
UNIT 5 TOOLING FOR CNC MACHINES

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5.1 INTRODUCTION

Cutting tools for CNC machines and their design features, Work holding devices for CNC machines, Automation tool changers are described in this chapter Unit.

Objectives

After studying this unit, you should be able to understand

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- , and
- .

5.2 CUTTING TOOLS FOR CNC MACHINES

Cutting tools are available in three basic material types: high-speed steel, tungsten carbide, and ceramic. High-speed steel is generally used on aluminum and other nonferrous alloys, while tungsten carbide is used on high-silicon aluminums, steels, stainless steels, and exotic metals. Ceramic inserts are used on hard steels and exotic metals. Inserted carbide tooling is becoming the preferred tooling for many CNC applications. For the full utilization of CNC machines it is essential to pay due attention to the selection and usage of tooling, namely tool holders, cutting tools and work holding devices. The tools for CNC machines must be quickly changeable to reduce non-cutting time, preset and reset outside the machine, high degree of interchangeability, increased reliability and high rigidity.

The cutting tools can be classified on the basis of setting up of tool, tool construction and cutting tool material :

On the Basis of Setting up of Cutting Tool

- (a) Preset tools.
- (b) Qualified tools.
- (c) Semi qualified tools.

On the Basis of Cutting Tool Construction

- (a) Solid tools.
- (b) Brazed tools.
- (c) Inserted bit tools.

On the Basis of Cutting Tool Material

- (a) High speed steel (HSS).
- (b) High carbon tool steel (HCS).
- (c) Cast alloy.
- (d) Cemented carbide.
- (e) Ceramics.
- (f) Boraon Nitride.
- (g) Diamond.
- (h) Sialon.

5.2.1 Preset Tools

The setting of tools in advance at a place away from the machine tool or offline, in special holders is known as preset tools. A presetting device is used to preset axial and radial positions of the tool tip on the tool holder. Once this is done, the tool holder is ready to be mounted on the machine and produce a known dimension. Presetting devices to various levels of sophistication are available like optical projector. Tool length and tool diameter compensation facilities available in the present day CNC machines have brought down the importance of presetting. Since the generation of actual geometry is taken care of by the CNC part program, which is essentially the coordinates through which the cutting tool tip moves, it is important to know the actual dimensions of the tool when it is placed in the spindle. The relationship of the tool with reference to the tool holding mechanism requires a special attention during CNC machining process. The actual point to be programmed in a CNC part program is the tip of the tool whereas the axes will be moving with respect to a known point in the spindle, e.g. the centre of the spindle in case of machining centres. It becomes therefore necessary to know precisely the deviation of the tool tip from the gauge point on the spindle.

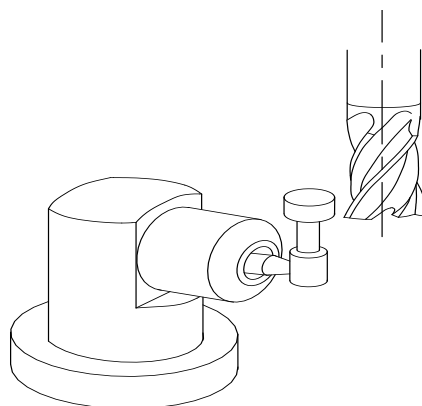


Figure 5.1 : Tool Offset Determination in CNC Machines

5.2.2 Qualified Tools

Tool which fits into a location on the machine, where its cutting edge is accurately positioned within close limits relative to a specified datum on the tool holder or slide, is known as qualified tool. The cutting tools satisfy the following requirements :

- (a) Tools need not be measured individually.
- (b) No presetting device is used.
- (c) The dimensions of the tool holder which are fixed and known.
- (d) Set up time is reduced.
- (e) Control dimensions of the tool are nominal and fixed.
- (f) Higher control on resharpening e.g. drills, reamers.
- (g) Cutter for better size control e.g. end mills, reamers.
- (h) Chip breaking facilities incorporated in tool.
- (i) Improved designs.

The qualified tool with holder shown in Figure 5.1



Figure 5.2 : Qualified Tooling for CNC Machines

5.2.3 Semi-qualified Tools

The qualified tools which can be adjusted to the dimensions by using several adjustable buttons on the tool shank are known as semi qualified tools. These tools demand regular maintenance and calibration for accurate dimensioning.

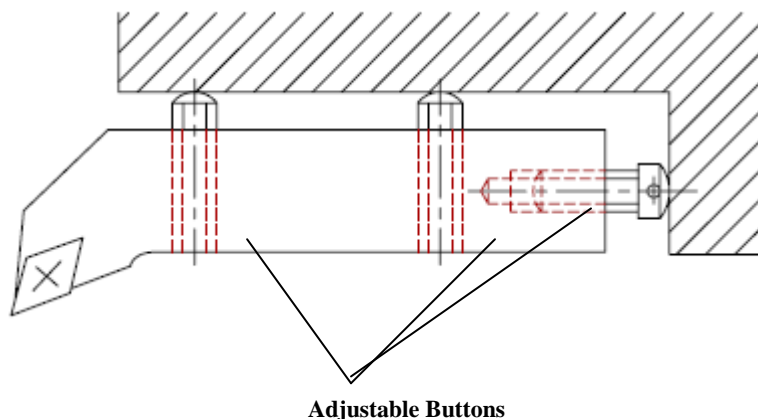


Figure 5.3 : Semi-qualified Tooling for CNC Machines

5.2.4 Solid Tools

Solid tools are usually made of High speed steel or High carbon steel. These tools are used on high speeds with sufficient quantity of cutting fluid to get good surface finish and longer tool life.



Figure 5.4 : Solid Tool

5.2.5 Brazed Tools

A forged shank of high strength steel with belt of high speed steel, tungsten carbide or cermet brazed to the shank on the cutting edge.

5.2.6 Inserted Bit Tools

The tools with indexable inserts of harder and special grade carbide or ceramic materials. A wear resistant layer of Titanium nitride or Titanium carbide is coated on the insert it reduces the cost of tool. Inserts can be easily removed from the tool holder. So tool changing time and cost of machining are less.

5.2.7 High Speed Steel

The H.S.S. is carbon steel to which alloying elements like tungsten, chromium, vanadium, cobalt and molybdenum to be added to increase their hardness and wear resistance.

5.2.8 High Carbon Tool Steel

High carbon tool steel is suitable for low cutting speeds and low temperatures. The hardness of this tool is determined by the carbon contents.

5.2.9 Cast Alloy

This is a non ferrous alloy and gives high machining performance than that of H.S.Steel. Its hardness and toughness are high at higher temperatures.

5.2.10 Cemented Carbides

It contains 5% carbon, 13% cobalt and 81% tungsten. This tool is widely used in modern costly machines as tip tools. The tool setting time is reduced.

5.2.11 Ceramics

It can be used for higher cutting speed, superior surface finish and greater machining flexibility. The Aluminium oxides, boron carbides, silicon carbide, titanium borides and titanium carbides are known as ceramics.

5.2.12 Boron Nitride

- (a) High wear resistance.
- (b) Used for machining hardened steel and high temperature alloys.

5.2.13 Diamond

- (a) Low friction and high wear resistance.
- (b) Good cutting edge.
- (c) Single crystal diamond is used to machine copper to a high surface finish.

5.2.14 Sialon

Used for machining aerospace alloys.

5.3 DESIGN FEATURES OF CNC TOOLING

In general the following points are to be considered while designing of CNC tooling :

- (a) To give High accuracy.
- (b) For variety of operations.
- (c) Interchangeability to produce same accuracy.
- (d) Flexibility.
- (e) Rigidity of tooling to withstand cutting forces.
- (f) Rigidity to transmit the power at higher speeds.
- (g) Quick changing of tools to keep the down time minimum.

5.4 WORK HOLDING DEVICES FOR CNC MACHINES

In the CNC machines, fixtures are still required to locate and hold the work pieces while machining. The work holding devices should have the following uniqueness :

- (a) Work holding devices must have required accuracy and must have matching reference surfaces with the reference system.
- (b) Work holding devices are allowed to perform a number of operations on different faces in a single setting.
- (c) Work holding devices must enable quick loading and unloading.
- (d) Work holding devices must be fool-proofing to avoid incorrect loading of the job.
- (e) Work holding devices must be sufficient rigidity to fully withstand the cutting forces.
- (f) Work holding devices must be safe in use and loading and unloading.
- (g) Work holding devices must have a sufficient of clamping force for use of full roughing cuts.
- (h) Work holding devices must be simple in construction maximum as possible.

Automatic pallet change over systems are used in modern CNC machines. These pallets simply move for interchanging their positions on the machine table. While machining is being done on a job kept on one pallet, the other pallets are accessible to the operator for clamping and unclamping raw material or finished product. This saves a lot of material handling and set up time, resulting in higher productivity.



Figure 5.5 : Automatic Pallet Changer

5.5 AUTOMATIC TOOL CHANGER

The CNC machines are designed to perform a number of operations in a single setting of the job. A number of tools may be required for making a complex part. In a manual machine, the tools are changed manually whenever required. In a CNC machine, tools are changed through program instructions. The tools are fitted in a tool magazine or drum. When a tool needs to be changed, the drum rotates to an empty position, approaches the old tool and pulls it. Then it again rotates to position the new tool, fits it and then retracts. This is a typical tool changing sequence of an automatic tool changer (ATC).

The concept of the ATC is that the range of tools for a specific job shall be made available for automatic selection and positioning. ATC can be

Drum Type

For holding small number of tools usually not more than 30, Stored on periphery of drum and tool search speed is faster.

Chain Type

For more number of tools (40 or more), tools search speed is less.



Figure 5.6 : Drum Type Automatic Tool Changer (ATC)

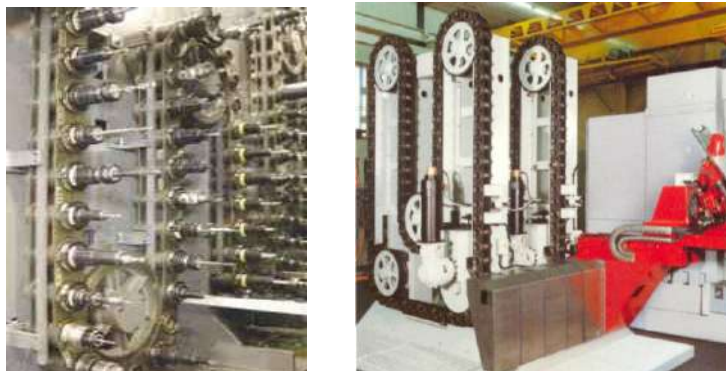


Figure 5.7 : Chain Type Automatic Tool Changer (ATC)

As soon as the tool selection command is received by the system, the selected tool comes to a fixed place known as tool change position. The selected tool is transferred to the spindle from magazine after the previous tool is transferred to the magazine from spindle. This is called tool change cycle.

5.5.1 Automatic Tool Changer Advantages

- (a) Lines changed in seconds instead of hours.
- (b) Increase operator safety by changing tools automatically.
- (c) Change tools in seconds for maintenance and repair.
- (d) Increase flexibility.
- (e) Heavy and large multi-tools that are automatically exchanged.

5.6 SUMMARY

5.7 ANSWERS TO SAQs

Refer the preceding text for all the Answers to SAQs.

FURTHER READING

G. E. Thyer (1988), *Computer Numerical Control of Machine Tools*, Heinemann Professional Publishing.

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CNC MACHINES

The design and construction of Computer Numerically Controlled (CNC) machines differs greatly from that of conventional machine tools. A CNC is specifically defined as “The numerical control system where a dedicated, stored program computer is used to perform some or all of the basic numerical control functions in accordance with control programs stored in read and write memory of the computer” by Electronic Industries Association (EIA).

