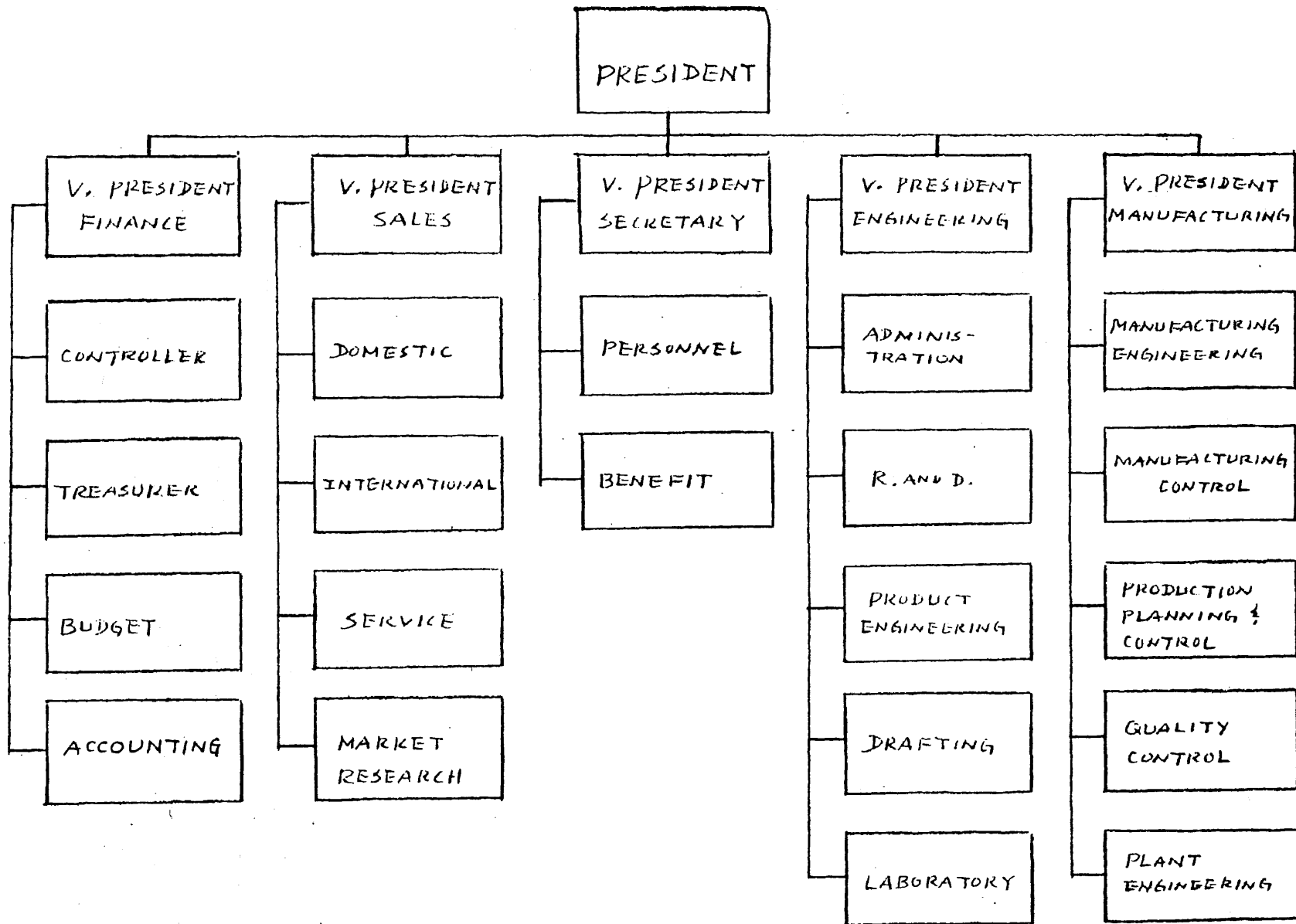


FIGURE 2-4 ORGANIZATION CHART
APOLLO VALVE COMPANY

shop order to produce the specified solenoid valve(s). The shop order is in one of three forms; a customer order to manufacture an item to the customer's specifications, buy one (or more) of the Company's proprietary products, or an order based on a forecast of future demand for a proprietary product.

Product Engineering The Engineering Department is responsible for product design and development, documented by means of component drawings, engineering specifications, and a bill of materials that defines the quantity of components in each product.

For new products, a prototype is often built for testing and demonstration purposes. The manufacturing engineering department is sometimes consulted to lend advice on matters of produceability. Cost estimates are prepared to establish an anticipated price for the product. Upon completion of the design; fabrication of the prototype, and approval by engineering management, an "engineering release" will be issued to Manufacturing Department for formal production.

Production Planning and Control (PP&C) The major functional duties of PP&C are master scheduling, ma-

terial requirements planning, product scheduling, dispatching, and expediting. The master schedule is a listing of the products to be produced, when they are to be delivered, and in what quantities. In turn, this master schedule must be converted into purchase orders for raw materials, orders for components from outside vendors, and manufacturing schedules for parts made in the shop; the individual components and subassemblies that make up each product must be planned. The next task is production scheduling; this involves the assignment of start dates and due dates for the various components to be processed through the factory. Based on the production schedule, the dispatching function is concerned with issuing the individual orders to the machine operators, giving out order tickets, route sheets, part drawings, and job instructions. Expeditors compare the actual progress of the order against the production schedule. For orders that fall behind, the expeditor takes corrective action. These events must be timed and coordinated to allow delivery of the final product according to the master schedule.

Manufacturing Control The activities of time standards and inventory control are the responsibility of

the Manufacturing Control Department. The purpose of setting time standards is to determine how much time the task should take using standard methods. The purpose of inventory control is to ensure that enough products of each type are available to satisfy customer demand under the constraint that the Company's financial investment in inventory be kept at a minimum. The inventory control function applies not only to the company's final products. It also applies to raw materials, purchased components, and work-in-process within the factory.

Manufacturing The manufacturing department is responsible for manufacturing engineering and production activities. The function consists manufacturing process planning, tool and equipment design, and manufacturing operations that transform raw materials into finished goods or spare parts.

Quality Control The Q.C. System assures that all material and products specified will meet all customer requirements and applicable quality standards. The Q.C. Department insures adequate quality control throughout the entire process of procurements, manufacture, fabrication, packaging and shipping.

DESCRIPTION OF THE
MANUFACTURING SYSTEM

Because Apollo Valve Company manufactures a variety of types of solenoid control valves, it is a typical job shop manufacturing system. The detailed manufacturing process is shown on Figure 2-5. We will briefly discuss the production operations in the paragraphs below.

Receiving Receiving Department is responsible for the receiving and counting of all materials, parts and components received from vendors and delivery them to Receiving Inspection or other designated departments. Quality Control is responsible for the acceptance or rejection of the materials, parts, and components in compliance with the Purchase Order requirements within the limits of established specifications of quality.

Stockroom The Receiving Department will deliver the purchased materials, parts, and components to Stockroom Stage Control Area after approval by Quality Control. Stockroom is responsible for checking each new receipt against the material requirement cards, filed by part number at Stage Control Desk. Then the purchased materials will be put into the bin or bay

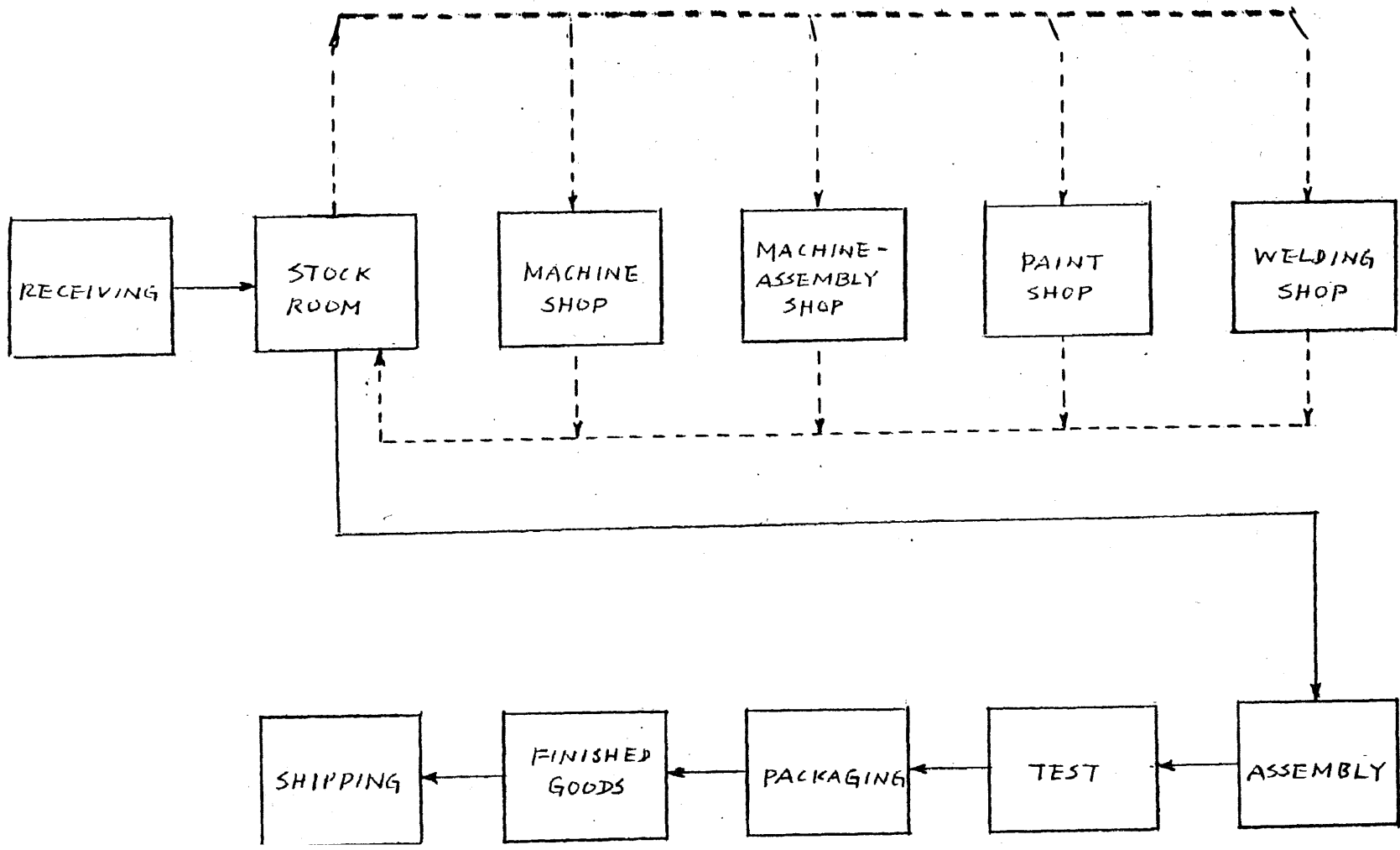


FIGURE 2-5 MANUFACTURING

PROCESS - PRESENT SYSTEM

area for storage. All material requisitions issued by Production Planning and Control Department or Assembly Shop, the Stockroom is responsible for withdrawing, staging and delivery to the designated locations.

Machine Shop Nearly all semi-finished parts are received from outside suppliers. The Machine Shop is responsible for machining them, maintaining a conformance to engineering drawing requirements. After acceptance by Quality Control, the finished parts are then sent to the Stockroom for storage.

Machine-Assembly Shop Sub-assemblies and components are assembled by the Machine-Assembly Shop, with special machines or equipment, in accordance with assembly specifications. After Quality Control acceptance, the sub-assembly or component are delivered to the Stockroom for storage.

Assembly Line The Stockroom delivers the required parts and sub-assemblies to Assembly Area according to the bill of materials issued by Production Planning and Control Department. Each Assembly Bench will only assemble a special line of solenoid valve. The solenoid valves will be assembled according to the specified Assembly Procedure and then put on

a hand truck. When finished a shop order lot, the hand trucks are moved to the Valve Test Department for testing.