In this course describes about the Introduction of CNC machines, advantages of NC machines, types of NC systems, controlled axes, basic components of NC machines, problems with conventional NC and principle of NC machines. It also covers the classification based on feedback controlling and classification based on control system features. It also explains the CNC machines, DNC machines, advantages and disadvantages of CNC machines, parts suitable for CNC machines, environmental control of CNC machines, types of part programming, computer aided part programming, part programming manual, part programme using sub routines, do loops and fixed cycles. Also, discusses the cutting tools for CNC machines and their design features, work holding devices for CNC machines, automation tool changers.

UNIT -1

COMPUTER INTEGRATED MANUFACTURING SYSTEMS

1. INTRODUCTION

Computer Integrated Manufacturing (CIM) encompasses the entire range of product development and manufacturing activities with all the functions being carried out with the help of dedicated software packages. The data required for various functions are passed from one application software to another in a seamless manner. For example, the product data is created during design. This data has to be transferred from the modeling software to manufacturing software without any loss of data. CIM uses a common database wherever feasible and communication technologies to integrate design, manufacturing and associated business functions that combine the automated segments of a factory or a manufacturing facility. CIM reduces the human component of manufacturing and thereby relieves the process of its slow, expensive and error-prone component. CIM stands for a holistic and methodological approach to the activities of the manufacturing enterprise in order to achieve vast improvement in its performance.

This methodological approach is applied to all activities from the design of the product to customer support in an integrated way, using various methods, means and techniques in order to achieve production improvement, cost reduction, fulfillment of scheduled delivery dates, quality improvement and total flexibility in the manufacturing system. CIM requires all those associated with a company to involve totally in the process of product development and manufacture. In such a holistic approach, economic, social and human aspects have the same importance as technical aspects. CIM also encompasses the whole lot of enabling technologies including total quality management, business process reengineering, concurrent engineering, workflow automation, enterprise resource planning and flexible manufacturing.

The challenge before the manufacturing engineers is illustrated in Fig. 1

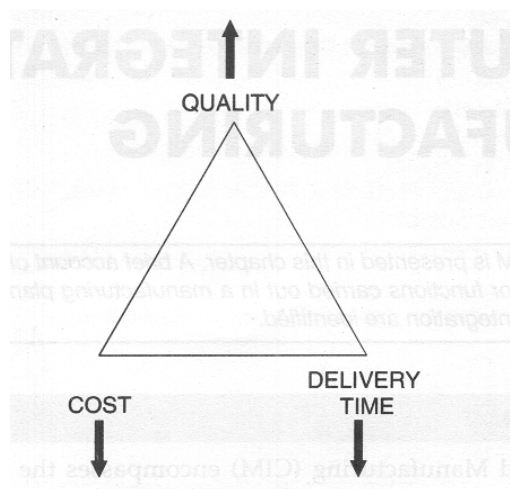


Figure 1 Challenges in manufacturing

Manufacturing industries strive to reduce the cost of the product continuously to remain competitive in the face of global competition. In addition, there is the need to improve the quality and performance levels on a continuing basis. Another important requirement is on time delivery. In the context of global outsourcing and long supply chains cutting across several international borders, the task of continuously reducing delivery times is really an arduous task. CIM has several software tools to address the above needs.

Manufacturing engineers are required to achieve the following objectives to be competitive in a global context.

- Reduction in inventory
- Lower the cost of the product
- Reduce waste
- Improve quality
- Increase flexibility in manufacturing to achieve immediate and rapid response to:
 - Product changes
 - Production changes
 - Process change
 - Equipment change
 - Change of personnel

CIM technology is an enabling technology to meet the above challenges to the manufacturing.

2. EVOLUTION OF COMPUTER INTEGRATED MANUFACTURING

Computer Integrated Manufacturing (CIM) is considered a natural evolution of the technology of CAD/CAM which by itself evolved by the integration of CAD and CAM. Massachusetts Institute of Technology (MIT, USA) is credited with pioneering the development in both CAD and CAM. The need to meet the design and manufacturing requirements of aerospace industries after the Second World War necessitated the development these technologies. The manufacturing technology available during late 40's and early 50's could not meet the design and manufacturing challenges arising out of the need to develop sophisticated aircraft and satellite launch vehicles. This prompted the US Air Force to approach MIT to develop suitable control systems, drives and programming techniques for machine tools using electronic control.

The first major innovation in machine control is the Numerical Control (NC), demonstrated at MIT in 1952. Early Numerical Control Systems were all basically hardwired systems, since these were built with discrete systems or with later first generation integrated chips. Early NC machines used paper tape as an input medium. Every NC machine was fitted with a tape reader to read paper tape and transfer the program to the memory of the machine tool block by block. Mainframe computers were used to control a group of NC machines by mid 60's. This arrangement was then called Direct Numerical Control (DNC) as the computer bypassed the tape reader to transfer the program data to the machine controller. By late 60's mini computers were being commonly used to control NC machines. At this stage NC became truly soft wired with the facilities of mass program storage, offline editing and software logic control and processing. This development is called Computer Numerical Control (CNC). Since 70's, numerical controllers are being designed around microprocessors, resulting in compact CNC systems. A further development to this technology is the distributed numerical control (also called DNC) in which processing of NC program is carried out in different computers operating at different hierarchical levels - typically from mainframe host computers to plant computers to the machine controller. Today the CNC systems are built around powerful 32 bit and 64 bit microprocessors. PC based systems are also becoming increasingly popular.

Manufacturing engineers also started using computers for such tasks like inventory control, demand forecasting, production planning and control etc. CNC technology was adapted in the development of co-ordinate measuring machine's (CMMs) which automated inspection. Robots were introduced to automate several tasks like machine loading, materials handling, welding, painting and assembly. All these developments led to the evolution of flexible manufacturing cells and flexible manufacturing systems in late 70's.

Evolution of Computer Aided Design (CAD), on the other hand was to cater to the geometric modeling needs of automobile and aeronautical industries. The developments in computers, design workstations, graphic cards, display devices and graphic input and output devices during the last ten years have been phenomenal. This coupled with the development of operating system with graphic user interfaces and powerful interactive (user friendly) software packages for modeling, drafting, analysis and optimization provides the necessary tools to automate the design process.

CAD in fact owes its development to the APT language project at MIT in early 50's. Several clones of APT were introduced in 80's to automatically develop NC codes from the geometric model of the component. Now, one can model, draft, analyze, simulate, modify, optimize and create the NC code to manufacture a component and simulate the machining operation sitting at a computer workstation.

If we review the manufacturing scenario during 80's we will find that the manufacturing is characterized by a few islands of automation. In the case of design, the task is well automated. In the case of manufacture, CNC machines, DNC systems, FMC, FMS etc provide tightly controlled automation systems. Similarly computer control has been implemented in several areas like manufacturing resource planning, accounting, sales, marketing and purchase. Yet the full potential of computerization could not be obtained

unless all the segments of manufacturing are integrated, permitting the transfer of data across various functional modules. This realization led to the concept of computer integrated manufacturing. Thus the implementation of CIM required the development of whole lot of computer technologies related to hardware and software.

3. CIM HARDWARE AND CIM SOFTWARE

CIM Hardware comprises the following:

- i. Manufacturing equipment such as CNC machines or computerized work centers, robotic work cells, DNC/FMS systems, work handling and tool handling devices, storage devices, sensors, shop floor data collection devices, inspection machines etc.
- ii. Computers, controllers, CAD/CAM systems, workstations / terminals, data entry terminals, bar code readers, RFID tags, printers, plotters and other peripheral devices, modems, cables, connectors etc.,

CIM software comprises computer programmes to carry out the following functions:

- Management Information System
- Sales
- Marketing
- Finance
- Database Management
- Modeling and Design
- Analysis
- Simulation
- Communications
- Monitoring
- Production Control
- Manufacturing Area Control
- Job Tracking
- Inventory Control
- Shop Floor Data Collection
- Order Entry
- Materials Handling
- Device Drivers
- Process Planning
- Manufacturing Facilities Planning
- Work Flow Automation
- Business Process Engineering
- Network Management
- Quality Management

4. NATURE AND ROLE OF THE ELEMENTS OF CIM SYSTEM

Nine major elements of a CIM system are in Figure 2 they are,

- Marketing
- Product Design
- Planning
- Purchase
- Manufacturing Engineering
- Factory Automation Hardware
- Warehousing
- Logistics and Supply Chain Management
- Finance
- Information Management



Figure 2 Major elements of CIM systems

- Marketing:** The need for a product is identified by the marketing division. The specifications of the product, the projection of manufacturing quantities and the strategy for marketing the product are also decided by the marketing department. Marketing also works out the manufacturing costs to assess the economic viability of the product.
- Product Design:** The design department of the company establishes the initial database for production of a proposed product. In a CIM system this is accomplished through activities such as geometric modeling and computer aided design while considering the product requirements and concepts generated by the creativity of the design engineer. Configuration management is an important activity in many designs. Complex designs

are usually carried out by several teams working simultaneously, located often in different parts of the world. The design process is constrained by the costs that will be incurred in actual production and by the capabilities of the available production equipment and processes. The design process creates the database required to manufacture the part.

- iii. **Planning:** The planning department takes the database established by the design department and enriches it with production data and information to produce a plan for the production of the product. Planning involves several subsystems dealing with materials, facility, process, tools, manpower, capacity, scheduling, outsourcing, assembly, inspection, logistics etc. In a CIM system, this planning process should be constrained by the production costs and by the production equipment and process capability, in order to generate an optimized plan.
- iv. **Purchase:** The purchase departments is responsible for placing the purchase orders and follow up, ensure quality in the production process of the vendor, receive the items, arrange for inspection and supply the items to the stores or arrange timely delivery depending on the production schedule for eventual supply to manufacture and assembly.
- v. **Manufacturing Engineering:** Manufacturing Engineering is the activity of carrying out the production of the product, involving further enrichment of the database with performance data and information about the production equipment and processes. In CIM, this requires activities like CNC programming, simulation and computer aided scheduling of the production activity. This should include online dynamic scheduling and control based on the real time performance of the equipment and processes to assure continuous production activity. Often, the need to meet fluctuating market demand requires the manufacturing system flexible and agile.
- vi. **Factory Automation Hardware:** Factory automation equipment further enriches the database with equipment and process data, resident either in the operator or the equipment to carry out the production process. In CIM system this consists of computer controlled process machinery such as CNC machine tools, flexible manufacturing systems (FMS), Computer controlled robots, material handling systems, computer controlled assembly systems, flexibly automated inspection systems and so on.
- vii. **Warehousing:** Warehousing is the function involving storage and retrieval of raw materials, components, finished goods as well as shipment of items. In today's complex outsourcing scenario and the need for just-in-time supply of components and subsystems, logistics and supply chain management assume great importance.
- viii. **Finance:** Finance deals with the resources pertaining to money. Planning of investment, working capital, and cash flow control, realization of receipts, accounting and allocation of funds are the major tasks of the finance departments.

ix. Information Management: Information Management is perhaps one of the crucial tasks in CIM. This involves master production scheduling, database management, communication, manufacturing systems integration and management information systems.

Definition of CIM

Joel Goldhar, Dean, Illinois Institute of Technology gives CIM as a computer system in which the peripherals are robots, machine tools and other processing equipment.

Dan Appleton, President, DACOM, Inc. defines CIM is a management philosophy, not a turnkey product.

Jack Conaway, CIM Marketing manager, DEC, defines CIM is nothing but a data management and networking problem.

The computer and automated systems association of the society of Manufacturing Engineers (CASA/SEM) defines CIM is the integration of total manufacturing enterprise by using integrated systems and data communication coupled with new managerial philosophies that improve organizational and personnel efficiency.