Valve Test All solenoid valves require 100 percent testing according to a specified Test Procedure in order to meet customer's requirement. The Valve Test Department is responsible for all the required tests. Test positions and fixtures are available in different sizes and mediums. Quality Control is responsible for the acceptance or rejection of the tested valves. When a shop order lot is finished then the hand trucks with tested solenoid valves are moved to the packaging area for further work.

Packaging and Shipping After the valves are received in the Packing Area, the Packer will pack each valve with cushioning material and put it in a box to protect the valve against damage in transit. Then the valves, put on a hand truck, are moved to finished goods stock or shipping area according to the instructions of the shop order.

Upon receipt of the shop order and solenoid valve(s), the Shipping Department will determine the type of exterior packaging and the size and type of shipping container, based upon the packaging specifications and the destination. The Shipping Clerk will then proceed to package the valve(s) and

mark the shipping container according to the outlined instructions.

CHAPTER 3

ANALYSIS OF PRESENT MANUFACTURING SYSTEM

It is general practice to analyze manufacturing systems according to three classification schemes: by volume and rate of production, by type of plant layout, and by model of manufacturing operations.

PRODUCTION QUANTITIES

In terms of production volume, manufacturing plants can be classified into three types: job lot shop production, batch production and mass production.

Job Lot Shop

"A factory which produces largely and directly to customers' order. It is characterized by its handling of many orders, often for small quantities, for a large variety of products."¹ Job shop production is commonly used to meet

1 MOORE, F.G. and JABLONSKI, R., "Production Control," McGraw-Hill Book Co., New York, 1969, p. 14.

specific customer orders, therefore, the production equipment must be flexible to allow for this ability of work. The distinguishing features of job shop production are low volume and low rate. Also, the skill level of workers must be high so that they can handle a range of different of work assignments. Examples of job shop products would be aircraft, special tools and equipment, and prototypes of future products.

The weekly production capacity of the present manufacturing system is summarized on table 3-1. The total production capacity of thirty two assembly benches is 44,220 valves per week, and the lot sizes are varied from 20 valves per week to 5000 valves per week. Due to special tools and equipments required, each assembly bench can only assemble the certain type(s) of valve(s), at the specific rate shown. Since Apollo Valve Company produces a wide variety of solenoid valves for customer's requirement, and most of production quantities are low volume. Consequently, we can conclude that the present system is a job shop type production, with complex scheduling problems.

Table 3-1 Apollo Valve Company
Assembly Bench Production Capacity

Bench Number	Valve type(s) (Catalog Number)	Production Capacity (Valves/Week)
B1	261, 520	5000
B2	262	2000
B3	262	300
B4	262	2200
B5	210A, 211A	1200
B6	210B, 211B, 223, 267	4000
B7	263, 314A	2000
B8	304, 305, 315A, 351	2500
B9	408, 409, 410, 411	500
B10	262, 314B	2200
B11	300, 302, 315B	700
B12	215A	1300
B13	344	550
B14	030, 031, 210C, 211C	1700
B15	027, 037, 340, 346	500
B16	322, 217	550
B17	210D, 211D	750
B18	316	500
B19	317, 331, 335, 337	1200
B20	015A, 025A, 035, 308	20
B21	210E, 211E, 222A	3000
B22	040, 260, 324, 349	2000
B23	360, 521	650
B24	347, 353	3000
B25	210F, 211F, 342	1200
B26	SPECIAL	350
B27	345	1000
B28	264, 318, 319	400
B29	015B, 025B, 266, 333	100
B30	210G, 211G, 222B, 600	750
B31	321, 268, 269, 271	300
B32	040, 041, 042, 215B	1800
Total		44,220

Batch Production

"Batch manufacture means that you process materials in batches equal to full loads on primary equipment. Usually the process is one of mixing or heating several ingredients together in large mixers or pressure or heating tanks and vessels."² No products come out of the process until the cycle is complete, at which time the whole batch is delivered. Therefore many types of chemical processes are included in this category.

This category of production is often used to satisfy continuous customer demand for an item. The shop produces a stock item to build up an inventory of the item. When the stock level becomes low or depleted, production is repeated to build up the inventory again. Therefore, this type of production usually involves the manufacture of medium-size lots of product.

The machine tools used in batch production are combined with special fixtures or jigs. The manufacturing equipment is often general purpose for higher rates of production. Typical batch production plants include machine shop, plastic

2 Ibid. 1 p. 641.

molding factories, and pressworking shops.

As we previously discussed in Chapter 2, the manufacturing system of Apollo Valve Company includes the Machine Shop, Machine-Assembly Shop, and Finished Good Stock. Supplied with semi-finished parts from vendors, the Machine Shop performs additional work to make finished parts. Sub-assembly components are assembled in the Machine-Assembly Shop, then move to the Stock Room to build up the required inventory. Continuously demanded solenoid valves are produced and stored in the Finished Good Stock. These production activities should be classified as the batch production category since the finished parts, sub-assemblies, and valves are produced to build up the established inventory level in discrete production runs, with an implied machine tear down after each run, and set up for a new type part.

Mass Production

"A factory which large quantities of a limited variety of products. The products are usually made to stock rather than to customers' orders."³ Mass production is characterized by very high production rates and continuous operation. The

3 Ibid. 1 p. 15.

equipment is special-purpose rather than general-purpose. Apollo Valve Company produces a large variety of solenoid valves, therefore the manufacturing system obviously is not a mass production type.

PLANT LAYOUT

The term plant layout refers to the physical arrangement of men, machines, and materials within the production plant. There are three traditional types of layouts; product layout, process layout, and fixed-position layout. These classical layout types are used with manufacturing operations, as well as with assembly operations.

Product Layout

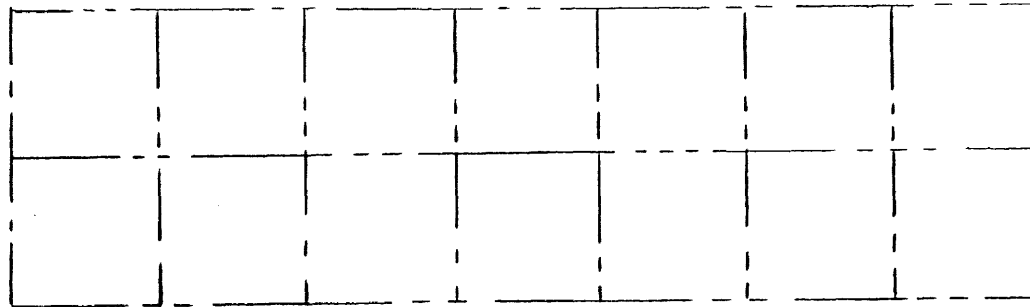
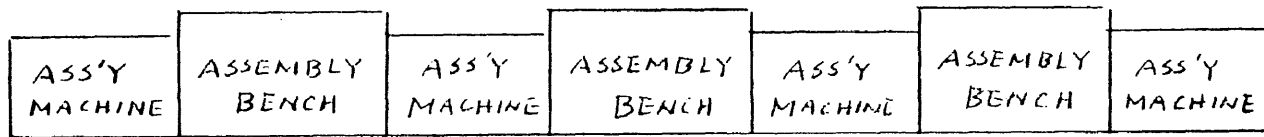
In this type of layout only one product is produced in a given area and the equipment is lined up in sequence order. The processing and assembly facilities are placed along the line flow. The work-in-process is moved by conveyor or similar means from one workstation to the next. This type of layout is appropriate for flow-type mass production in large volumes products.

A typical assembly bench layout of Apollo Valve Company is shown on Chart 3-2. This set-up, Bench Number B2, is similar to product layout concept, as only one type of solenoid valve, catalog number 262, is produced in this Bench. There are thirty two assembly benches of a similar flow-type layout, each bench producing one specified type of valve. Therefore we conclude the assembly benches area has a product type layout.

Process Layout

The process-layout groups together all operations of the same type in a department. Similar equipment and similar operation are arranged into groups according to general type of manufacturing process or functional layout. Forklift trucks and hand carts are used to move materials from one work center to the next. The process layout is typical in job-lot shop and in batch production where low volume is required. The advantage of process layout is its flexibility. Different parts can be routed through the respective departments in the proper order.

The present manufacturing system is designed in the form of process layout. General operations are receiving, storage, assembly, testing, packaging, and shipping.



STORAGE AREA

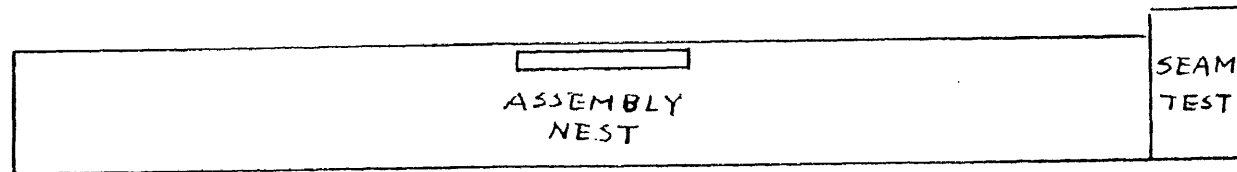
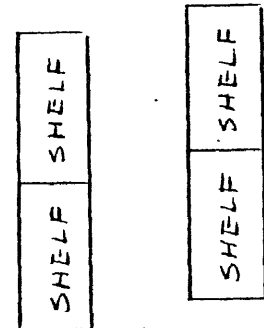


FIGURE 3-2 B-2 ASSEMBLY BENCH LAYOUT

Materials are moved by forklift or hand cart from one workstation to the next. The process layout is typical to job shop production; consequently, the present layout is generally as a process type.

Fixed-Position Layout

In this type of layout the material, or component, remains in a fixed location and the equipment and tools are brought to this location. Obviously, this is not the case here since the solenoid valves move along the production line and the jobs are done in each department of manufacturing process.

By analysis of the detailed layout, we conclude the Apollo Valve Company has adopted the combination of two traditional layouts: product layout and process layout.

MANUFACTURING OPERATIONS

The objective of this section is to study only the general characteristics of manufacturing processes of the present system; the manufacturing process technology is excluded.

The requirement of production operations is to transform raw materials into finished product. We shall discuss these operations into two types: assembly operations and processing operations.

Assembly Operations

The major feature of assembly and joining process is that two or more separate components are joined together. In this category are included mechanical fastening operations, using of screws, nuts, rivets, etc., and joining processes, as welding, brazing, and soldering.

The principal operations conducted in the present manufacturing system are in the assembly process, since there are approximately 25,000 combinational forms/types of solenoid valves to be assembled and almost 300 assemblers working on thirty two assembly benches. Also, since the skill level of assembly workers is relatively high, they perform a range of different work assignments, assembling many different types of solenoid valves. The present system also includes a machine-assembly shop. This department is responsible for the assembling of sub-components, such as solenoid base assembly, diaphragm assembly, and core-disc assembly, utilizing special assembly-machines. There are approximately 35,000 different

types of parts; 95 percent of them are made by outside vendors. Clearly, the assembly operation is the most important process of the present manufacturing system.

Processing Operations

Processing operations, generally, change the shape of the workpart, remove material from it, or change its physical properties. Operations are performed to give the workpart its final desired geometry, to enhance physical properties and to provide a finished appearance.

The present manufacturing system also includes the Machine Shop and The Special Department. The Machine Shop is responsible for performing minor operations on the semi-finished parts; for example: drill a hole, or polish the seat(s) of a valve body. The Special Department is responsible for brazing or painting of some types of parts, such as brazing the special plugnut assembly, painting the solenoid enclosure, etc. These manufacturing activities only involve very low volume products; hence, we shall not make a further investigation.

SUMMARY

The characteristics of the present manufacturing system are summarized as below. The plant is:

1. A typical job-shop production plant but with some exceptions; some operational processes are performed as batch production.
2. Plant layout: adopted as a combination of two classical layouts; process layout for the general manufacturing system and product layout for the assembly benches.
3. Mixed products fabrication: approximately 25,000 combinations of solenoid valve types.
4. Production quantity: 40,000 \pm 10,000 valves per week.
5. Types of parts: approximately 35,000 different parts, 95 percent sourced by outside suppliers.
6. Inventory/asset ratio: 30 percent.

CHAPTER 4

AUTOMATION CONSIDERATIONS AND PROPOSED IMPROVEMENTS

Productivity has become a very popular term in industry vocabulary. Generally, a productivity measure is expressed as a ratio of output to input. In order to improve productivity, we must utilize our resources more efficiently, to produce the desired product at a lower cost. In this chapter, we shall discuss methods and considerations, for improving the present manufacturing system at Apollo Valve Company.

PRE-AUTOMATION STUDY

Since manufacturing automation began receiving national attention in the late 1950s and early 1960s, there have been many different concepts and arguments for and against automation. This thesis will concern itself with the technical feasibility of automated manufacturing system. However, some of the major economic factors will be considered.

Automation Possibilities

Most of the manufacturing methods of the present system have been in use for a long time without much improvement. Long usage does not necessarily imply inefficiency of operations, but it does hint there may be some room for improvement. Therefore, there are many areas at Apollo Valve Company where automation could potentially be applied, such as: those jobs using high labor content, those departments with high volume production, antedated manufacturing methods, inadequate production capacity, quality problems, etc.

As previously mentioned, there are approximately 35,000 different types of parts being used in the present system, 95 percent of them made by outside suppliers. Obviously, assembly is the principal operation in the present manufacturing system, hence, a great amount of man hours are needed in assembly operations. For one high volume product, (refer to Table 3-1 Assembly Bench Production Capacity) there are four assembly benches, B2, B3, B4 and B10, producing the same type of valve, catalog number 262. Obviously, we should develop an automatic assembly system for this valve.

Due to the engineering specifications and customer's

demand's all the production solenoid valves require 100 percent functional testing. Therefore, an automatic testing process will be considered in order to reduce the number of labor hours required for the testing of those high volume production valves (catalog number 262).

Certainly, there are other automation possibilities in the present system but one can confidently say - that starting with automatic assembly and testing of the high volume valves would be the first step of a successful automation system.

Pre-Automation Considerations

There are certain basic rules that can be used to improve productivity in manufacturing operations. Since these rules are commonly implemented by means of automation technology, it would be helpful to review some planning strategies.

1. Use Prepared Materials: Use materials that already have some of the configuration needed for the product. Demand that materials come in the most continuous and preworked forms possible, as material on reels, coild, drums, etc.

2. Transfer Directly: Avoid intermachine storage of parts, which increase process lag time. Thus, transfer of

parts directly from one operation to the next one.

3. Combine Operations: The processes are performed in sequence at the same machine. Accomplish as many operations as possible at each station. Where practical, use multiple action tooling.

4. Reduce Cutting Operations: The operations for a conventional manufacturing process are not necessarily those for automation. Favor nonchip processes such as molding, forming, stamping, casting or extrusion in preference to metal cutting.

5. Specialize Operations: Use special-purpose machines designed to perform one operation with the greatest possible efficiency. Utilize multiple operations at the same workstation and at the same time. For example, multiple spindle drill presses utilize this concept for drilling more than one hole simultaneously.

6. Integrate Operations: A series of workstations are linked together as a single integrated mechanism by automatic work handling devices. With several stations, more than one part can be processed at one time, therefore, this strategy increases overall productivity and reduces work-in-process time.

7. Reduce Setup Time: Schedule of similar workparts through the production machine, use of common fixtures for

different but similar parts.

8. Improve Material Handling: Use of mechanized and automated materials handling methods. Minimize the distances over which the workparts must be moved and provide for smooth flow of work through adjacent stations, in order to reduce work-in-process time.

These pre-automation strategies, generally, can improve productivity, but actual application will be justified by each manufacturing system, single-operation automation or integration of process operations. Utilizing these strategies, we will develop improvement methods in later sections.

Automation Procedure-Step by Step

The incorporation of an automatic process by a manufacturer of fabrication industry involves five progressive phases. These are the preliminary, design, building, installation and adjustment stages of development.

Preliminary Phase: This is the educational stage of an automation program, before any formal studies are made. Evaluate automation possibilities and consider preliminary methods for improving production. Discuss production methods

with independent consulting engineers and conduct an automation feasibility study.

Design Phase: Create two or more preliminary automation systems. Repeat and refine to a best functional system, specifically integrating machine and control. Prepare drawings and specifications. Consider power required by the machines, future product changes, reserve capacity of every machine operation, and maintenance.

Building Phase: Award the contracts to vendors and contractors. Then it is necessary to check progress and delivery schedules, and to compare the machine being manufactured with the purchase specifications. When the machinery nears completion, as many pilot runs as possible should be done before delivery.

Installation Phase: Pre-installation arrangements are necessary for transportation and the installers. Foundations and machinery mounts must be prepared. Installation involves study, preparation, and arrangements for all necessary utilities. When installed, the equipment must be tested; first without materials, then with actual production runs with materials. A final inspection and operational check

should be completed before turning over the installed equipment to the production men.

Adjustment Phase: Adjustment activities generally include actual operational try-out; balancing operating cycles, correcting and trimming-up problems, preparing procedures for start-up, shut-down and service, and organizing manual for training operations and maintenance.

This procedure is used as a general guide line for automation of a fabrication industry. For a computerized manufacturing system, it may be necessary to discuss with an independent consultant the aids needed in bringing about automation for your plant and to act as liaison between the user and vendor.

GROUP TECHNOLOGY

"Group technology (GT) is a manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in manufacturing and

design."¹ Similar parts are arranged into part families. To do this, a part coding system is used. The code for each part identifies such things as part size, shape and material, and the manufacturing processes used. Each part family would possess similar design and manufacturing characteristics, therefore the efficiencies will be increased. In this section, we will discuss these technologies - coding system and computer-aided process planning (CAPP).

Coding Systems

"A part family is collection of parts which are similar either because of geometric shape and size or because similar processing steps are required in their manufacture."² One of the positive manufacturing developments resulting from the grouping of parts into families is the group technology layout. The machines or equipment arranged into cells. Each cell is organized to specialize in the manufacture of a particular part family and to operate as a shop within a shop. In contrast with process-type layout, various machines or equipment are arranged by function. Advantages of GT layout

1 GROOVER, M.P., "Automation, Production Systems, and Computer-Aided Manufacturing," Prentice-Hall, Englewood Cliffs, New Jersey, 1980, p. 538.

2 Ibid. 1 p. 539.

are gained in the form of reduction of a significant amount in material handling, lower set-up times, less in-process inventory, and shorter lead times.

There are three general methods for grouping parts into families, as outlined in the following paragraphs.

Visual Inspection: By looking at either physical parts, drawings or photographs and arranging them into similar groups, one can quickly and inexpensively group parts into families. This is the least sophisticated and least accurate method of the three. The Langston Division of Molins Machine Company, located in Cherry Hill, N.J., provides one of the first major success stories of GT in the United States. The Langston Division adopted the visual inspection method to group some 60,000 different parts into six families. The new production system resulted in 50% improvement in productivity, and in-process time for a part was substantially reduced; the amount varied in the different family lines, with the greatest improvement occurring in the small milling parts line (The average time was reduced from 4 to 6 weeks to 2 to 5 days).³

3 HOLTS, R.D., "GT and CAPP Cut Work-in-Process Time 80%," Assembly Engineering, June 1978, p. 27.

Coding by Examination of Design and Production Data:

The second method for grouping parts into families is by examining the individual design and/or manufacturing attributes of each part, and then applying a coding system which results in a code number that uniquely identifies the part's attributes.

Coding systems generally form families based either on (1) part design attributes, similar shapes within specific dimension ranges, or (2) part manufacturing attributes, common manufacturing operations, regardless of shape. In part design, a designer is concerned with such things as shape, size, tolerances, material, surface finish, and part function. In manufacturing an engineer is also concerned with manufacturing operations, processes, machine tools, fixtures, production time, batch size, and the sequence of processing steps required to make the part. There is a certain amount of overlap between the design and manufacturing attributes of a part.

A coding system consists of a sequence of numerical digits to identify the part's design and manufacturing attributes. GT systems may use monocodes, polycodes or mixed codes as the basic structures.⁴

⁴ Ibid. 3 p. 24.

1. Monocodes, sometimes called hierarchical codes, are a sort of family tree coding system; each digit divides the category identified by the preceding digit into subcategories, the interpretation of each succeeding symbol depends on the value of the preceding symbols. An advantage of this system is that a tremendous amount of information can be coded into a relatively short number.
2. Polycode, sometimes called an attribute code, uses each digit to code a different piece of information, and each digit is independent of all other digits. The interpretation of each symbol in the sequence is fixed; it does not depend on the value of the preceding symbol. Thus a search of these codes is relatively easy.
3. Mixed code uses a combination of the monocodes and polycode. It is composed of groups of monocodes within a polycode. Sections can be used to identify almost anything needed by the user company.

The reason for using coding system is to facilitate retrieval for design and manufacturing purposes. For examples, a designer can use the design - retrieval system to determine if a similar part is already in existence, and in

manufacturing information such things as process data, costs, setup and run times, and tool, jig and fixture data can be retrieved. However, coding system should be custom - engineered for a given company or industry. Therefore many systems, such as OPITZ System⁵ and MICLASS System⁶ have been developed but none of them has been generally adopted.

Parts classification and coding system requires the most significant investment in time and man-power of the three methods of identifying part families, however, this method seems to be the most commonly used method today. Ham⁷ has summarized the major benefits of a coding system for group technology as below:

1. It facilitates the formation of part families and machine cells.
2. It permits quick retrieval of designs, drawings, and process plans.
3. It reduces design duplication.

5 This coding system was developed by H. Opitz of the University of Aachen in West Germany.

6 This classification system was developed by TNO, the Netherlands Organization for Applied Scientific Research.

7 HAM, I., "Introduction to Group Technology," Technical Report MMR 76-03, Society of Manufacturing Engineers, Dearborn, Mich., 1976.

4. It provides reliable workpiece statistics.
5. It facilitates accurate estimation of machine tool requirements.
6. It permits rationalization of tooling setups, reduces setup time, and reduces production throughput time.
7. It allows rationalization and improvement in tool design.
8. It aids production planning and scheduling procedures.
9. It improves cost estimation and facilitates cost accounting procedures.
10. It provides for better machine tool utilization and better use of tools, fixtures, and manpower.
11. It facilitates NC part programming.

Production Flow Analysis The third method for grouping parts into families uses of the information contained on route sheets rather than part drawings. Production flow analysis is used to analyze the operation sequence and machine routing for the parts produced in the given shop. Workparts with identical or similar routings are classified into part families. These families can be used to form logical machine cells in a group technology layout.

A disadvantage of production flow analysis is that it provides no mechanism for rationalizing the production route sheets; no consideration is given to whether the manufacturing routings are logical or optimal. However, this method requires less time to perform than a complete parts coding procedure, therefore, it is attractive to many companies for making the changeover to a group technology layout.

Computer-Aided Process Planning (CAPP)

The manual preparation of manufacturing process plans is obviously an inefficient process. A great deal of labor is required, and it can also be a very expensive operation. Computer-aided process planning system is designed to eliminate unnecessary errors and increase production efficiency. CAPP is derived from group technology part classification and coding, and involves the use of a computer to organize the operation sequence (route sheet) based on input data relative to workpart and direct the production system from design through final shipping.

The process plan is documented on a route sheet that lists the sequence of work stations and operations required in the manufacture. Process planning systems could be divided

into two groups: variant systems and generative systems. A variant process system is a less complex device - it produces plans by modifying (varying) standard plans already in file. In other words, a process plan for a part is retrieved and then more or less edited. A generative process system makes it possible to automatically create process plans based on the total picture by going through a series of complex operations, unrestricted by standard plans. The process plan is generated without any human intervention.

A CAPP system provides maximum benefits when the process plans in its files have been standardized. To develop standardized process plans, individual part families have to be identified; where part families are distinguished by the sequence of operations required. The coding of the part is then used to identify the standard process plan, the standard routing and operation sequence. Consequently, the CAPP systems are developed and depend upon two prerequisites - some form of parts coding system, and standard process plans for the part families produced by the plant.