CIM is recognized as Islands of Automation. They are

1. CAD/CAM/CAE/GT
2. Manufacturing Planning and Control.
3. Factory Automation
4. General Business Management

CASA/SME's CIM Wheel is as shown in figure 4

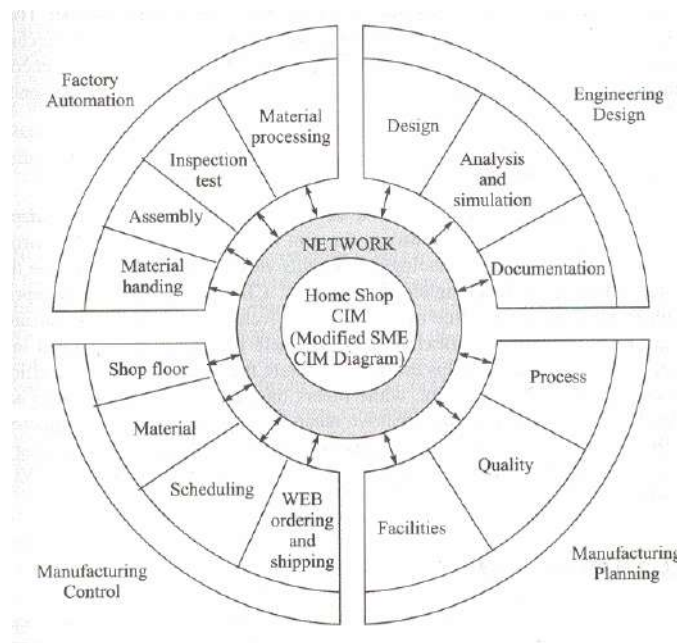


Figure 4 CASA/SME's CIM Wheel

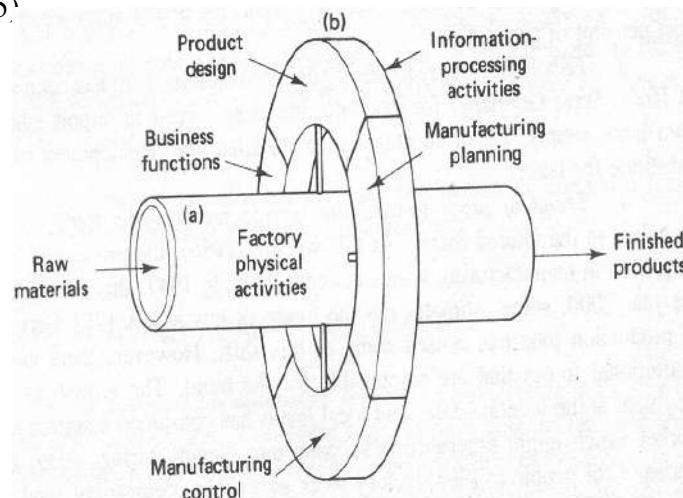
Conceptual model of manufacturing

The computer has had and continues to have a dramatic impact on the development of production automation technologies. Nearly all modern production systems are implemented today using computer systems. The term computer integrated manufacturing (CIM) has been coined to denote the pervasive use of computers to design the products, plan the production, control the operations, and perform the various business related functions needed in a manufacturing firm. *CAD/CAM* (computer-aided design and computer-aided manufacturing) is another term that is used almost synonymously with CIM.

Let us attempt to define the relationship between automation and CIM by developing a conceptual model of manufacturing. In a manufacturing firm, the physical activities related to production that take place in the factory can be distinguished from the information-processing activities, such as product design and production planning, that usually occur in an office environment. The physical activities include all of the manufacturing processing, assembly, material handling, and inspections that are performed on the product. These operations come in direct contact with the product during manufacture. They touch the product. The relationship between the physical activities and the information-processing activities in our model is depicted in Figure 5. Raw materials flow in one end of the factory and finished products flow out the other end. The physical activities (processing, handling, etc.) take place inside the factory. The information-processing functions form a ring that surrounds the factory, providing the data and knowledge required to produce the product successfully. These information-processing functions include (1) certain business activities (e.g., marketing and sales, order entry, customer billing, etc.), (2) product design, (3) manufacturing planning, and (4) manufacturing control. These four functions form a cycle of events that must accompany the physical production activities but which do not directly touch the product.

Now consider the difference between automation and CIM. Automation is concerned with the physical activities in manufacturing. Automated production systems are designed to accomplish the processing, assembly, material handling, and inspecting activities with little or no human participation. By comparison, computer integrated manufacturing is

(figure 5)



In the figure 5 Model of manufacturing, showing (a) the factory as a processing pipeline where the physical manufacturing activities are performed, and (b) the information-processing activities that support manufacturing as a ring that surrounds the factory concerned more with the information-processing functions that are required to support the production operations. CIM involves the use of computer systems to perform the four types of information-processing functions. Just as automation deals with the physical activities, CIM deals with automating the information-processing activities in manufacturing.

AUTOMATION DEFINED

Automation is a technology concerned with the application of mechanical, electronic, and computer-based systems to operate and control production. This technology includes:

- ☞ Automatic machine tools to process parts
- ☞ Automatic assembly machines
- ☞ Industrial robots
- ☞ Automatic material handling and storage systems
- ☞ Automatic inspection systems for quality control
- ☞ Feedback control and computer process control
- ☞ Computer systems for planning, data collection, and decision making to support manufacturing activities

TYPES OF AUTOMATION

Automated production systems are classified into three basic types:

1. Fixed automation
2. Programmable automation
3. Flexible automation

Fixed automation

Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration. The operations in the sequence are usually simple. It is the integration and coordination of many such operations into one piece of equipment that makes the system complex. The typical features of fixed automation are:

- ☞ High initial investment for custom-engineered equipment
- ☞ High production rates
- ☞ Relatively inflexible in accommodating product changes

The economic justification for fixed automation is found in products with very high demand rates and volumes. The high initial cost of the equipment can be spread over a very large number of units, thus making the unit cost attractive compared to alternative methods of production.

Programmable automation

In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations. The operation sequence is controlled by a program, which is a set of instructions coded so that the system can read and interpret them. New programs can be prepared and entered into the equipment to produce new products. Some of the features that characterize programmable automation include:

- ☞ High investment in general-purpose equipment
- ☞ Low production rates relative to fixed automation
- ☞ Flexibility to deal with changes in product configuration
- ☞ Most suitable for batch production

Automated production systems that are programmable are used in low and medium-volume production. The parts or products are typically made in batches. To produce each new batch of a different product, the system must be reprogrammed with the set of machine instructions that correspond to the new product. The physical setup of the machine must also be changed over: Tools must be loaded, fixtures must be attached to the machine table, and the required machine settings must be entered. This changeover procedure takes time. Consequently, the typical cycle for a given product includes a period during which the setup and reprogramming takes place, followed by a period in which the batch is produced.

Flexible automation

Flexible automation is an extension of programmable automation. The concept of flexible automation has developed only over the last 15 to 20 years, and the principles are still evolving. A flexible automated system is one that is capable of producing a variety of products (or parts) with virtually no time lost for changeovers from one product to the next. There is no production time lost while reprogramming the system and altering the physical setup (tooling, fixtures and machine settings). Consequently, the system can produce various combinations and schedules of products, instead of requiring that they be made in separate batches.

The features of flexible automation can be summarized as follows:

- ☞ High investment for a custom-engineered system
- ☞ Continuous production of variable mixtures of products
- ☞ Medium production rates
- ☞ Flexibility to deal with product design variations

The essential features that distinguish flexible automation from programmable automation are (1) the capacity to change part programs with no lost production time, and (2) the capability to change over the physical setup, again with no lost production time. These features allow the automated production system to continue production without the downtime between batches that is characteristic of programmable automation. Changing the part programs is generally accomplished by preparing the programs off-line on a computer system and electronically transmitting the programs to the automated production system. Therefore, the time required to do the programming for the next job does not interrupt production on the current job. Advances in computer systems technology are largely responsible for this programming capability in flexible automation. Changing the physical setup between parts is accomplished by making the changeover off-line and then moving it into place simultaneously as the next part comes into position for processing. The use of pallet fixtures that hold the parts and transfer into position at the workplace is one way of implementing this approach. For these approaches to be successful, the variety of parts that can be made on a flexible automated production system is usually more limited than a system controlled by programmable automation.

The relative positions of the three types of automation for different production volumes and product varieties are depicted in Figure 5

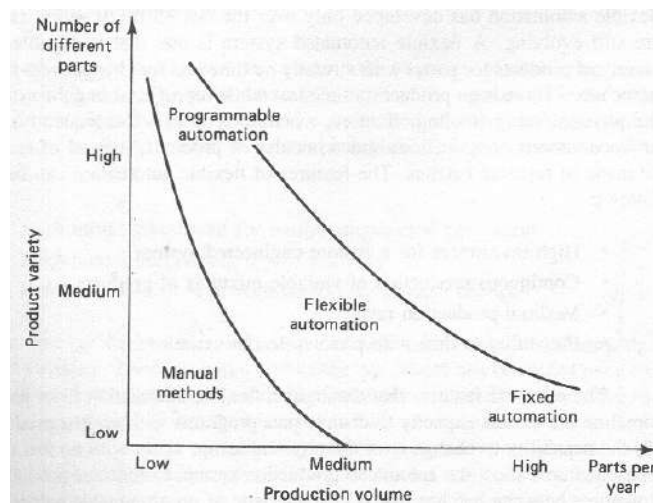


Figure 5 Three types of production automation as a function of volume of production verses product variety

REASONS FOR AUTOMATING

The important reasons for automating include the following:

1. ***Increased productivity:*** Automation of manufacturing operations holds the promise of increasing the productivity of labor. This means greater output per hour of labor input. Higher production rates (output per hour) are achieved with automation than with the corresponding manual operations.
2. ***High cost of labor:*** The trend in the industrialized societies of the world has been toward ever-increasing labor costs. As a result, higher investment in automated equipment has become economically justifiable to replace manual operations. The high cost of labor is forcing business leaders to substitute machines for human labor. Because machines can produce at higher rates of output, the use of automation results in a lower cost per unit of product.
3. ***Labor shortages:*** In many advanced nations there has been a general shortage of labor. Labor shortages also stimulate the development of automation as a substitute for labor.
4. ***Trend of labor toward the service sector:*** This trend has been especially prevalent in the advanced countries. First around 1986, the proportion of the work force employed in manufacturing stands at about 20%. In 1947, this percentage was 30%. By the year 2000, some estimates put the figure as low as 2%, certainly, automation of production jobs has caused some of this shift. The growth of government employment at the federal, state, and local levels has consumed a certain share of the labor market which might otherwise have gone into manufacturing. Also, there has been a tendency for people to view factory work as tedious, demeaning, and dirty. This view has caused them to seek employment in the service sector of the economy.
5. ***Safe:*** By automating the operation and transferring the operator from an active participation to a supervisory role, work is made safer. The safety and physical well-being of the worker has become a national objective with the enactment of the Occupational Safety and Health Act of 1970 (OSHA). It has also provided an impetus for automation.
6. ***High cost of raw materials:*** The high cost of raw materials in manufacturing results in the need for greater efficiency in using these materials. The reduction of scrap is one of the benefits of automation.
7. ***Improved product quality:*** Automated operations not only produce parts at faster rates than do their manual counterparts, but they produce parts with greater consistency and conformity to quality specifications.
8. ***Reduced manufacturing lead time:*** For reasons that we shall examine in subsequent chapters, automation allows the manufacturer to reduce the time between customer order and product delivery. This gives the manufacturer a competitive advantage in promoting good customer service.

9. ***Reduction of in-process inventory:*** Holding large inventories of work-in-process represents a significant cost to the manufacturer because it ties up capital. In-process inventory is of no value. It serves none of the purposes of raw materials stock or finished product inventory. Accordingly, it is to the manufacturer's advantage to reduce work-in-progress to a minimum. Automation tends to accomplish this goal by reducing the time a workpart spends in the factory.
10. ***High cost of not automating:*** A significant competitive advantage is gained by automating a manufacturing plant. The advantage cannot easily be demonstrated on a company's project authorization form. The benefits of automation often show up in intangible and unexpected ways, such as improved quality, higher sales, better labor relations, and better company image. Companies that do not automate are likely to find themselves at a competitive disadvantage with their customers, their employees, and the general public.