The major contributory step of CAPP is the replacement of human memory with machine memory. With a computer-aided process planning system, the planner can use the computer not

only to retrieve existing plans, but also to perform other plans. The computer will generate its own plans using memory, internal computations and decision-making ability. The ultimate system will generate complete process plans without specific aid from human.

The benefits of computer-aided process planning are the following:

1. Increased profit. Some reports have indicated a return on investment of more than 500% and a success rate of better than 80%.⁸
2. Increased productivity of process planners. One system was reported to increase productivity of process planners by 600%.⁹
3. Process standardization. Optimal standardized process plans result in lower manufacturing costs.
4. Reduced clerical time. Using the computer should result in significant reductions in manual clerical work, in part by making possible the use of electronic rather than paper filing systems.

8 HOUTZELL, A., "Computer-Assisted Process Planning Minimizes Design and Manufacturing Costs," *Industrial Engineering*, November, 1981, p. 61.

9 McNEELY, R.A., and MALSTROM, E.M., "Computer Generates Process Routings," *Industrial Engineering*, July, 1977, pp. 32-35.

5. Incorporation of other applications. The CAPP system can be designed in conjunction with work standards packages, cost estimating programs, and other automated systems to support the time-consuming manufacturing functions.

Summary

Group technology, parts coding, and computer-aided process planning are all interrelated. Using group technology and coding and classification, it is possible to capture both design and manufacturing characteristics of each part entering the system. GT is the basic for most computer-aided manufacturing (CAM) systems, and provides key elements to bridge the gap between the design and manufacturing functions. The capability of the GT coding system to serve as the link in an integrated CAD/CAM system is very important since it can develop a system which makes maximum use of the potential benefits of the computer.

In computer-aided process planning area, a process planner can begin by coding random parts to create a GT data base. GT programs can then be used to establish parts families and standard routings. When a new part enters the system,

it is compared to the families produced in the past. If the same or a similar part is in the data file, the standard machine routing and operation sequence are available for use, either as they stand or with editing.

The ultimate aim of group technology is to help improve productivity in manufacturing; lower production costs and increase product quality. The benefits are generally realized in the related areas: product design, tooling and setups, material handling, production and inventory control, and process planning.

Comments

The present manufacturing system of Apollo Valve Company is a typical job shop organization as discussed in Chapter 3. The manufacturing process plans are not standardized, and the work-in-process parts, most of the time, are waiting or being moved around. Also, due to the modern industrial environment, the conventional job shop is turning out to be inefficient, since there is a growing demand to integrate the activities of design and manufacturing. Therefore, the top management of Apollo Valve Company should carefully and seriously consider the adaption of group technology, in order to take

the advantage of modern manufacturing technology and improve overall productivity. This would be the first step toward successful automation of manufacturing system.

Practical considerations in establishing a GT system are outlined as below:

1. Management commitment. One primary necessity in implementing GT is for strong commitment from top management, communicated to everyone in the company, and the assignment of one top-level person to manage the program.
2. Learn the concept. The best place to start GT is to get some early experience by visiting other plants using the technique.
3. Product design. "The product designed with production in mind," is a must for group technology and automation. Design concept should be incorporated along with a part coding system.
4. Part classification and coding. All departments in the firm can benefit from a good parts classification and coding system; consequently, it should be accurate and custom-engineered to suit the company.
Note: This is the most important step for Apollo Valve Company. Since there are approximately

250,000 basic parts drawings in the present manufacturing system, a significant number of parts could be combined or eliminated.

AUTOMATIC ASSEMBLY

"Automatic assembly is a term that refers to the use of mechanized and automated devices to replace manual assembly operations."¹⁰ There are two basic types of automatic assembly: (1) When special devices are used to aid an operator - partially-automatic assembly. (2) When the assembly operation is undertaken without human assistance - fully-automatic assembly.

Assembly operation involves the attachment of parts by the use of standard items or processes such as screws, bolts, rivets, or welding. The labor cost of assembly, particularly in small industries, may well be 60 percent of the total labor cost. In cases where most of the components are supplied by outside manufacturers and the main effort is that of final assembly, the ratio of labor cost to total cost may be

10 Ibid. 1 p. 84.

far higher.¹¹ The present manufacturing system of Apollo Valve Company is exactly the case; 95 percent of the parts or components are supplied by outside vendors, and the principal operation is to assemble the solenoid valves. There is, therefore, every reason to endeavour to reduce this labor cost ratio by introducing the modern technology - automatic assembly, or at least providing some degree of automation.

There are two fundamental categories of automated manufacturing systems:

1. Fixed Automation. The equipment is designed to produce one type of product in high volume, for example: the assembly line of auto industry. The advantage of this arrangement is high rate production and low cost per unit. However, the disadvantage of this type of automated system is lack of flexibility; when the product run is finished, the automated equipment is useless.
2. Programmable Automation. Its principal applications are used in low-to-medium production runs of different parts and jobs. This type of automated system is designed to accommodate changes in

11 THOMAS, H.A., "Automation for Management," Gower Press, London, 1969, p. 114.

product. The numerical control machine for discrete metal parts manufacture is a prime example of programmable automation.

As previously discussed in Chapter 3, there are 32 assembly benches in the present manufacturing system. Each assembly bench is designed to assemble only certain type(s) of solenoid valve(s). These assembly benches are operating as a partially-automatic assembly station and with high labor cost. Therefore, fully-automatic assembly and programmable automation should be utilized for the new manufacturing system.

Industrial Robots

An industrial robot is a general-purpose, programmable machine possessing certain anthropomorphic characteristics. Robots can search, find, transport, grasp, position, assemble, and inspect. The motions a robot makes are taught by a human. Simultaneous movements of the robot system's mechanical elements should be as natural to the robot manipulator as they are for a human's back, shoulders, arms, and hands. The robot workers are stronger, more accurate and more dependable and can be given physical and mental capacities.

Industrial robots have three basic elements: (1) The manipulator is the mechanical unit that does the work; it is often referred to as the arm. (2) The power supply provides the strength. There are three types: hydraulic, electric and pneumatic. (3) The controller is the brain that remembers the tasks, controls the motions, and adapts to limited changes in the robot's environment.

Robot types and classifications: There are a number of ways to classify industrial robots. We will outline the general features as follows:

1. Physical configuration. There are three principal robot configurations as illustrated in Figure 4-1. Spherical coordinate robots have a boom that goes in and out and is raised and lowered through an arc and rotated about the base. Cylindrical coordinate robots have a horizontal shaft that goes in and out and rides up and down on a vertical shaft which rotates about the base unit. The jointed coordinate robot works much like a human shoulder, arm and elbow arrangement, moving along tracks.
2. Degrees of Freedom. There are six basic motions or degrees of freedom in the design of robot. If you put the entire robot on a traversing slide, a

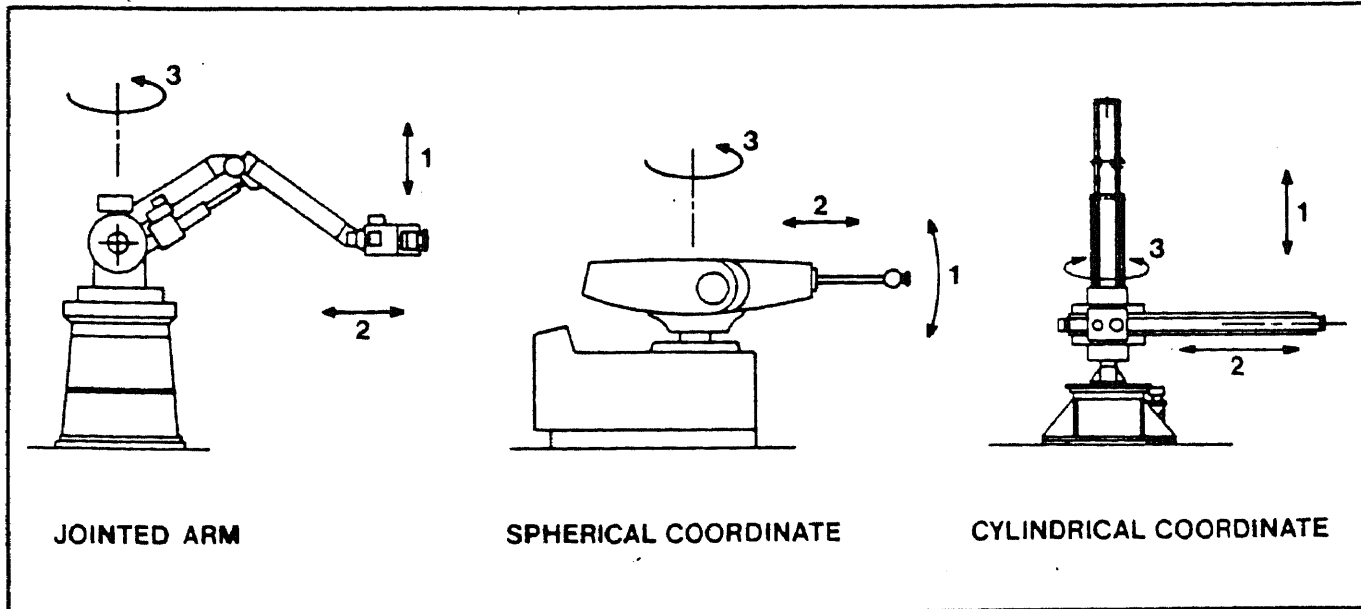


FIGURE 4-1 MAIN AXES OF MOTION

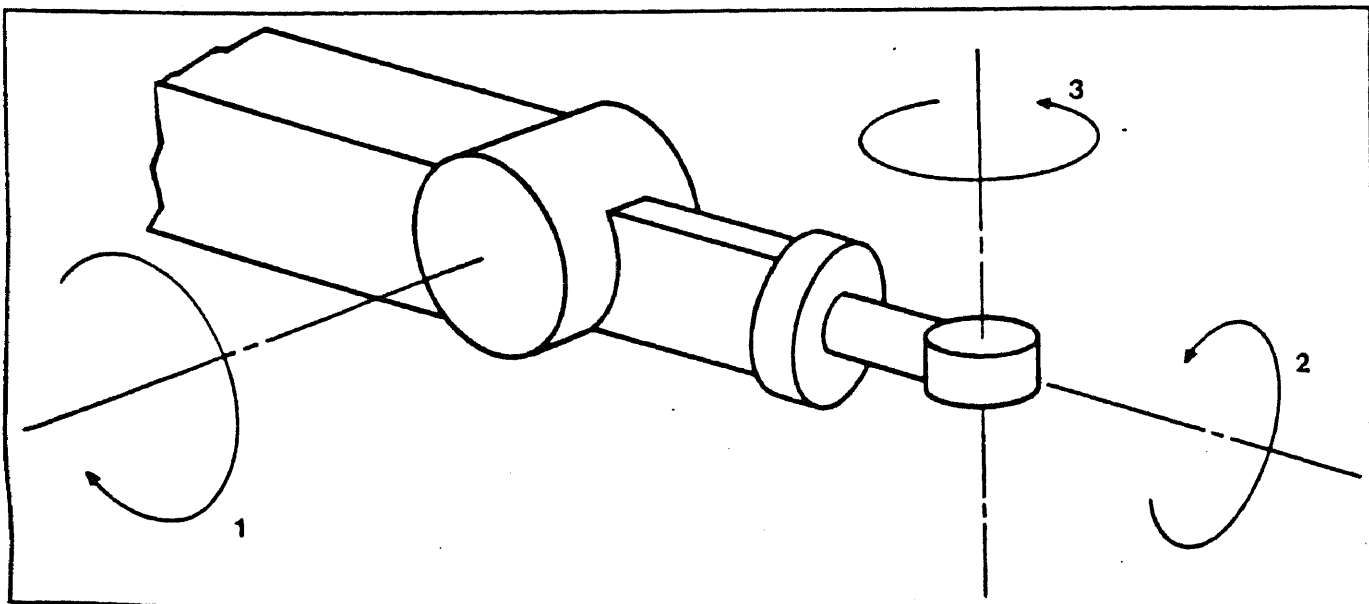


FIGURE 4-2 WRIST AXES OF MOTION

seventh degree of freedom is added.

Arm and body motions:

Vertical traverse - Up and down motion of the arm.

Radial traverse - In and out movement of the arm.

Rotational traverse - Right or left swivel of the robot body.

Wrist motions: Shown on Figure 4-2

Wrist swivel - Rotation of the wrist.

Wrist bend - Up and down movement of the wrist.

Wrist yaw - Right or left swivel of the wrist.

3. Servo versus Non-Servo. A servo robot has valves or actuators that can be controlled to provide gradients of speed and positioning, which greatly increase program capacities. A non-servo robot has directional control valves that are either fully open or fully closed. These provide only a limited number of steps in a program.
4. Point-to-Point versus Continuous Path. Point-to-point robots are taught one point at a time with a teach pendant. When the desired position is achieved then the robot controller will remember that point's position. With continuous path robots, the operator physically moves the robot manipulator through the desired motions to teach it a path

of motion.

5. Programming Methods. There are three principal ways to program a robot, depending on the type of memory system used in the robot:

Manual method. This memory system consists of relay-time sequences or a pinboard matrix or some similar electrical-mechanical devices for simpler robots. The degrees of freedom, typically, in two to four axes of motion.

Walkthrough method. More-complex robots use magnetic tape or discs, or small computers as the memory unit. The programmer 'teaches' the robot by manually moving the arm and hand through the sequence of motions. At each move it records the position in memory for future playback.

Leadthrough method. The programmer power drives the robot through its sequence of motions by a control console. Each position is recorded in the robot's memory.

6. Technology classification.¹²

Low Technology. One or more three-to four-axis manipulator arms on a robot with pick and place

12 BERGER, C., "Selecting Robots for Assembly Operations," Assembly Engineering, May 1982, p. 45.

motions. Non-sensory equipment (mechanical stops, programmable controllers, etc.) makes the control decisions. Few support fixtures are required.

Medium Technology. One or more four-to six-axis manipulator arms on a robot with a minimal sensory feedback. Simple vision, remote center compliance wrists or tactile sensing may be used. Moderately complex support fixtures or equipment for parts presentation are usually required.

High Technology. One or more four-to six-or more axis manipulator arms on a robot with sensory closed-loop adaptive control feedback for parts presentation, inspection or limited decision making capability. Complex parts positioning and orientation support fixtures and equipment may be required.

Industrial robots provide positioning, transfer, and handling functions and are used when maximum flexibility is required in production systems. Robots are insensitive to heat, cold, noise, dust, and fumes. Possibly their greatest value lies in their ability to perform tasks in hazardous working conditions, which are unpleasant, injurious to health, or dangerous.

Proposed Improvement

Consider to utilize the robotic technology for the Assembly Benches B2, B3, B4, and B10 (refer to Table 3-1, Assembly Bench Production Capacity), and develop a systematic approach for identifying possible sites for automation applications within the present manufacturing system.

In surveying possible robotic applications, each of the following criteria has to be satisfied.

1. Appropriate Volume. Volume must be large enough for consideration as robotic application.
2. Repeatable Task. The motions required of the operation must be repetitive. Each part must be presented to the robot in a consistently oriented position and each assembly must exit in the same manner.
3. Design Compatibility. The part, with which the robot assembles or works, must be designed for mechanized handling.
4. Process Compatibility. The work unit must arrive in a known position and parts within the work unit must have known positions. Operations before and after the automated operation must be compatible

with the work flow.

5. Consistency of Work-in-Progress. The incoming parts must be of consistent quality and tolerance so as to prevent jamming in parts presentation mechanisms or the assembly of defective products.
6. Product Life. Any product which is planned to be phased out in the near future should not be considered for robotic application.
7. Mature Design. New products with frequent design changes are not good candidates for automation. However, some changes must take place, otherwise hard automation is better.

Evaluations and comments of the above criteria for Assembly Benches B2, B3, B4, and B10 are discussed as follow. Each of the criteria is evaluated on a YES or NO Basic, i.e., "Satisfies that criterion "or" Fails to satisfy that criterion." Comments are added to each of the criteria for later reference.

1. Appropriate Volume. YES. These assembly benches are producing the same type of solenoid valve, catalog number 262, with production quantity 6,500 valves per week.
2. Repeatable Task. YES. The same assembly pro-

cedure is used. The orientation devices for parts will be presented in later section.

3. Design Compatibility. YES, except the retaining cap and solenoid housing. Redesign of these parts will be discussed later.
4. Process Compatibility. YES. New system will be described later.
5. Consistency of Work-in-Process. YES. All parts are accepted by Quality Control department before assembly operation.
6. Product Life. YES. Catalog number 262 valves will not be phased out in the near future, since they have good performance and high profit.
7. Mature Design. YES. Catalog number 262 valves have been in production over twenty years.

Obviously, by this survey, we can conclude the robotic application for these Assembly Benches is satisfying all the criteria.

Like other fields of technology, robotics has originated some special attributes, therefore the major factors in robot justification are described as follow.

1. Work Envelopes. All the points in space that robot can touch with the mounting plate on the end

of its arm make up its work envelope. Each robot has a distinctive reaching, moving, and carrying capability. Consequently, the type of work envelope can be a significant consideration in the selection of a robot for a given task. Many robots are unable to reach more than six feet.

2. Payload. The amount of weight a robot arm can carry is its payload. The payload includes the weight of the hand (sometimes called an end effector or end-of-arm tool) mounted on its wrist plate. Payload capacity varies based on the articulation and speed of the manipulator. Light high speed assembly robots that can achieve tight tolerances generally cannot lift more than two to five pounds.
3. Axis Estimate. The cost of robots generally increases with the numbers of axes or degrees of freedom. Requirements in an application for several axes of movement to perform certain tasks will lessen the weight load and positioning accuracy of a robot.
4. Tolerances. Accuracy and repeatability usually are dependent upon the weight applied to the arm. Typically, tolerances tighter than ± 0.005 inch are difficult to achieve without guides or fixtures.

5. End Effector. Investigation should be given to precisely how a robot would grasp a part, or tool. In many cases a simple parallel action opposing fingers gripper will suffice.

Summary. Motion and time study for assembly of catalog number 262 solenoid valve is presented on Table 4-3, in which we developed the requirements for reach, speed, and payload. Also we have summarized the robot's attributes on Table 4-4. On comparison, the actual requirement fits the IBM 7565 robot specification closely, hence we select the IBM 7565 robot as having the capacity to meet needed requirements. The proposed set-up for automatic assembly of catalog number 262 valve is shown on Figure 4-5, on which the assembly operations are briefly described.

Note:

1. Solenoid housing and fluxwasher should be redesigned as a whole piece. .
2. Retaining cap should be modified as a one step 'Snap On' installation. .
3. Robot selection analysis should compare price and performance.

Table 4-3. Motion and Time Study for Assembly of
Catalog Number 262 Valve, Manual Method

Steps Used	Name of Motion	Time (.01 sec.) Note: (1)
Reaches for body	Transport empty	90
Grasps body	Grasp	44
Carries body to assembly machine	Transport loaded	111
Positions body on fixture	Position	94
Secures body on fixture	Use	314
Reaches for 'O' ring	Transport empty	142
Grasps 'O' ring	Grasp	88
Carries 'O' ring to body	Transport loaded	143
Positions 'O' ring on body	Position	105
Reaches for core	Transport empty	112
Grasps core	Grasp	51
Carries core to body	Transport loaded	150
Positions core on body	Position	100
Holds core with left hand	Hold	85
Reaches for spring	Transport empty	90
Grasps spring	Grasp	50
Carries spring to core	Transport loaded	95
Positions spring into the core hole	Position	135
Lets go of spring	Release	54
Reaches for solenoid base sub-assembly (S.B.S.A.)	Transport empty	70
Grasps S.B.S.A.	Grasp	32
Carries S.B.S.A. to body	Transport loaded	89
Positions S.B.S.A. on top of spring and core	Position	98
Lets go of core	Release	47
Positions S.B.S.A. on body and aligns	Position	130
Assembles S.B.S.A. on body	Assemble	242

Reaches for buttons	Transport empty	101
Pushes buttons and releases (2)	Use	45
Reaches solenoid assembly	Transport empty	95
Grasps solenoid assembly	Grasp	35
Carries solenoid assembly to valve	Transport loaded	67
Positions solenoid assembly on top of S.B.S.A.	Position	648
Reaches for nameplate	Transport empty	121
Grasps nameplate	Grasp	46
Carries nameplate and puts on top of solenoid assembly	Transport loaded	170
Reaches for cap	Transport empty	103
Grasps cap	Grasp	50
Carries cap and installs on top of nameplate	Transport loaded and assemble	660
Unsecure fixture	Use	241
Reaches for valve	Transport empty	56
Grasps valve	Grasp	60
Carries valve to cart	Transport loaded	<u>154</u>
Total		5413 (54.13 seconds)

NOTE:

- (1) The average time of five measurements.
- (2) Turn on assembly machine to tighten S.B.S.A. for 175 in-lbs. then turn off machine.
- (3) Distance: Within 16 in. of radius.
- (4) Valve Weight: 1.25 lbs.

Table 4-4
Summary of Robot's Attributes

1. The general quantitative attributes of an industrial robot are listed as follow.

Reach

Payload

Axis estimate (degrees of freedom)

Speed

Accuracy

End effectors

Power consumption/type

Weight

Floor space requirement

Memory

Manipulative power

Teaching ease

Interface compatibility

Reliability (function of application)

Sensory perception

Mobility (portability)

Maintainability/self-diagnostics

Cost effectiveness

Inherent safety

2. The major attributes of manual assembly method and the specifications of IBM 7565 robot are summarized as below.

Attribute	Manual Assembly	IBM 7565 Robot
	Note: (1)	
Reach	16 in.	58.8 in. (2)
Payload	(3)	5.0 lbs.
Axes (degrees of freedom)	4	6
Speed	15 in./sec.	40 in./sec.
Accuracy	————	±.005 in.

NOTE:

- (1) The results are developed from motion and time study, refer to Table 4-4.
- (2) Work envelope: X-axis 17.8 in. wide
Y-axis 58.8 in. long
Z-axis 17.6 in. high
- (3) Catalog number 262 valve:
Weight - 1.25 lbs.
Envelope dimension - 1.7 x 2.1 x 3.0 in.
- (4) IBM 7565 Robot provides a two-finger gripper, with a Maximum opening of 3.25 in.

AUTOMATIC TESTING

Computer-aided manufacturing is defined by CAM-I¹³ as:
"The effective utilization of computer technology in the management, control, and operations of the manufacturing facility through either direct or indirect computer interface with the physical and human resources of the company." In this section, we will discuss the utilization of computer technology in conducting test for catalog number 262 solenoid valves.

Test Procedure - Present Manual Method

The test procedure for catalog number 262, normally closed miniature 2-way valve, are outlined as follow:

1. Test medium. Air
2. Test Voltage. 120/60
3. Operational Test. Operate valve ten (10) times at maximum operating pressure 50 P.S.I.. Valve must operate perfectly at test voltage.
4. Coil Test. Energize solenoid and check milliam-

13 CAM-I stands for Computer-Aided Manufacturing-International, a nonprofit firm based in Arlington, Texas.

pere reading. Value should agree with the required range, 220 - 250 milliamperes.

Note: Seat leakage and external leakage test will be conducted by Quality Control Department with sampling method.

Automatic Testing Program - Proposed Method

The proposed automatic testing procedure for catalog number 262 valve are described as follow:

1. Position and secure valve on fixture by a robot.
2. Turn on inlet air pressure, 50 P.S.I..
3. Connect power to coil, 120/60.
4. Energize valve ten (10) times and measure down stream pressure, 30 ± 5 P.S.I..
5. Shut off inlet air pressure.
6. Energize valve and measure milliampere reading, 220 - 250 MA.
7. De-energize valve.
8. Accept or reject tested valve.
9. Disconnect power.
10. Unsecure valve.
- 11.. Remove valve from fixture and put the accepted valve on conveyor to packaging area or the rejected

valve on conveyor to repair area (by a robot).