All of these factors act together to make production automation a feasible and attractive alternative to manual methods of manufacture.

TYPES OF PRODUCTION

Another way of classifying production activity is according to the quantity of product made. In this classification, there are three types of production:

1. Job shop production
2. Batch production
3. Mass production

1. Job shop production. The distinguishing feature of job shop production is low volume. The manufacturing lot sizes are small, often one of a kind. Job shop production is commonly used to meet specific customer orders, and there is a great variety in the type of work the plant must do. Therefore, the production equipment must be flexible and general-purpose to allow for this variety of work. Also, the skill level of job shop workers must be relatively high so that they can perform a range of different work assignments. Examples of products manufactured in a job shop include space vehicles, aircraft, machine tools, special tools and equipment, and prototypes of future products. Construction work and shipbuilding are not normally identified with the job shop category, even though the quantities are in the appropriate range. Although these two activities involve the transformation of raw materials into finished products, the work is not performed in a factory.

2. Batch production: This category involves the manufacture of medium-sized lots of the same item or product. The lots may be produced only once, or they may be produced at regular intervals. The purpose of batch production is often to satisfy continuous customer demand for an item. However, the plant is capable of a production rate that exceeds the demand rate. Therefore, the shop produces to build up an inventory of the item. Then it changes over to other orders. When the stock of the first item becomes depleted, production is repeated to build up the inventory again. The manufacturing equipment used in batch production is general-purpose but designed for higher rates of production. Examples of items made in batch-type shops include industrial equipment, furniture, textbooks, and component parts for many assembled consumer products (household appliances, lawn mowers, etc.). Batch production plants include machine shops, casting foundries, plastic molding factories, and press working shops. Some types of chemical plants are also in this general category.

3. Mass production: This is the continuous specialized manufacture of identical products. Mass production is characterized by very high production rates, equipment that is completely dedicated to the manufacture of a particular product, and very high demand rates for the product. Not only is the equipment dedicated to one product, but the entire plant is often designed for the exclusive purpose of producing the particular product. The equipment is special-purpose rather than general-purpose. The investment in machines and specialized tooling is high. In a sense, the production skill has been transferred from the operator to the machine. Consequently, the skill level of labor in a mass production plant tends to be lower than in a batch plant or job shop.

2.3 FUNCTIONS IN MANUFACTURING

For any of the three types of production, there are certain basic functions that must be carried out to convert raw materials into finished product. For a firm engaged in making discrete products, the functions are:

1. Processing
2. Assembly
3. Material handling and storage
4. Inspection and test
5. Control

The first four of these functions are the physical activities that "touch" the product as it is being made. Processing and assembly are operations that add value to the product. The third and fourth functions must be performed in a manufacturing plant, but they do not add value to the product. The Figure 6, shows the model of the functions of manufacturing in factory .

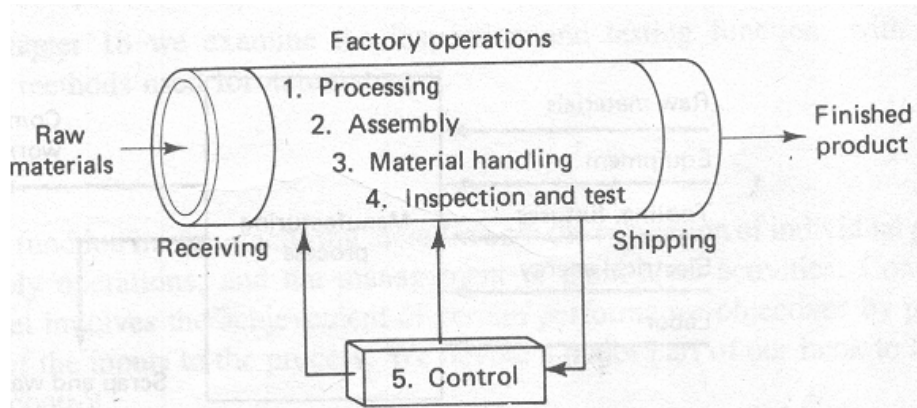


Figure 6 Model of the factory showing five functions of manufacturing

Processing operations

Processing operations transform the product from one state of completion into a more advanced state of completion. Processing operations can be classified into one of the following four categories:

1. Basic processes
2. Secondary processes
3. Operations to enhance physical properties
4. Finishing operations

Basic processes are those which give the work material its initial form. Metal casting and plastic molding are examples. In both cases, the raw materials are converted into the basic geometry of the desired product.

Secondary processes follow the basic process and are performed to give the work part its final desired geometry. Examples in this category include machining (turning, drilling, milling, etc.) and press working operations (blanking, forming, drawing, etc.).

Operations to enhance physical properties do not perceptibly change the physical geometry of the work part. Instead, the physical properties of the material are improved in some way. Heat-treating operations to strengthen metal pans and preshrinking used in the garment industry are examples in this category.

Finishing operations are the final processes performed on the work part. Their purpose is, for example, to improve the appearance, or to provide a protective coating on the part. Examples in this fourth category include polishing, painting, and chrome plating.

Figure 6 presents an input/output model of a typical processing operation in manufacturing. Most manufacturing processes require five inputs:

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

Assembly operations

Assembly and joining processes constitute the second major type of manufacturing operation. In assembly, the distinguishing feature is that two or more separate components are joined together. Included in this category are mechanical fastening operations, which make use of screws, nuts, rivets, and so on, and joining processes, such as welding, brazing, and soldering. In the fabrication of a product, the assembly operations follow the processing operations.

Material handling and storage

A means of moving and storing materials between the processing and assembly operations must be provided. In most manufacturing plants, materials spend more time being moved and stored than being processed. In some cases, the majority of the labor cost in the factory is consumed in handling, moving, and storing materials. It is important that this function be carried out as efficiently as possible.

Inspection and testing

Inspection and testing are generally considered part of quality control. The purpose of inspection is to determine whether the manufactured product meets the established design standards and specifications. For example, inspection examines whether the actual dimensions of a mechanical part are within the tolerances indicated on the engineering drawing for the part and testing is generally concerned with the functional specifications of the final product rather than the individual parts that go into the product.

Control

The control function in manufacturing includes both the regulation of individual processing and assembly operations, and the management of plant-level activities. Control at the process level involves the achievement of certain performance objectives by proper manipulation of the inputs to the process. Control at the plant level includes effective use of labor, maintenance of the equipment, moving materials in the factory, shipping products of good quality on schedule, and keeping plant operating costs at the minimum level possible. The manufacturing control function at the plant level represents the major point of intersection between the physical operations in the factory and the information-processing activities that occur in production.

2.4 ORGANIZATION-AND INFORMATION PROCESSING IN MANUFACTURING

Manufacturing firms must organize themselves to accomplish the five functions described above. Figure 7 illustrates the cycle of information-processing activities that typically occur in a manufacturing firm which produces discrete parts and assembles them into final products for sale to its customers. The factory operations described in the preceding section are pictured in the center of the figure. The information-processing cycle, represented by the outer ring, can be described as consisting of four functions:

1. Business functions
2. Product design
3. Manufacturing planning
4. Manufacturing control

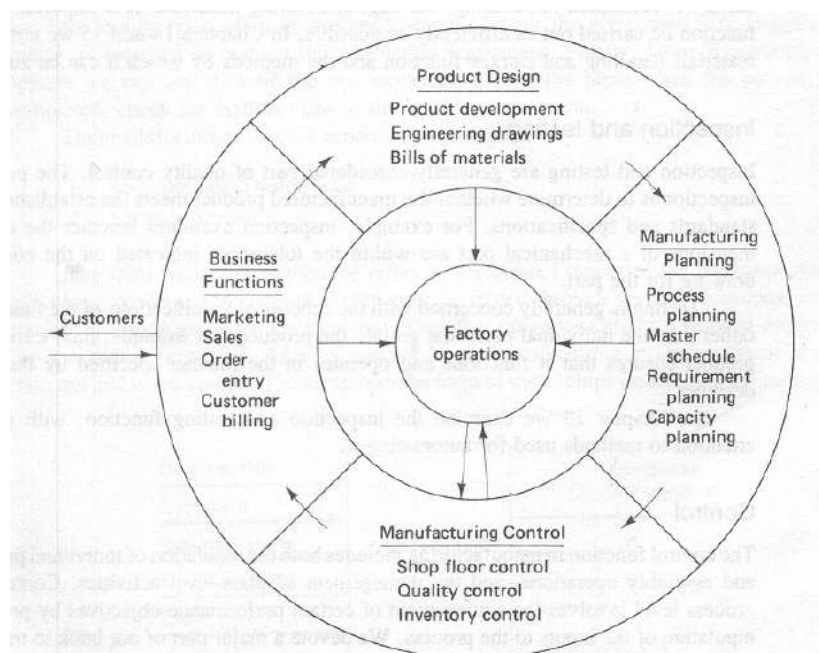


Figure 7 Information-processing cycle in a typical manufacturing firm

Business functions

The business functions are the principal means of communicating with the customer. They are the beginning and the end of the information-processing cycle. Included within this category are sales and marketing, sales forecasting, order entry, cost accounting, customer billing, and others.

An order to produce a product will typically originate from the sales and marketing department of the firm. The production order will be one of the following forms: (1) an order to manufacture an item to the customer's specifications, (2) a customer order to buy one or more of the manufacturer's, proprietary products, or (3) an order based on a forecast of future demand for a proprietary product.

Product design

If the product is to be manufactured to customer specifications, the design will have been provided by the customer. The manufacturer's product design department will not be involved.

If the product is proprietary, the manufacturing firm is responsible for its development and design. The product design is documented by means of component drawings, specifications, and a bill of materials that defines how many of each component goes into the product.

Manufacturing planning

The information and documentation that constitute the design of the product flow into the *manufacturing planning* function. The departments in the organization that perform manufacturing planning include manufacturing engineering, industrial engineering, and production planning and control.

As shown in Figure 7, the information-processing activities in manufacturing planning include process planning, master scheduling, requirements planning, and capacity planning. *Process planning* consists of determining the sequence of the individual processing and assembly operations needed to produce the part. The document used to specify the process sequence is called a *route sheet*. The route sheet lists the production operations and associated machine tools for each component (and subassembly) of the product. The manufacturing engineering and industrial engineering departments are responsible for planning the processes and related manufacturing details. The authorization to produce the product must be translated into the master schedule or master production schedule. The *master schedule* is a listing of the products to be made, when they are to be delivered, and in what quantities. Units of months are generally used to specify the deliveries on the master schedule. Based on this schedule, the individual components and subassemblies that make up each product must be planned. Raw materials must be requisitioned, purchased parts must be ordered from suppliers, and all of these items must be planned so that they are available when needed. This whole task is called *requirements planning* or *material requirements planning*. In addition, the master schedule must not list more quantities of products than the factory is capable of producing with its given number of machines and workers each month. The production quantity that the factory is capable of producing is referred to as the plant capacity. We will define and discuss this term later in the chapter. *Capacity planning* is concerned with planning the manpower and machine resources of the firm.

Manufacturing control

Manufacturing control is concerned with managing and controlling the physical operations in the factory to implement the manufacturing plans.

Shop floor control is concerned with the problem of monitoring the progress of the product as it is being processed, assembled, moved, and inspected in the factory. The sections of a traditional production planning and control department that are involved in shop floor control include scheduling, dispatching, and expediting. Production scheduling is concerned with assigning start dates and due dates to the various parts (and products) that are to be made in the factory. This requires that the parts be scheduled one by one through the various production machines listed on the route sheet for each part. Based on the production schedule, *dispatching* involves issuing the individual work orders to the machine operators to accomplish the processing of the parts. The dispatching function is performed in some plants by the shop foremen, in other plants by a person called the dispatcher. Even with the best plans and schedules, things sometimes go wrong (e.g., machine breakdowns, improper tooling, parts delayed at the vendor). The *expediter* compares the actual progress of a production order against the schedule. For orders that fall behind, the expediter attempts to take the necessary corrective action to complete the order on time.

Inventory control overlaps with shop floor control to some extent. *Inventory control* attempts to strike a proper balance between the danger of too little inventory (with possible stock-outs of materials) and the expense of having too much inventory. Shop floor control is also concerned with inventory in the sense that the materials being processed in the factory represent inventory (called work-in-process). The mission of quality *control* is to assure that the quality of the product and its components meet the standards specified by the product designer. To accomplish its mission, quality control depends on the inspection activities performed in the factory at various times throughout the manufacture of the product. Also, raw materials and components from outside sources must be inspected when they are received. Final inspection and testing of the finished product is performed to ensure functional quality and appearance.

2.5 PLANT LAYOUT

In addition to the organizational structure, a firm engaged in manufacturing-must also be concerned with its physical facilities. The term *plant layout* refers to the arrangement of these physical facilities in a production plant. A layout suited to flow-type mass production is not appropriate for job shop production, and vice versa. There are three principal types of plant layout associated with traditional production shops:

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

1.Fixed-position layout

In this type of layout, the term "fixed-position" refers to the product. Because of its size and weight, the product remains in one location and the equipment used in its fabrication is brought to it. Large aircraft assembly and shipbuilding are examples of operations in which fixed-position layout is utilized. As product is large, the construction equipment and workers must be moved to the product. This type of arrangement is often associated with job shops in which complex products are fabricated in very low quantities.

2.Process layout

In a process layout, the production machines are arranged into groups according to general type of manufacturing process. The advantage of this type of layout is its flexibility. Different parts, each requiring its own unique sequence of operations, can be routed through the respective departments in the proper order.

3.Product-Flow Layout

Productions machines are arranged according to sequence of operations. If a plant specializes in the production of one product or one class of product in large volumes, the plant facilities should be arranged to produce the product as efficiently as possible with this type of layout, the processing and assembly facilities are placed along the line of flow of the product. As the name implies, this type of layout is appropriate for flow-type mass production. The arrangement of facilities within the plant is relatively inflexible and is warranted only when the production quantities are large enough to justify the investment.

PRODUCTION CONCEPTS AND MATHEMATICAL MODELS

A number of production concepts are quantitative, or require a quantitative approach to measure them.

Manufacturing lead time

Our description of production is that it consists of a series of individual steps: processing and assembly operations. Between the operations are material handling, storage, inspections, and other nonproductive activities. Let us therefore divide the activities in production into two main categories, operations and non operation elements. An operation on a product (or work part) takes place when it is at the production machine. The non operation elements are the handling, storage, inspections, and other sources of delay. Let us use T_o to denote the lime per operation at a given machine or workstation, and T_{no} to represent the non operation time associated with the same machine. Further, let us suppose that there are n_m separate machines or operations through which the product must be routed in order to be completely processed. If we assume a batch production situation, there are Q units of the product in the batch, A setup procedure is generally required to prepare each production machine for the particular product. The setup typically includes arranging the workplace and installing the tooling and fixturing required for the product. Let this setup time be

denoted as T_m .

Given these terms, we can define an important production concept, manufacturing lead time. The *manufacturing lead time* (MLT) is the total time required to process a given product (or work part) through the plant. We can express it as follows:

$$MLT = \sum_{i=1}^{n_m} (T_{sui} + QT_{oi} + T_{noi})$$

Where i indicates the operation sequence in the processing, $i = 1, 2, \dots, n$. The MLT equation does not include the time the raw work part spends in storage before its turn in the production schedule begins.

Let us assume that all operation times, setup times, and non operation times are equal, respectively then MLT is given by

$$MLT = n_m (T_{su} + QT_o + T_{no})$$

For mass production, where a large number of units are made on a single machine, the MLT simply becomes the operation time for the machine after the setup has been completed and production begins.

For flow-type mass production, the entire production line is set up in advance. Also, the non operation time between processing steps consists simply of the time to transfer the product (or part) from one machine or workstation to the next. If the workstations are integrated so that parts are being processed simultaneously at each station, the station with the longest operation time will determine the MLT value. Hence,

$$MLT = n_m (\text{Transfer time} + \text{Longst } T_o)$$

In this case, n_m represents the number of separate workstations on the production line.

The values of setup time, operation time, and non operation time are different for the different production situations. Setting up a flow line for high production requires much more time than setting up a general-purpose machine in a job shop. However, the concept of how time is spent in the factory for the various situations is valid.

Problem .1

A certain part is produced in a batch size of 50 units and requires a sequence of eight operations in the plant. The average setup time is 3 h, and the average operation time per machine is 6 min. The average non operation time due to handling, delays, inspections, and so on, is 7 h. compute how many days it will take to produce a batch, assuming that the plant operates on a 7-h shift per day.

Solution:

The manufacturing lead time is computed from

$$MLT = n_m (T_{su} + QT_o + T_{no})$$

$$MLT =_m 8(3 + 50 \times 0.1 + 7) = 120 \text{ Hr}$$

Production Rate

The production rate for an individual manufacturing process or assembly operation is usually expressed as an hourly rate (e.g., units of product per hour). The rate will be symbolized as R_p

$$R_p = \frac{1}{T_p}$$

Where T_p is given by

$$T_p = \frac{\text{Batch time per Machine}}{Q}$$

$$T_p = \frac{(T_{su} + QT_o)}{Q}$$

If the value of Q represents the desired quantity to be produced, and there is a significant scrap rate, denoted by q , then T_p is given by

$$T_p = \frac{\left(T_{su} + \left(\frac{QT_o}{1-q} \right) \right)}{Q}$$

Components of the operation time

The components of the operation time T_o . The operation time is the time an individual workpart spends on a machine, but not all of this time is productive. Let us try to relate the operation time to a specific process. To illustrate, we use a machining operation, as machining is common in discrete-parts manufacturing. Operation time for a machining operation is composed of three elements: the actual machining time T_m , the workpiece handling time T_h , and any tool handling time per workpiece T_{th} . Hence,

$$T_o = T_m + T_h + T_{th}$$

The tool handling time represents all the time spent in changing tools when they wear out, changing from one tool to the next for successive operations performed on a turret lathe, changing between the drill bit and tap in a drill-and-tap sequence performed at one drill press, and so on. T_{th} is the average time per workpiece for any and all of these tool handling activities.

Each of the terms T_m , T_h , and T_{th} has its counterpart in many other types of discrete-item production operations. There is a portion of the operation cycle, when the material is actually being worked (T_m), and there is a portion of the cycle when either the work part is being handled (T_h) or the tooling is being adjusted or changed (T_{th}). We can therefore generalize on Eq. (2.8) to cover many other manufacturing processes in addition to machining.

Capacity

The term *capacity*, or *plant capacity*, is used to define the maximum rate of output that a plant is able to produce under a given set of assumed operating conditions. The assumed operating conditions refer to the number of shifts per day (one, two, or three), number of days in the week (or month) that the plant operates, employment levels, whether or not overtime is included, and so on. For continuous chemical production, the plant may be operated 24 h per day, 7 days per week.

Let PC be the production capacity (plant capacity) of a given work center or group of work centers under consideration. Capacity will be measured as the number of good units produced per week. Let W represent the number of work centers under consideration. A work center is a production system in the plant typically consisting of one worker and one machine. It might also be one automated machine with no worker, or several workers acting together on a production line. It is capable of producing at a rate R_p units per hour. Each work center operates for H hours per shift. H is an average that excludes time for machine breakdowns and repairs, maintenance, operator delays, and so on. Provision for setup time is also included.

Problem 2

The turret lathe section has six machines, all devoted to production of the same pad. The section operates 10 shifts per week. The number of hours per shift averages 6.4 because of operator delays and machine breakdowns. The average production rate is 17 units/h. Determine the production capacity of the turret lathe section.

Solution:

$$PC = 6(10)(6.4)(17) = 6528 \text{ units/week}$$

If we include the possibility that in a batch production plant, each product is routed through n_m machines, the plant capacity equation must be amended as follows:

$$PC = \frac{(WS_w HR_p)}{n_m}$$

Another way of using the production capacity equation is for determining how resources might be allocated to meet a certain weekly demand rate requirement. Let D_w be the demand rate for the week in terms of number of units required. Replacing PC and rearranging, we get

$$WS_w H = \frac{(D_w n_m)}{R_p}$$

Given a certain hourly production rate for the manufacturing process, indicates three possible ways of adjusting the capacity up or down to meet changing weekly demand requirements:

1. Change the number of work centers, W , in the shop. This might be done by using equipment that was formerly not in use and by hiring new workers. Over the long term, new machines might be acquired.
2. Change the number of shifts per week, 5_w . For example, Saturday shifts might be authorized.
3. Change the number of hours worked per shift, W . For example, overtime might be authorized.

In cases where production rates differ, the capacity equations can be revised, summing the requirements for the different products.

$$WS_w H = \sum \frac{(D_w n_m)}{R_p}$$

Problem 3

Three products are to be processed through a certain type of work center. Pertinent data are given in the following table.

<i>Product</i>	<i>Weekly demand</i>	<i>Production rate (units/hi</i>
1	600	10
2	1000	20
3	2200	40

Determine the number of work centers required to satisfy this demand, given that the plant works 10 shifts per week and there are 6.5 h available for production on each work center for each shift. The value of $n_m = 1$.

Solution:

<i>Product</i>	<i>Weekly demand</i>	<i>ProductionHrs</i>
1	600	600/10
2	1000	1000/20
3	2200	2200/40
Total production hours required		165

Since each work center can operate (10 shifts/week)(6.5 h) or 65 h/week, the total number of work centers is

$$W = 165/65 = 2.54 \text{ work centers} \approx 3$$

Utilization

Utilization refers to the amount of output of a production facility relative to its capacity. Letting U represent utilization, we have

$$U = \frac{Output}{Capacity}$$

Problem 4

A production machine is operated 65 h/week at full capacity. Its production rate is 20 units/hr. During a certain week, the machine produced 1000 good parts and was idle the remaining time.

(a) Determine the production capacity of the machine.

(b) What was the utilization of the machine during the week under consideration?

Solution:

(a) The capacity of the machine can be determined using the assumed 65-h week as follows:

$$PC = 65(20) = 1300 \text{ units/week}$$

(b) The utilization can be determined as the ratio of the number of parts made during productive use of the machine relative to its capacity.

$$U = \frac{\text{Output}}{\text{Capacity}} = \frac{1000}{1300} = 76.92\%$$

Availability

The availability is sometimes used as a measure of-reliability for equipment. It is especially germane for automated production equipment. Availability is defined using two other reliability terms, the *mean time between failures* (MTBF) and the *mean time to repair* (MTTR). The MTBF indicates the average length of time between breakdowns of the piece of equipment. The MTTR indicates the average time required to service the equipment and place it back into operation when a breakdown does occur:

$$\text{Availability} = \frac{MTBF - MTTR}{MTBF}$$

Work-in-process

Work-in-process (WIP) is the amount of product currently located in the factory that is either being processed or is between processing operations. WIP is inventory that is in the state of being transformed from raw material to finished product. A rough measure of work-in-process can be obtained from the equation

$$WIP = \frac{PC}{S_w} \frac{U}{H} (MLT)$$

Where WIP represents the number of units in-process.