Note: The Cincinnati Milacron Model T3-726 robot is recommended.

Computer Interface and Sensors

To implement a computerized system for automatic testing of catalog number 262 valve, two categories of data must be considered for interface with the computer. These categories are as follow:

1. Analog-to-Digital Interface. The continuous analog signals must be converted into digital values in order to be used by the computer. These steps involve a variety of hardware devices, however the general process is through transducer, signal conditioning, multiplexer, amplifier, analog-to-digital converter and digital input.
2. Contact Input Interface. This interface consists of relatively simple contacts that can be either opened or closed to indicate the status of valve positions during the test. The computer stores in memory the desired status of these contacts for comparison.

Transducers are often called sensors when they are

used to measure the value of a physical quantity and convert into another type (commonly electrical voltage). Therefore, a pressure sensor (for measuring downstream pressure) and an ammeter are needed as the interface hardware devices for this automatic testing system.

Computer technology is continuously progressing. The latest development in this area is silicon micromechanical devices.¹⁴ The integrated sensor is a silicon chip that includes both a sensor and associated signal-conditioning electronics. The signal from an integrated sensor is less vulnerable to noise and leakage. Integrated sensors also perform better than discrete sensors and have a wider variety of applications. Tiny valves, nozzles, pressure sensors and other mechanical systems can be chemically etched in a wafer of single-crystal silicon. Such devices can be mass-produced much as microelectronic circuits are. Hence, integrated sensors are less expensive than sensors and the necessary electronic components fabricated separately. Consequently, the integrated sensor and better interface hardware will commercially be available in the near future.

14 ANGEL, J.B. and TERRY, S.C., "Silicon Micromechanical Devices," Scientific American, April 1983, p. 44.

Microcomputer Sampling Rate

A microcomputer uses a microprocessor as the basic central processing unit (CPU). The microprocessor consists of single integrated circuits contained on very small silicon bases, which are called LSI (large scale integration) chips. Microprocessor choice greatly affects overall system characteristics, so we will discuss the word length and clock speed in the following paragraphs.

"A microprocessor's bit width is defined as the number of parallel lines contained in the data bus."¹⁵ The word length (bit width) is the number of bits (binary digits) that can be handled by the CPU at one time. The word length determines the amount of data that can be processed in a given time, therefore it has a great effect on system capability and complexity. Computer words can typically be 4, 8, 16, 32, or 64 bits long. The advantage of a microcomputer with a

¹⁵ ARTWICK, B.A., "Microcomputer Interfacing," Prentice-Hall, New Jersey, 1980, p. 38.

wide word-width is having a higher memory bit widths and a larger set of single-word instructions, but the disadvantage is having more parts counts for wider data buses and connectors, on the interfaces tied to the bus. Consequently, it is wise to keep the bit width as low as is reasonably possible in an application.

The automatic testing program for catalog number 262 valve needs pressure and milliamperage measurements. Hence a 16-bit word length is recommended for the testing system.

Microprocessor clock rate is defined as the frequency of the clock input to the microprocessor,¹⁶ the number of clock pulses produced per second. The clock is the governor of all timed operations within a system. The sampling process is illustrated in Figure 4-6.

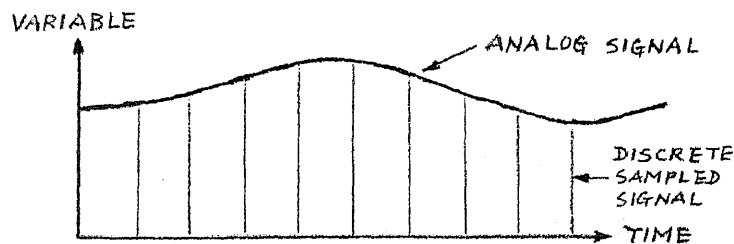


FIGURE 4-6 ANALOG SIGNAL VS.
DISCRETE (SAMPLED) SIGNAL

16 Ibid. 15 p. 40.

Sampling rate is defined as the rate at which the continuous analog signal is sampled. Higher sampling rates mean that the continuous waveform of the analog signal can be more closely approximated. Therefore, a high clock rate should be used for the automatic testing system.

Information Processing

Processing will consist of sorting, merging, file maintenance and reports. The data from automatic testing of catalog number 262 valves will be processed and utilized for the following purposes.

1. Statistical Analysis. All test data will be stored in the main and secondary memory units. Computerized summary of test results will be issued weekly, in which the accepted rate, rejected rate, and defective causes will be analyzed. This statistical data will be forward to management for evaluation.
2. Historical Records. All weekly test data will be stored in a historical file for one year. The accumulated test data will be issued monthly, as a monthly report. At the end of each calendar year, the historical data will be stored in mass memory for future information.

3. Graphics Output. Each test result will be shown on a graphics terminal, from which the quality control inspector or related production person can verify the test data.

Note: The mainframe computer system at Apollo Valve Company is IBM Model 370, large general-purpose computer.

Computer Data Base and Memory

A data base provides for data storage and retrieval in the computer system. A data base management system consists of a software package designed for the creation and maintenance of a data base. Usually, it also provides ways of retrieving information from the data base and for recovering from system failures.

Main memory is located in the computer and is used by the CPU for manipulation of data, storage, and retrieval functions. The memory section consists of binary storage units which are organized into bytes. A byte is a convenient size for the computer to handle, typically 8 bits per byte. Each computer word has an address in memory. The CPU calls words from memory by the word address.

The usual main memory types associated with computers are Random Access Memory (RAM) and Read Only Memory (ROM). We will describe these main memory technologies in the following paragraphs.

RAM allows a user to write into and read from its contents. The peripherals, control processor and programming languages perform the physical operations of reading and writing into the memory. There are two types of RAM; dynamic and static. The dynamic variety is cheaper but involves creating systems and writing programs to continuously rewrite the contents of memory since dynamic RAM will not hold a charge for any length of time. Therefore, the dynamic memory is best suited for large data stores. Static RAM, as its name implies, will hold the contents of memory as long as power is maintained. Static memories are easier to interface because they don't have as many control lines associated with them. For small memory applications, static memory is usually the best choice.

The ROM is a memory type which can only be written into once by a special programming device. This is usually done with microprocessor development system. The ROM is actually of no use until it is programmed, and is considerably more expensive than RAM.

The memory types and functions have already been discussed. The automatic testing program of catalog number 262 valve needs the both types, RAM and ROM memories; RAM for test, analysis, historical and graphics programs and ROM for machine control programs. For historical data, each test will require about 20 bytes memory and all test data will be kept in an active file for one year.

Physical Attributes of Computer

The microcomputer system and its interfaces for automatic testing of catalog number 262 valve is illustrated in Figure 4-7. The physical attributes of the microcomputer system are discussed as follow.

1. Main Memory Requirements (RAM). The automatic testing program was described in the previous section of this chapter, hence we can estimate the required memory for the proposed microcomputer system, based on program complexity and data storage requirements.

The main memory requirements are estimated to be as follows.

- (1) Test program: 12K RAM
- (2) Analysis program: 10K RAM
- (3) Historical records program: 3K RAM

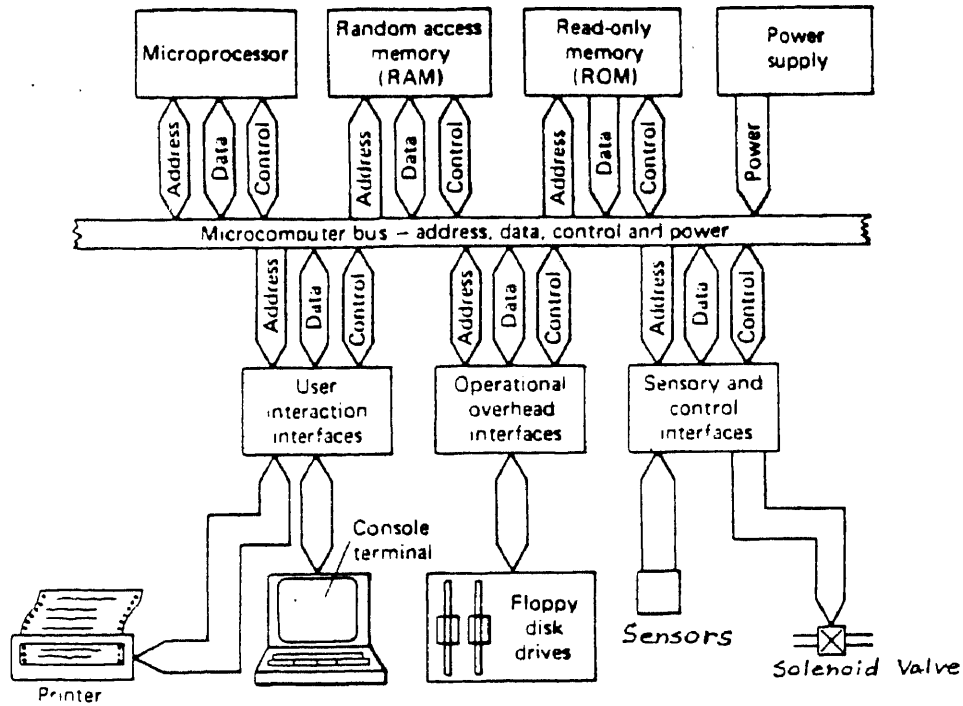


FIGURE 4-7 MICROCOMPUTER SYSTEM
AND ITS INTERFACES FOR
AUTOMATIC TESTING PROGRAM

- (4) Graphics: Memory map 30K RAM
Control program for graphics utilities
1K RAM
- (5) Input and output ports (from sensors): Minimal
(neglectable)

2. Control Programs (ROM). The proposed automatic testing system will automatically conduct the production test, one valve per minute. Therefore, it needs the monitor program to control the testing system (Testing program is not in ROM). The required memory is listing as follows.

- (1) Monitor system or master control program: 2K ROM
- (2) Basic language: 16K ROM
- (3) Disc operating memory system: 16K ROM

Note: The disk operating system and basic language are stored in ROM to prevent the need to reload them in the event of a shop floor power disturbance.

3. Mass Storage. The files from programs and data contained in mass memory (external to the computer) are not directly available to the CPU. The contents of mass memory must be read into the computer (for storage in the main memory) through the input or output section. Hence, the proposed automatic testing system needs the following parts for external storage of data.

- (1) Mass storage disk: 2Mb. For storage of completed test data, 4 bytes per valve, for 325,000 valves a year.
- (2) Video tape: For storage of other data for long term mass storage and system back up.

The proposed automatic testing system requires the minimum memory of 56Kb in RAM and 34Kb in ROM, total 90Kb, therefore a 128Kb machine is recommended..

Summary - Automatic Testing System for Catalog Number 262 Valve.

1. The system contains a simple robot for positioning and removing valves on the test fixture.
2. The microcomputer system includes a 128Kb capacity machine and related interface hardware (a pressure sensor and an ammeter also included).
3. The sampling rate will require, at least a 16-bit micro-computer.
4. The information processing system comprises the statistical analysis, historical records and graphics output of test results.
5. The system will be a completely automated testing system, without any human assistance.

PACKAGING

The packaging section of the present manufacturing system is operating with the manually antiquated method. There are four working benches, four persons in each bench, in the packing area. Each packer picks up a cart, loaded with valves to be packed, and carries to his/her working station. When packing job is done, then the packer pushes the cart to shipping or finished good area. There is a lack of control over work-in-process valves; therefore, most of time, many valves are waiting for packing. Obviously, the improvement of packing method is needed for the new manufacturing system.

In order to reduce the waiting time for packing, the production system flow concept should be considered. A queueing situation is characterized by a flow of customers (e.g. valves) arriving at one or more service facilities (e.g. packing benches). On arrival at the facility the customer may be serviced immediately or may have to wait until the facility is available. The service facilities of the Packaging Section are difficult to schedule optimally because of the presence of randomness in the arrival and service patterns.

Consequently, we introduce a mathematical theory that provides means for analyzing this situation. This queueing (or waiting line) theory, which is based on the arrival and departure (service) patterns by the appropriate probability distributions and then derived by using probability theory. The parameters of the system (such as the service rate) may then be adjusted to ensure a more effective operation.