Eugene Merchant, an advocate and spokesman for the manufacturing industry for many years, has observed that materials in a typical metal machining batch factory spend more time waiting or being moved than in processing. His observation is illustrated in Figure 8. About 95% of the time of a workpart is spent either moving or waiting; only 5% of its time is spent on the machine tool. Of this 5%, less than 30% of the time at the machine (1.5% of the total time of the part) is time during which actual cutting is taking place. The remaining 70% (3.5% of the total) is required for loading and unloading, positioning, gaging, and other causes of nonprocessing time. These time proportions are evidence of the inefficiencies with which work-in-process is managed in the factory.

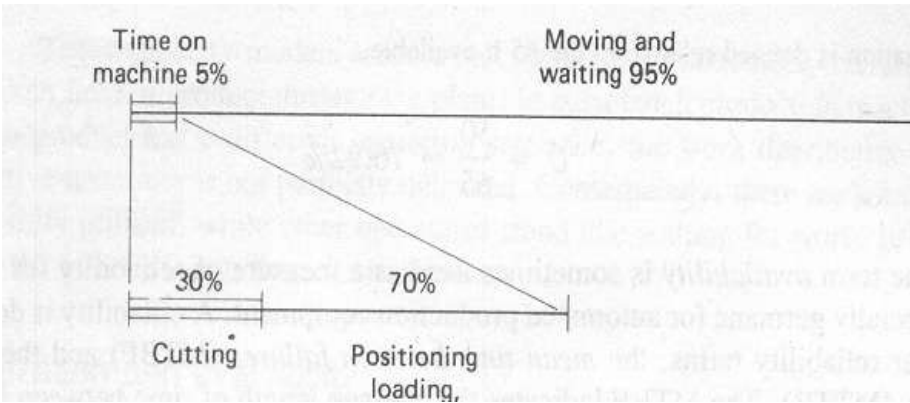


Figure 8 Time spent a part in batch production shop

Two measures that can be used to assess the magnitude of the work-in-process problem in a given factory are the WIP ratio and the TIP ratio. The WIP *ratio* provides an indication of the amount of inventory-in-process relative to the work actually being processed. It is the total quantity of a given part (or assembly) in the plant or section of the plant divided by the quantity of the same part that is being processed (or assembled).

The WIP ratio is therefore determined as

$$WIP\ ratio = \frac{WIP}{Number\ of\ machine\ processing}$$

$$Number\ of\ processing\ machine = WU \frac{QT_0}{T_{su} + QT_0}$$

The ideal WIP ratio is 1: 1, which implies that all parts in the plant are being processed. In a high-volume flow line operation, we would expect the WIP ratio to be relatively close to 1: 1 if we ignore the raw product that is waiting to be launched onto the line and the finished product that has been completed. In a batch production shop, the WIP ratio is significantly higher, perhaps 50: 1 or higher, depending on the average batch size, nonproductive time, and other factors in the plant.

The *TIP* ratio measures the time that the product spends in the plant relative to its actual processing time. It is computed as the total manufacturing lead time for a part divided by the sum of the individual operation times for the part.

$$TIP \text{ ratio} = \frac{MLT}{n_m T_0}$$

Again, the ideal *TIP* ratio is 1: 1, and again it is very difficult to achieve such a low ratio in practice. In the Merchant observation of Figure 2.6, the *TIP* ratio = 20: 1.

It should be noted that the *WIP* and *TIP* ratios reduce to the same value in our simplified model of manufacturing presented in this section. This can be demonstrated mathematically. In an actual factory situation, the *WIP* and *TIP* ratios would not necessarily be equal, owing to the complexities and realities encountered in the real world. For example, assembled products create complications in evaluating the ratio values because of the combination of parts into one assembly.

AUTOMATION STRATEGIES

There are certain fundamental strategies that can be employed to improve productivity in manufacturing operations. Since these strategies are often implemented by means of automation technology,

1. ***Specialization of operations:*** The first strategy involves the use special-purpose equipment designed to perform one operation with the greatest possible efficiency. This is analogous to the concept of labor specialization, which has been employed to improve labor productivity. *Reduce T_o*

2. ***Combined operations:*** Production occurs as a sequence of operations. Complex parts may require dozens, or even hundreds, of processing steps. The strategy of combined operations involves reducing the number of distinct production machines or workstations through which the part must be routed.
Reduce n_m, T_h, T_{no}, T_{su}

3. ***Simultaneous operations:*** A logical extension of the combined operations strategy is to perform at the same time the operations that are combined at one workstation. In effect, two or more processing (or assembly) operations are being performed simultaneously on the same workpart, thus reducing total processing time.

Reduce $n_m, T_h, T_{no}, T_{su}, T_o$

4. ***Integration of operations.*** Another strategy is to link several workstations into a single integrated mechanism using automated work handling devices to transfer parts between stations. In effect, this reduces the number of separate machines through which the product must be scheduled. With more than one workstation, several parts can be processed simultaneously, thereby increasing the overall output of the system.

Reduce n_m, T_h, T_{no}, T_{su}

5. **Increased flexibility.** This strategy attempts to achieve maximum utilization of equipment for job shop and medium-volume situations by using the same equipment for a variety of products. This normally translates into lower manufacturing lead time and lower work-in-process.

Reduce T_{su} , MLT , WIP , increase U

6. **Improved material handling and storage.** A great opportunity for reducing nonproductive time exists in the use of automated material handling and storage systems. Typical benefits included reduced work-in-process and shorter manufacturing lead times.

Reduce T_{no} , MLT , WIP

7. **On-line inspection.** Inspection for quality of work is traditionally performed after the process. This means that any poor-quality product has already been produced by the time it is inspected. Incorporating inspection into the manufacturing process permits corrections to the process as product is being made. This reduces scrap and brings the overall quality of product closer to the nominal specifications intended by the designer.

Reduce T_{no} , MLT , q

8. **Process control and optimization.** This includes a wide range of control schemes intended to operate the individual processes and associated equipment more efficiently. By this strategy, the individual process times can be reduced and product quality improved.

Reduce T_o , q , improved quality control

9. **Plant operations control.** Whereas the previous strategy was concerned with the control of the individual manufacturing process, this strategy is concerned with control at the plant level. It attempts to manage and coordinate the aggregate operations in the plant more efficiently. Its implementation usually involves a high level of computer networking within the factory,

Reduce T_{no} , MLT , increase U

10. **Computer integrated manufacturing (CIM).** Taking the previous strategy one step further, we have the integration of factory operations with engineering design and many of the other business functions of the firm. CIM involves extensive use of computer applications, computer data bases, and computer networking in the company.

Reduce MLT , increase U , design time production planning time

2 AUTOMATED FLOW LINES

An automated flow line consists of several machines or workstations which are linked together by work handling devices that transfer parts between the stations. The transfer of workparts occurs automatically and the workstations carry out their specialized functions automatically. The flow line can be symbolized as shown in Figure1 using the symbols presented in Table1. A raw workpart enters one end of the line and the processing steps are performed sequentially as the part moves from one station to the next. It is possible to incorporate buffer storage zones into the flow line, either at a single location or between every workstation. It is also possible to include inspection stations in the line to automatically perform intermediate checks on the quality of the workparts. Manual stations might also be located along the flow line to perform certain operations which are difficult or uneconomical to automate.

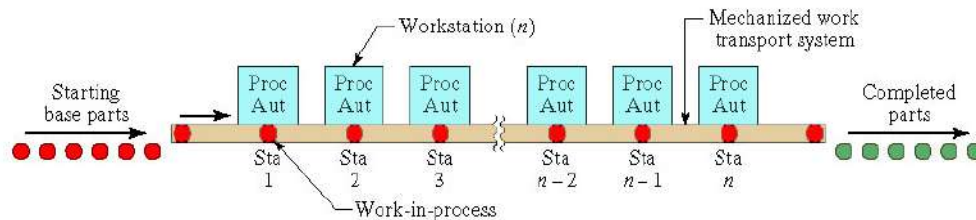


Figure 1 In-line configuration

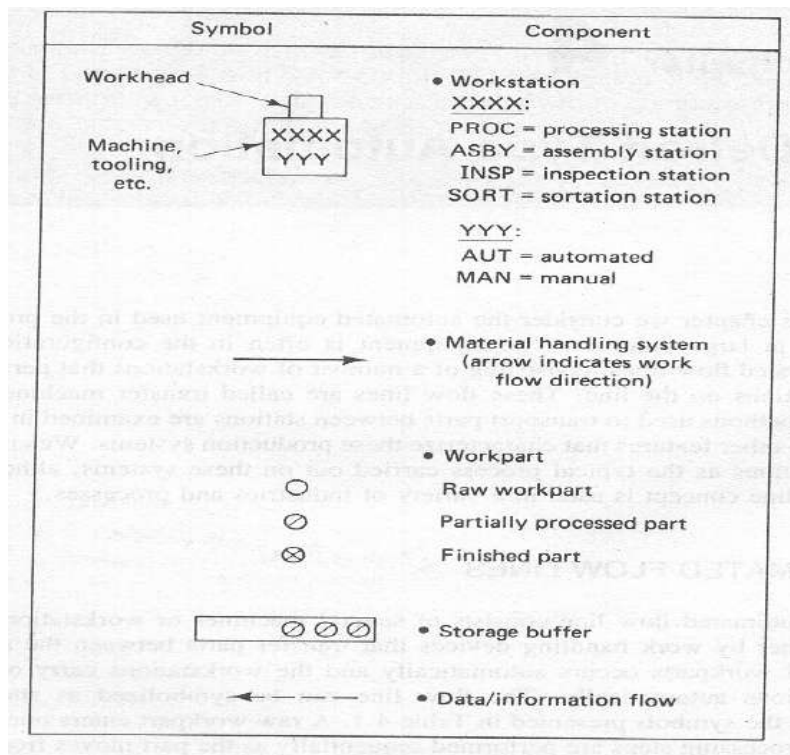


Figure 2 symbols used in production systems diagrams

The objectives of the use of flow line automation are, therefore:

- To reduce labor costs
- To increase production rates
- To reduce work-in-process
- To minimize distances moved between operations
- To achieve specialization of operations
- To achieve integration of operations

Configurations of automated flow line.

1) In-line type

The *in-line* configuration consists of a sequence of workstations in a more-or-less straight-line arrangement as shown in figure 1. An example of an in-line transfer machine used for metal-cutting operations is illustrated in Figure 4 and 5.



Figure 4 Example of 20 stations In-line

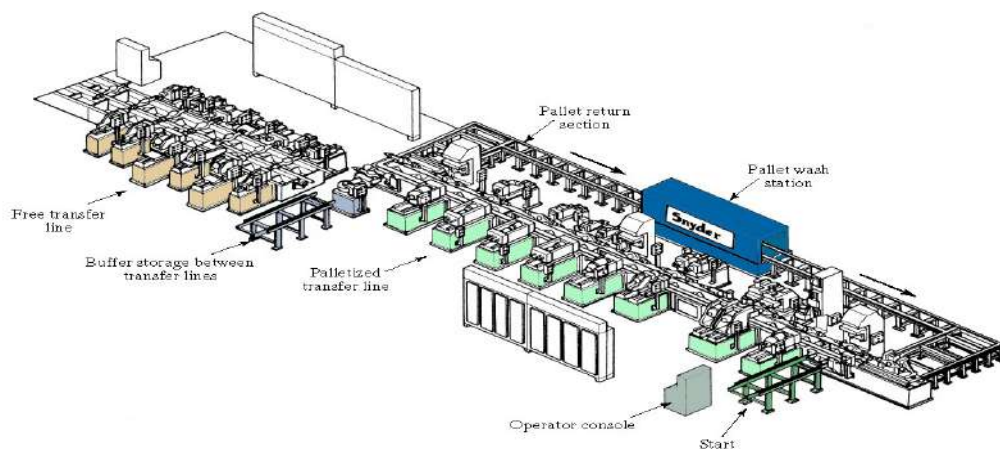


Figure 5 Example of 20 stations In-line configuration

2) Segmented In-Line Type

The segmented *in-line* configuration consists of two or more straight-line arrangement which are usually perpendicular to each other with L-Shaped or U-shaped or Rectangular shaped as shown in figure 5-7. The flow of work can take a few 90° turns, either for workpieces reorientation, factory layout limitations, or other reasons, and still qualify as a straight-line configuration.