A multi-server queueing system is shown in Figure 4-8. S parallel servers ($s \geq 1$) are considered so that s customers may be in service simultaneously. It is assumed that all arrivals have the exponential interarrival time and all channels have the same (exponential) service distribution with mean rate μ per unit time. This is the Poisson queues in which arrivals and departures occurs according to Poisson distributions. Also assuming the parameters of the system are such that a steady state solution exists, the steady state solution is then given by:¹⁷

$$P_0 = \left\{ \left(\sum_{n=0}^{s-1} \frac{\rho^n}{n!} \right) + \left[\frac{\rho^s}{s! \left(1 - \frac{\rho}{s} \right)} \right] \right\}^{-1}$$

17 TAHA, H.A., "Operations Research," MacMillan Publishing Co., New York, 1976, p. 469.

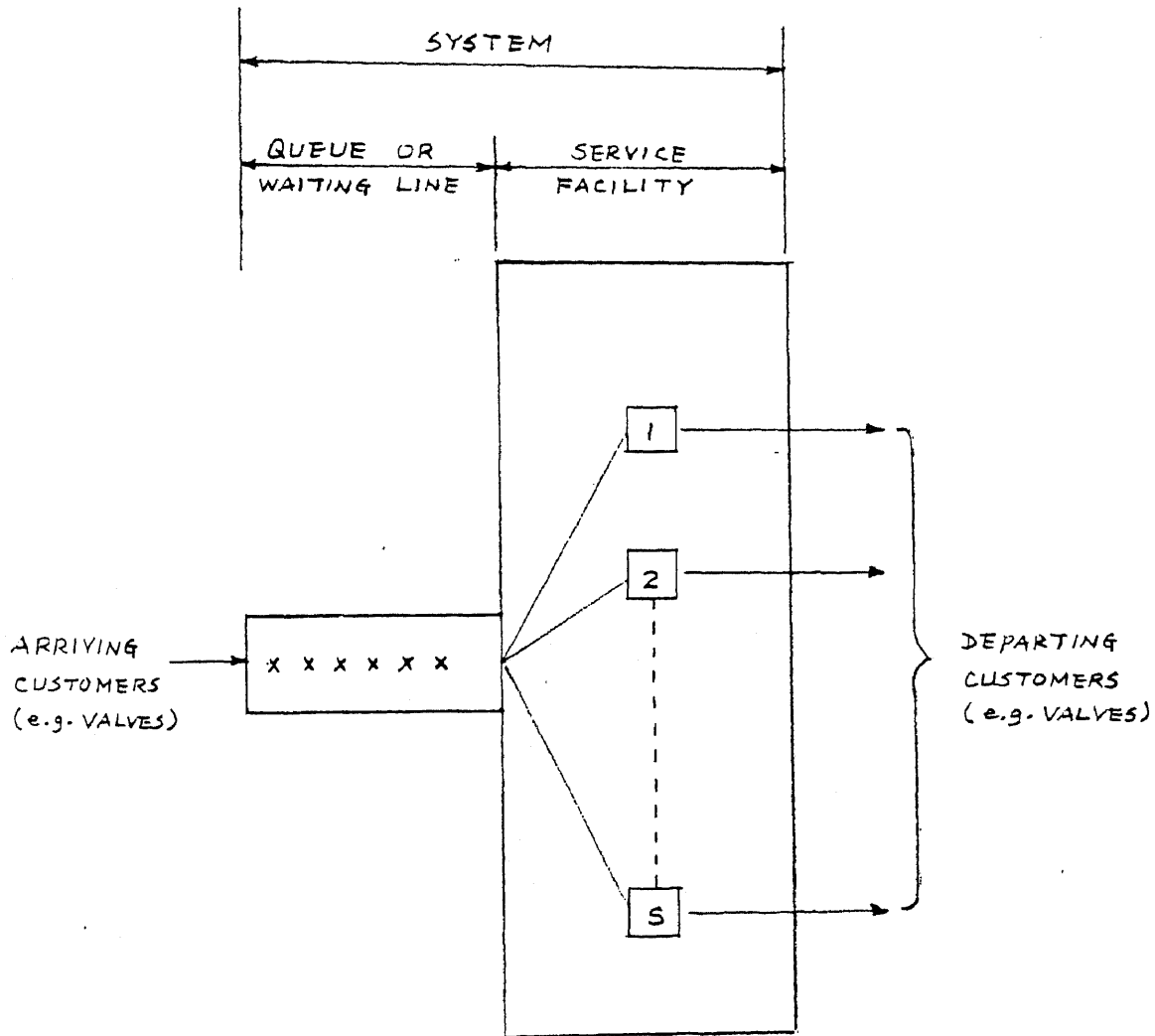


FIGURE 4-8 QUEUEING SYSTEM WITH
S PARALLEL SERVERS (MULTI-SERVER)

$$L_q = \frac{P_0 \rho^{(s+1)}}{s!(1-\rho)^2}$$

$$L_s = L_q + \rho$$

$$W_q = L_q / \lambda$$

$$W_s = W_q + \frac{1}{\mu}$$

Notation:

P_n steady state probabilities of exactly n customers in the system

n number of customers in the system

λ mean arrival rate (number of customers arriving per unit time)

μ mean service rate per busy server (number of customers served per unit time)

s number of parallel servers

ρ traffic intensity = λ/μ

L_q expected number of customer in the queue

L_s expected number of customers in the system

W_q expected waiting time per customer in the queue

W_s expected waiting time per customer in the system

Note: A steady state condition is said to prevail when the

behavior of the queueing system becomes independent of time.¹⁸

The Fortran program, as an example shown in Figure 4-9, demonstrates the application of digital computer for queueing theory. We briefly discuss the program as follows.

1. Assumption:

$L = 0.4$ arrivals per minute (λ , mean arrival rate)

$U = 0.308$ customers served per minute (μ , mean service rate per busy server)

2. This program is designed for multi-channel service, working for any number of channels.

3. Management can analyze the output data, 1 to 10 servers, and make the best decision for the system.

4. When $s = 5$:

$L_q = 0.122$ customers in the queue

$L_s = 1.421$ customers in the system

$W_q = 0.306$ minutes waiting time per customer in the queue

$W_s = 3.552$ minutes waiting time per customer in the system

Because $1/\mu = 3.2468$ minutes per customer, therefore, 5 servers ($s = 5$) will be the best choice.

18 Ibid. 17 p. 455.

FIGURE 4-9 FORTRAN PROGRAM 112

QUEUEING THEORY BY MARVIN WANG

```
1.0000 C
2.0000 C MULTIPLE CHANNELS PROGRAM FOR ANY NUMBER OF CHANNELS
3.0000 C OUTPUT OF THIS PROGRAM,1-10 SERVERS
4.0000 INTEGER S
5.0000 REAL L,LQ,LS
5.5000 DO 77 K=1,10
6.0000 READ,S
7.0000 L=.4
8.0000 U=.308
9.0000 R=L/U
10.0000 N=S-1
11.0000 PRON=1.0
12.0000 PROS=1.0
13.0000 DO 22 J=1,S
14.0000 PROS=PROS*J
15.0000 22 CONTINUE
16.0000 TERM=0.0
17.0000 DO 33 M=1,S
18.0000 IF(M.NE.1) GO TO 44
19.0000 PRON=1.0
20.0000 GO TO 55
21.0000 44 CONTINUE
22.0000 PRON=PRON*(M-1)
23.0000 55 CONTINUE
24.0000 TERM=(R**(M-1)/PRON)+TERM
25.0000 33 CONTINUE
26.0000 PO=1/(TERM+(R**S/(PROS*(1-(R/S)))))
27.0000 WRITE(2,10) S,PO
28.0000 10 FORMAT(' ',S=',I2,6X,'PO=',E14.7)
29.0000 SU=S*U
30.0000 IF(L.GT.SU)GO TO 66
31.0000 LQ=(PO*R**(S+1))/(PROS*(1-R)**2)
32.0000 WRITE(2,20) LQ
33.0000 20 FORMAT(' ',12X,'LQ=',E14.7)
34.0000 LS=LQ+R
35.0000 WRITE(2,30) LS
36.0000 30 FORMAT(' ',12X,'LS=',E14.7)
37.0000 WQ=LQ/L
38.0000 WRITE(2,40) WQ
39.0000 40 FORMAT(' ',12X,'WQ=',E14.7)
40.0000 WS=WQ+(1/U)
41.0000 WRITE(2,50) WS
42.0000 50 FORMAT(' ',12X,'WS=',E14.7)
43.0000 GO TO 77
44.0000 66 WRITE(2,60)
45.0000 60 FORMAT(' ',6X,'INFINITIVE QUEUE DUE TO L'
46.0000 X,' GREATER THAN S*U')
46.5000 77 CONTINUE
47.0000 STOP
48.0000 END
```

```

*1
S= 1      PO=-0.2987003E 00
          INFINITIVE QUEUE DUE TO L GREATER THAN S*U

*2
S= 2      PO= 0.2125988E 00
          LQ= 0.2609674E 01
          LS= 0.3908374E 01
          WQ= 0.6524183E 01
          WS= 0.9770936E 01

*3
S= 3      PO= 0.2641479E 00
          LQ= 0.1403655E 01
          LS= 0.2702355E 01
          WQ= 0.3509137E 01
          WS= 0.6755890E 01

*4
S= 4      PO= 0.2715477E 00
          LQ= 0.4684985E 00
          LS= 0.1767199E 01
          WQ= 0.1171246E 01
          WS= 0.4417998E 01

*5
S= 5      PO= 0.2726878E 00
          LQ= 0.1221987E 00
          LS= 0.1420898E 01
          WQ= 0.3054968E 00
          WS= 0.3552249E 01

*6
S= 6      PO= 0.2728588E 00
          LQ= 0.2646652E-01
          LS= 0.1325167E 01
          WQ= 0.6616628E-01
          WS= 0.3312919E 01

*7
S= 7      PO= 0.2728829E 00
          LQ= 0.4910730E-02
          LS= 0.1303611E 01
          WQ= 0.1227682E-01
          WS= 0.3259029E 01

*8
S= 8      PO= 0.2728860E 00
          LQ= 0.7972049E-03
          LS= 0.1299497E 01
          WQ= 0.1993012E-02
          WS= 0.3248745E 01

*9
S= 9      PO= 0.2728864E 00
          LQ= 0.1150369E-03
          LS= 0.1298815E 01
          WQ= 0.2875922E-03
          WS= 0.3247040E 01

*10
S=10     PO= 0.2728865E 00
          LQ= 0.1493985E-04
          LS= 0.1298715E 01
          WQ= 0.3734962E-04
          WS= 0.3246790E 01

```

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Comment

1. The layout of the packaging section should be changed from benches set-up to production flow set-up (as shown on Figure 4-8), in order to reduce valves handling time and moving distance.
2. The number of servers (packers) should be determined, by utilizing queueing theory, especially for the high volume production valves (e.g. catalog number 262, etc.). The waiting time and work-in-process cost should be minimized. Note: The arrivals and departures should be tested as Poisson distributions.
3. The mathematical equations of queueing theory should be calculated by computer program to facilitate the analysis of data, as shown on Figure 4-9.
4. An automatic packing machine should be considered for packing the small valves with high production volume, such as catalog number 262.

FLEXIBLE MANUFACTURING SYSTEMS

Flexible manufacturing systems (FMS) can be defined as

a group of machines and related equipment brought together to completely process a group of family of parts. "FMS consist of a group of processing stations (usually NC machines) connected together by an automated workpart handling system. It operates as an integrated system under computer control."¹⁹ FMS is a concept of utilizing existing technology in an integrated system of individual reprogrammable stations or cells.

The system components are described as follow:

1. Machine tools. Generally, the FMS concept will be applied to a production environment that can be defined as mid-volume, mid-variety. Therefore, most of the machine tools will feature NC technology and elements of flexibility which allow them to address numerous part types with no changeover.