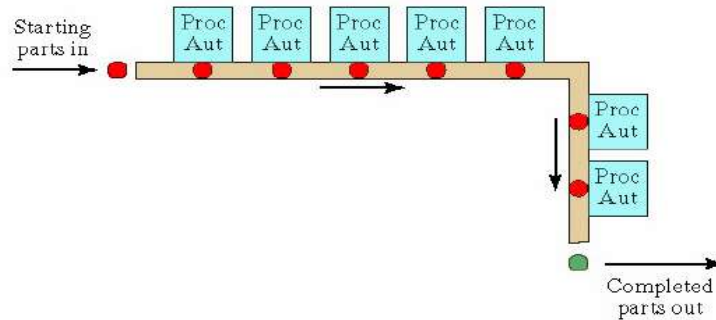


Figure 5 L-shaped configuration

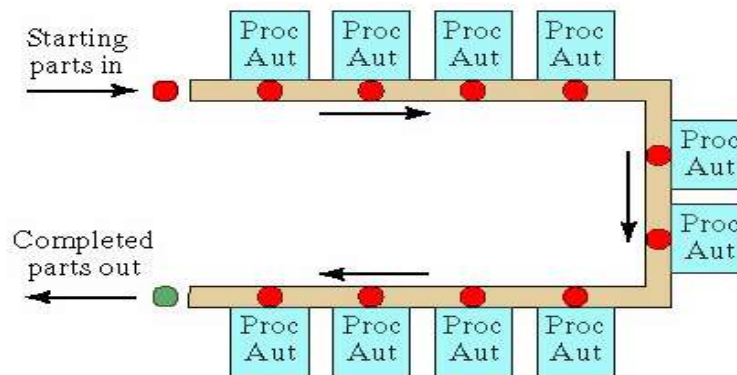


Figure 6 U-shaped configuration

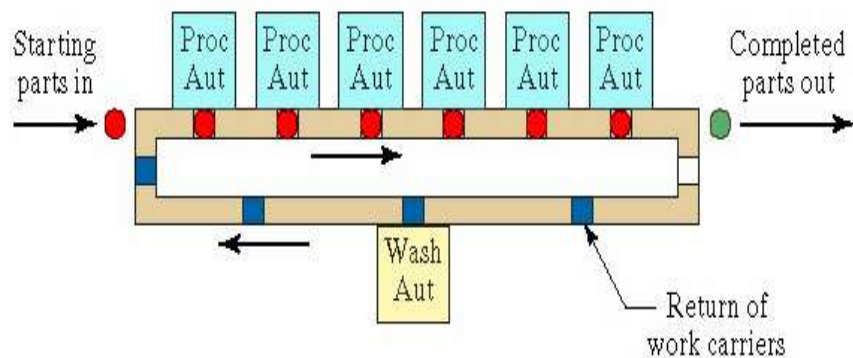


Figure 7 Rectangular-shaped configuration

3) *Rotary type*

In the *rotary* configuration, the workparts are indexed around a circular table or dial. The workstations are stationary and usually located around the outside periphery of the dial. The parts ride on the rotating table and are registered or positioned, in turn, at each station for its processing or assembly operation. This type of equipment is often referred to as an *indexing machine* or *dial index machine* and the configuration is shown in Figure 8 and example of six station rotary shown in figure 9.

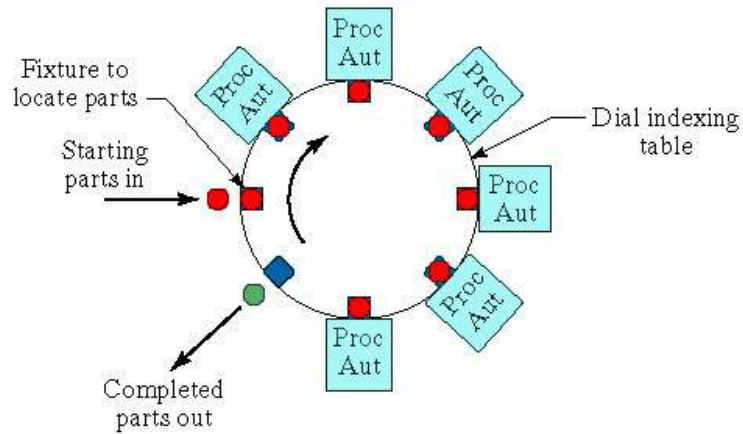


Figure 8 Rotary configuration



Figure 9 Example of 6 station rotary configuration

METHODS OF WORKPART TRANSPORT

The transfer mechanism of the automated flow line must not only move the partially completed workparts or assemblies between adjacent stations, it must also orient and locate the parts in the correct position for processing at each station. The general methods of transporting workpieces on flow lines can be classified into the following three categories:

1. Continuous transfer
2. Intermittent or synchronous transfer
3. Asynchronous or power-and-free transfer

The most appropriate type of transport system for a given application depends on such factors as:

- ☞ The types of operation to be performed
- ☞ The number of stations on the line
- ☞ The weight and size of the work parts
- ☞ Whether manual stations are included on the line
- ☞ Production rate requirements
- ☞ Balancing the various process times on the line

1) Continuous transfer

With the continuous method of transfer, the workparts are moved continuously at Constant speed. This requires the workheads to move during processing in order to maintain continuous registration with the workpart. For some types of operations, this movement of the workheads during processing is not feasible. It would be difficult, for example, to use this type of system on a machining transfer line because of inertia problems due to the size and weight of the workheads. In other cases, continuous transfer would be very practical. Examples of its use are in beverage bottling operations, packaging, manual assembly operations where the human operator can move with the moving flow line, and relatively simple automatic assembly tasks. In some bottling operations, for instance, the bottles are transported around a continuously rotating drum. Beverage is discharged into the moving bottles by spouts located at the drum's periphery. The advantage of this application is that the liquid beverage is kept moving at a steady speed and hence there are no inertia problems.

Continuous transfer systems are relatively easy to design and fabricate and can achieve a high rate of production.

2) *Intermittent transfer*

As the name suggests, in this method the workpieces are transported with an intermittent or discontinuous motion. The workstations are fixed in position and the parts are moved between stations and then registered at the proper locations for processing. All workparts are transported at the same time and, for this reason, the term "synchronous transfer system" is also used to describe this method of workpart transport.

3) *Asynchronous transfer*

This system of transfer, also referred to as a "power-and-free system," allows each workpart to move to the next station when processing at the current station has been completed. Each part moves independently of other parts. Hence, some parts are being processed on the line at the same time that others are being transported between stations.

Asynchronous transfer systems offer the opportunity for greater flexibility than do the other two systems, and this flexibility can be a great advantage in certain circumstances. In-process storage of workparts can be incorporated into the asynchronous systems with relative ease. Power-and-free systems can also compensate for line balancing problems where there are significant differences in process times between stations. Parallel stations or several series stations can be used for the longer operations, and single stations can be used for the shorter operations. Therefore, the average production rates can be approximately equalized. Asynchronous lines are often used where there are one or more manually operated stations and cycle-time variations would be a problem on either the continuous or synchronous transport systems. Larger workparts can be handled on the asynchronous systems. A disadvantage of the power-and-free systems is that the cycle rates are generally slower than for the other types.

TRANSFER MECHANISMS

There are various types of transfer mechanisms used to move parts between stations. These mechanisms can be grouped into two types: those used to provide linear travel for in-line machines, and those used to provide rotary motion for dial indexing machines.

Linear transfer mechanisms

We will explain the operation of three of the typical mechanisms; the walking beam transfer bar system, the powered roller conveyor system, and the chain-drive conveyor system. This is not a complete listing of all types, but it is a representative sample.

Walking beam systems

With the walking beam transfer mechanism, the work-parts are lifted up from their workstation locations by a transfer bar and moved one position ahead, to the next station. The transfer bar then lowers the parts into nests which position them more accurately for processing. This type of transfer device is illustrated in Figure 10 and 11. For speed and accuracy, the motion of the beam is most often generated by a rotating camshaft powered by an electric motor or a roller movement in a profile powered by hydraulic cylinder. Figure 12 shows the working of the beam mechanism.



6-Station Walking Beam including
2-Vibration stations

Figure 10 Almac Industrial Systems, the Ontario-based manufacturer of material handling equipment- Walking Beam'.



Figure 11 SIKAMA INTERNATIONAL has developed a Walking beam mechanism for FALCON 1200 and 8500

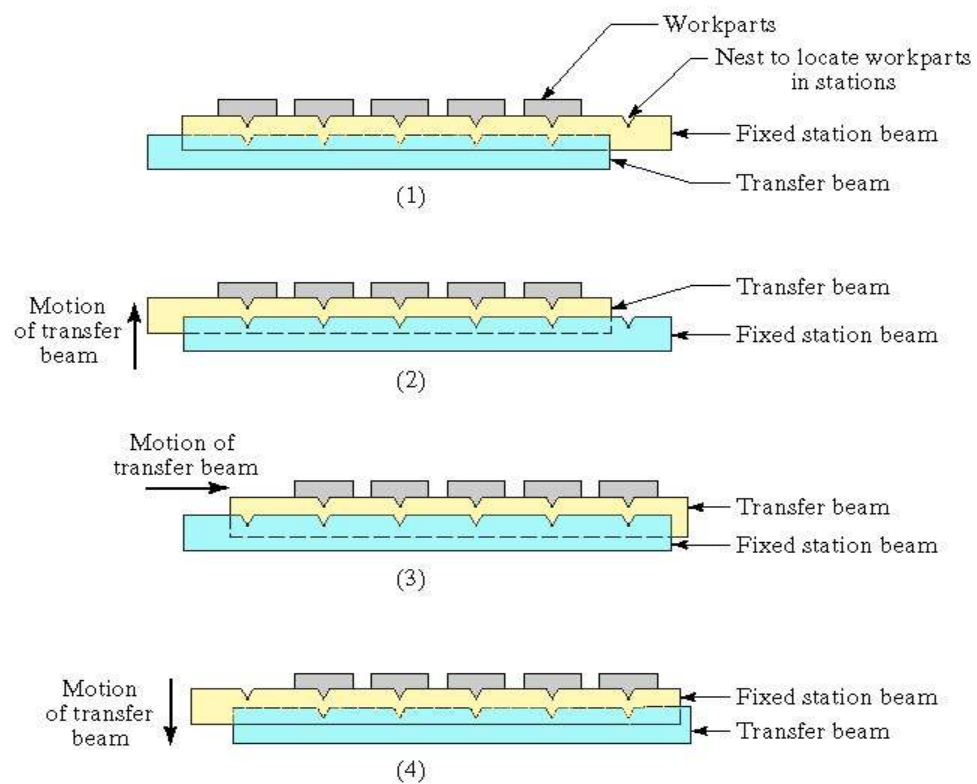


Figure 12 walking beam transfer system, showing various stage during transfer stage

Powered roller conveyor system

This type of system is used in general stock handling systems as well as in automated flow lines. The conveyor can be used to move pans or pallets possessing flat riding surfaces. The rollers can be powered by either of two mechanisms. The first is a belt drive, in which a flat moving belt beneath the rollers provides the rotation of the rollers by friction. A chain drive is the second common mechanism used to power the rollers. Powered roller conveyors are versatile transfer systems because they can be used to divert work pallets into workstations or alternate tracks.



(13 a)



(13 b)



Figure 13 a, b and c Power Conveyor

Chain-drive conveyor system

In chain-drive conveyor system either a chain or a flexible steel belt is used to transport the work carriers. The chain is driven by pulleys in either an "over-and-under" configuration, in which the pulleys turn about a horizontal axis, or an "around-the-corner" configuration, in which the pulleys rotate about a vertical axis. Figure 14 shows the chain conveyor transfer system.