2. Material handling system. The basic objectives a material handling system must have include: lack of floor obstructions, low cost per unit transport, low cost per foot transport, design flexibility, proven reliability, quietness, expandability and speed. Hence, these characteristics should

19 Ibid. 1 p. 564.

be considered when selecting a material handling equipment for specific system.

3. Computer control system. The supervisory computer control systems for FMS now utilize a series of control systems. Each level of control performs to a limited decision level:

Level 1 This includes programmable controllers and computerized numerical control (CNC) units of machinery; the most basic units of control.

Level 2 The parts flow and process are controlled at this level.

Level 3 Management information, real-time routing, decisions and manpower direction exist at this level.

The FMS will require no machine operators. A group of load/unload area workers and roving tool maintenance personnel will tend the system. The FMS computer system will control the entire production sequences, maximizing work flow and minimizing in-process queue.

In a well run plant, the following benefits of FMS can be realized:

Increased production flexibility related to product design or production volume.

Reduced inventories - queues at each machine are virtually eliminated, work-in-process inventories are confined to the capacity of the system.

Reduced direct and indirect labor costs.

Higher utilization rates for equipment.

Reduction of leadtime.

Reduction in scrap and rework - greater accuracy with reduced set-ups.

Reliable production time.

Reduction in material handling and damage.

Summary. No one flexible manufacturing system design is capable of satisfying all the varying elements in the range of manufacturing problems. Each application must establish its own criteria and objectives.

Some conclusion can be drawn from the operating experience gained from FMS:

The use of computer technology will increase.

Greater automation will occur in systems, including robot load/unload functions, automated tool delivery and tool setting facilities and integrated storage facilities.

The combined technologies of machines, material handling and computers are providing major advancements in productivity.

Comment. As previously discussed in Chapter 3, in the present manufacturing system, some parts are processed by the Machine Shop and some components are assembled by the Machine-Assembly Shop. These finished parts or components are returned to Stock Room then, by the job order, they are delivered to assembly bench for production process. Obviously, this 'reverse' flow operation has increased the inventory, work-in-process and labor costs. Therefore, FMS technology should be utilized for the Machine, and Machine-Assembly Departments in order to improve the productivity. Since the flexible manufacturing systems are expensive; a long term commitment must be stressed. Hence the application of FMS for the proposed manufacturing system should be considered to place in the second phase of implementation.

COST ANALYSIS

The cost of automatic assembly and testing for proposed manufacturing system is analyzed in this section.

Present Manufacturing System

1. Assembly:

Labor: 3.6 minutes/valve

Average wage: \$7.00/hour

Unit cost: \$0.43/valve

Number of workers:

Production quantity: 6500 valves/week

Needed 9.75 workers (10 workers)

2. Testing:

Labor: 2.5 minutes/valve

Average wage: \$7.00/hour

Unit cost: \$0.30/valve

Number of workers:

Production quantity: 6500 valves/week

Needed 6.77 workers (7 workers)

3. Sales:

Cost: Labor \$0.73/valve

Material \$9.00/valve

Sales price: \$30.00/valve

Sales volume: 325,000 valves/year

Proposed Manufacturing System - Based on the following data

1. Automatic Assembly:

Assembly speed: 1 minute/valve
 1440 valves/day
 7200 valves/week (5 days)

Cost: Labor \$7.00/hour (One person for feeding)

Robot machine, new	\$28,500
Installation	\$5,000
Feed and orientation equipment	\$10,000
Power	\$400/year
Maintenance	\$2,000/year

2. Automatic Testing:

Testing speed: 1 minute/valve
 7200 valves/week (5 days)

Cost: Robot machine, new	\$10,000
Microcomputer hardware, new	\$15,000
Installation	\$6,000
Power	\$500/year
Maintenance	\$2,500/year

Table 4-10, Cost Analysis for Automatic Assembly and
Testing of Catalog number 262 Valve.

A. Data of Present Manufacturing System

Labor: \$7.00/hour

Man Hours/year: Assembly = $10 \times 2000 = 20,000$

Testing = $7 \times 2000 = 14,000$

Production Volume: 325,000 Valves/year

B. Investment for Automation

1. Assembly equipment

Robot	\$28,500.00	
Installation	\$5,000.00	
Feed Equipments	\$10,000.00	
Subtotal		\$43,500.00

2. Test Equipment

Hardware	\$15,000.00	
Robot	\$10,000.00	
Installation	\$6,000.00	
Subtotal		<u>\$31,000.00</u>

Total \$74,500.00

C. Manual Assembly and Testing

1. Cost/Valve

Labor: Assembly \$0.43

Test	\$0.30
Material	<u>\$9.00</u>
Total	\$9.73

2. Total Cost/Year

Labor (34,000 hours x \$7.00)	\$238,000.00
Materials (325,000 valves x \$9.00)	<u>\$2,925,000.00</u>
Total	\$3,163,000.00

D. Automatic Assembly and Testing

1. Cost/Valve

Labor: Assembly	\$0.04
Test	\$0.00
Material	<u>\$9.00</u>
Subtotal	\$9.04
Robot-Assembly:	
Power	\$0.01
Maintenance	\$0.01
Assembly Equipment	<u>\$0.01</u>
Subtotal	\$0.03
Robot-Test:	
Power	\$0.01
Maintenance	\$0.01
Test Equipment	<u>\$0.01</u>
Subtotal	<u>\$0.03</u>
Total	\$9.10

2. Total Cost/Year

Labor (one person, 200 hours x \$7.00)	\$14,000.00
Robot (325,000 valves x \$0.06)	\$19,500.00
Materials (325,000 valves x \$9.00)	<u>\$2,925,000.00</u>
Total	\$2,958,500.00

E. Costs Saving

Total-Manual Method	\$3,163,000.00
Total-Automatic Method	<u>\$2,958,500.00</u>
Difference	\$204,500.00

F. Pay Back

Investment	\$74,500.00
Costs Saving	\$204,500.00/year
	\$17,041 /month

Pay back: $\frac{74,500}{17,041} = 4.37$ Months

Conclusion

The total cost saving is \$204,500 per year. And the pay back is less than one year (4.37 months).

The major characteristics and functions of the proposed manufacturing system are summarized as follow.

Pre-automation study. By the analysis of automation possibilities, we obtained the conclusion: to develop a automatic assembly, automatic testing, and packaging system for the valves with highest production volume (e.g. Catalog Number 262).

Group technology (GT) application. GT, as the basis for most CAM systems, provides key elements to bridge the gap between the design and manufacturing functions. Group technology, part coding, and computer-aided process planning (CAPP) are all interrelated. Therefore, the top management of Apollo Valve Company should consider utilizing group technology and taking advantage of modern manufacturing technology to improve overall productivity. This would be the first step toward the successful automation of any new manufacturing system.

Automatic Assembly. According to the evaluation of the criteria of robotic application, we can conclude that the proposed automatic assembly method is satisfying all the criteria. The robot's attributes are also studied. Hence,

the IBM 7565 robot is projected for the new manufacturing system.

Automatic testing. The automatic testing procedures have been developed. The basic elements of microcomputer, such as computer interface, sensor, sampling rate, memory, database, information processing and physical attributes have been studied. Per the analyzed result, a 128K capacity machine and a simple robot are recommended for the automatic testing program. The testing speed is established, one valve per minute, to incorporate the automatic assembly rate.

Packaging. The packing method of the present manufacturing system has been studied. The proposed improvements are (1) The layout of the Packaging Section should be changed to a production flow set-up. (2) The number of packers should be determined by the queueing theory model, and analyzed by a computer programming technique. (3) An automatic packing machine should be utilized for packing the small valves with high production volume.

Flexible Manufacturing Systems (FMS). An FMS is a group of NC machines or other mechanized workstations interconnected by a material handling system, all controlled by

computer. It is an attempt to incorporate the flexibility of NC with the efficiency of automated flow lines. The combined technologies of machines, material handling and computer are providing major advancements in productivity. Therefore, FMS technology should be utilized for the Machine, and Machine-Assembly Departments of the present manufacturing system, to reduce the excessive work-in-process costs. This is the major step toward the integrated manufacturing system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter summarizes the conclusions reached in the foregoing thesis and presents recommendations for applying the proposed manufacturing system.

CONCLUSIONS

The present manufacturing system of Apollo Valve Company was concluded to be subject to improvement or consideration in the following respects.

1. Job shop layout. The present system is a typical job shop set-up. Today in 1983, it has become a less efficient system, in comparison with the integrated manufacturing system.

2. Inventory level. The present system contains 35,000 different types of parts and 25,000 combinations of types of valves. Due to its complexity, the inventory-to-asset ratio is high (30%).

3. Material handling. The production volume is 40,000 \pm 10,000 valves per week. The lot sizes are varied from 20 valves per week to 5000 valves per week. Hence, the material handling operations are complicated and cost is increased.

4. Valve assembly. There are thirty two assembly benches, with 300 assemblers in the present system. Most of the assembly processes are manual; and generally there is a lack of production system concepts and controls. The productivity is consequently low.

5. Valve test. All valves are manually tested. Excessive transport operations are needed between valve assembly benches and packaging section, due to improper system layout. Therefore, most of the time, there are valves, waiting for testing.

6. Packaging and shipping. The packing methods and set-up are antiquated and inefficient. Many valves are idle in the packing area.

7. Work-in-process. Generally, there are many parts and valves delayed in the present system. Work-in-process is improperly controlled.

RECOMMENDATIONS

The following improvements and considerations for the proposed manufacturing system are recommended.

1. Intergrated Manufacturing System. It is no longer a luxury to use computers in automated manufacturing system; it has become a necessity, due to industry competition. Job shop operation has become inefficient. "It is the constant aim and tendancy of every improvement in machinery to supersede human labor altogether." -Dr. Andrew Ure, wrote in 1832.¹ Therefore, the top management of Apollo Valve Company should seriously consider taking advantage of the modern technologies of the integrated manufacturing system, and establish a long term project for an automated factory.

2. Phase I of Automation. It is extremely important that the first automation attempt be successful so that the company feels positive about automation. Consequently, only a simple application will be implemented in this stage.

(1) Application of group technology, part coding, and computer-aided process planning. A minimal investment is needed for training program.

(2) Automatic assembly and testing. This automated

1 LUKE, H.D., 'Automation for Productivity,' John Wiley and Sons, New York, 1972, p. 227.

system will save \$204,500 per year, for catalog number 262 valves.

- (3) Packaging. The layout of Packaging Section should be changed to incorporate the system concept. Utilize the queueing theory to determine the optimal number of packers.

3. Phase II of Automation. The long term and expensive applications will be considered in this stage.

- (1) New development of automated system. The automation feasibilities should be continuously studied for the other types of valves with high production volumes, in order to develop the new automatic assembly and testing systems.
- (2) Material Requirements Planning (MRP). Utilize MRP technology to determine when to order raw materials and parts for assembly of valves, to reduce the inventory level.
- (3) Automatic material handling. Combine the technologies of GT, CAPP, MRP, and material handling, to reduce the excessive material handling cost.
- (4) Flexible Manufacturing Systems (FMS). Utilize the FMS technology to reduce the work-in-

process cost in the Machine, and Machine-Assembly Departments.

4. Phase III-Automated Factory. CAD/CAM has been described as 'the new industrial revolution' and other similar expressions. In the manufacturing industries, complex difficulties are encountered in processing, assembling, testing, and handling a diverse mix of discrete products. The future automated factory assumes that these technical problems can be solved, through the control capabilities of computer. If present trends continue, this computer-integrated automatic factory will be realized by approximately the year 2000.² Therefore, it is again recommended that the top management of Apollo Valve Company consider, study, and adopt the modern technologies of integrated manufacturing systems.

There are a number of factors and reasons that manufacturing executives have difficulties in making decisions for automation. "The important facets of the industrial automation policy must be placed in proper perspective. The chief executive can examine corporate goals and philosophy in terms

² MERCHANT, M.E., "The Inexorable Push for Automated Production," Production Engineering, January, 1977, pp. 44-49.

of the present and the future. He alone can set the course for the future, and he must answer the critical question, 'On the day we open, is our new plant already obsolete?'"³

³ Ibid. 1 p. 5.

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