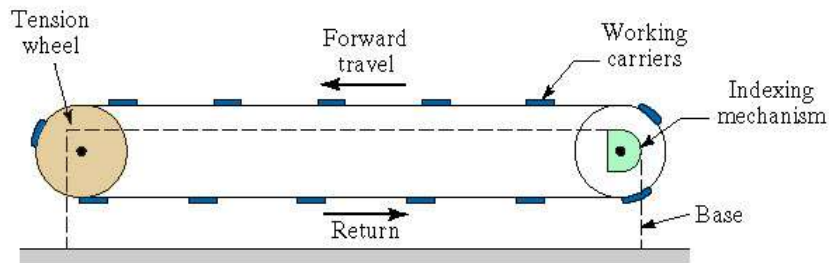


Figure 14 Chain drive conveyor

This general type of transfer system can be used for continuous, intermittent, or nonsynchronous movement of workparts. In the nonsynchronous motion, the workparts are pulled by friction or ride on an oil film along a track with the chain or belt providing the movement. It is necessary to provide some sort of final location for the workparts when they arrive at their respective stations.

Rotary transfer mechanisms

There are several methods used to index a circular table or dial at various equal angular positions corresponding to workstation locations.

Rack and pinion

This mechanism is simple but is not considered especially suited to the high-speed operation often associated with indexing machines. The device is pictured in Figure 4.6 and uses a piston to drive the rack, which causes the pinion gear and attached indexing table to rotate. A clutch or other device is used to provide rotation in the desired direction.

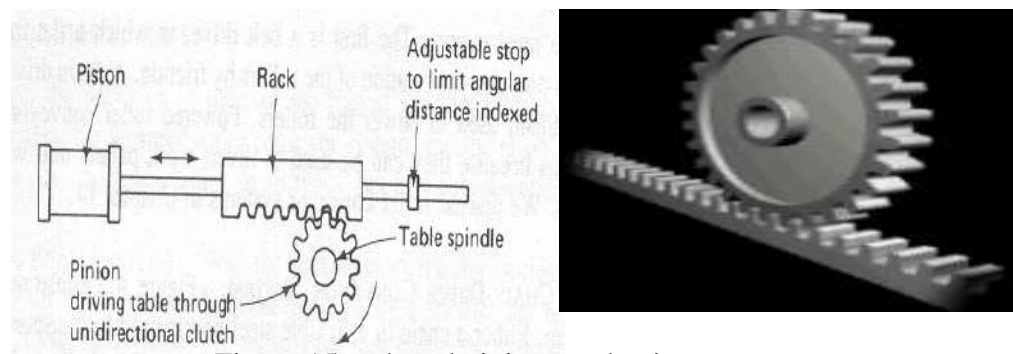


Figure 15 rack and pinion mechanisms

Ratchet and pawl:

A ratchet is a device that allows linear or rotary motion in only one direction, while preventing motion in the opposite direction.

Ratchets consist of a gearwheel and a pivoting spring loaded finger called a pawl that engages the teeth. Either the teeth, or the pawl, are slanted at an angle, so that when the teeth are moving in one direction, the pawl slides up and over each tooth in turn, with the spring forcing it back with a 'click' into the depression before the next tooth. When the teeth are moving in the other direction, the angle of the pawl causes it to catch against a tooth and stop further motion in that direction. This drive mechanism is shown in Figure 16.

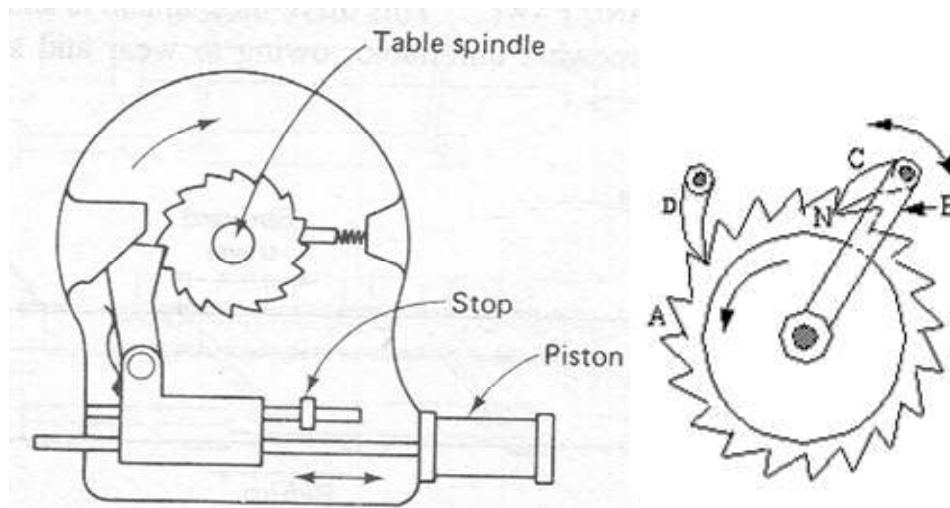


Figure 16 Ratchet and pawl mechanism

Geneva mechanism:

The two previous mechanisms convert a linear motion into a rotational motion. The Geneva mechanism uses a continuously rotating driver to index the table, as pictured in Figure 17. If the driven member has six slots for a six-station dial indexing machine, each turn of the driver will cause the table to advance one-sixth of a turn. The driver only causes movement of the table through a portion of its rotation. For a six-slotted driven member, 120° of a complete rotation of the driver is used to index the table. The other 240° is dwell. For a four-slotted driven member, the ratio would be 90° for index and 270° for dwell. The usual number of indexings per revolution of the table is four, five, six, and eight.

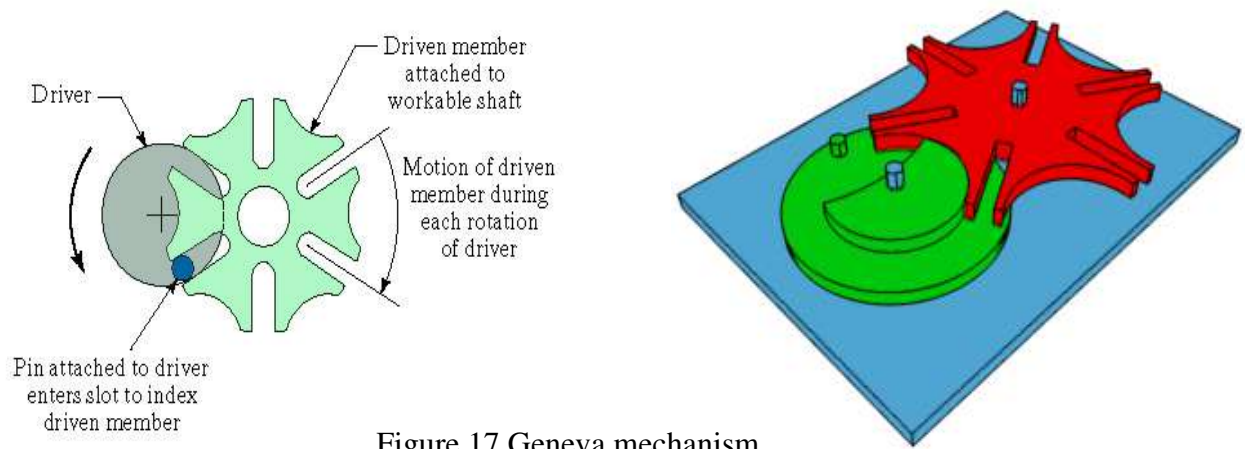


Figure 17 Geneva mechanism

CAM Mechanisms:

Various forms of cam mechanism, an example of which is illustrated in Figure 18, provide probably the most accurate and reliable method of indexing the dial. They are in widespread use in industry despite the fact that the cost is relatively high compared to alternative mechanisms. The cam can be designed to give a variety of velocity and dwell characteristics.

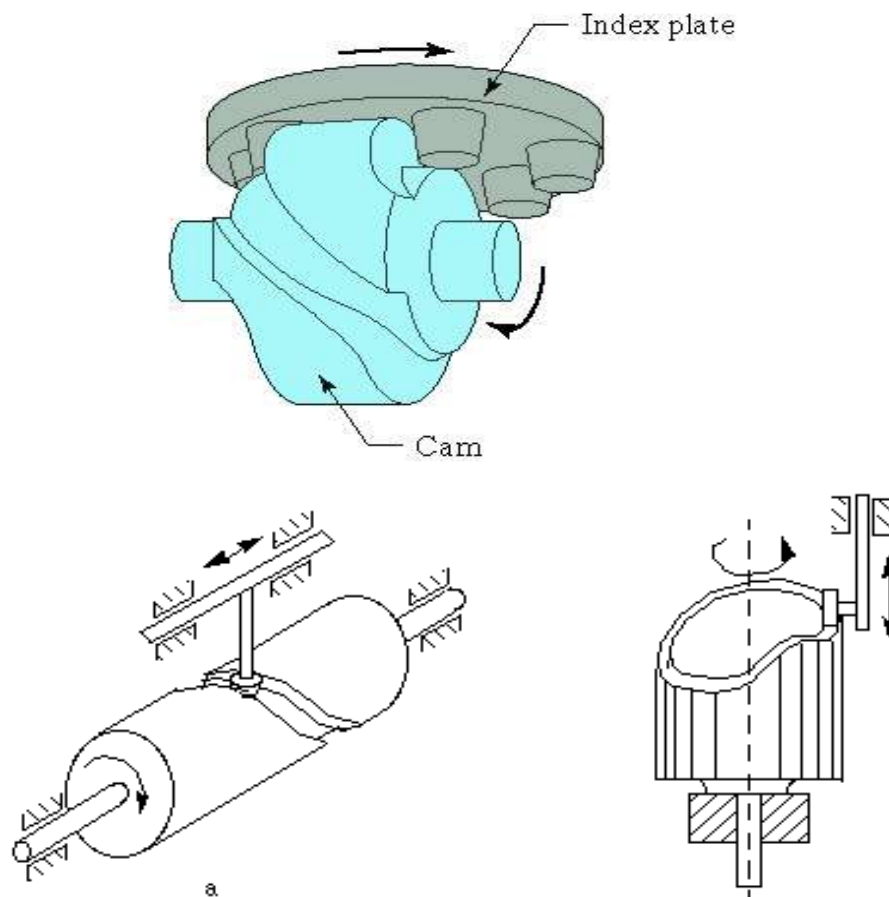


Figure 18 CAM mechanisms

CONTROL FUNCTIONS

Controlling an automated flow line is a complex problem, owing to the sheer number of sequential steps that must be carried out. There are three main functions that are utilized to control the operation of an automatic transfer system. The first of these is an operational requirement, the second is a safety requirement, and the third is dedicated to improving quality.

1. Sequence control.

The purpose of this function is to coordinate the sequence of actions of the transfer system and its workstations. The various activities of the automated flow line must be carried out with split-second timing and accuracy.

Sequence control is basic to the operation of the flow line.

2. Safety monitoring:

This function ensures that the transfer system does not operate in an unsafe or hazardous condition. Sensing devices may be added to make certain that the cutting tool status is satisfactory to continue to process the workpart in the case of a machining-type transfer line. Other checks might include monitoring certain critical steps in the sequence control function to make sure that these steps have all been performed and in the correct order. Hydraulic or air pressures might also be checked if these are crucial to the operation of automated flow lines.

3. Quality monitoring:

The third control function is to monitor certain quality attributes of the workpart. Its purpose is to identify and possibly reject defective workparts and assemblies. The inspection devices required to perform quality monitoring are sometimes incorporated into existing processing stations. In other cases, separate stations are included in the line for the sole purpose of inspecting the workpart as shown in figure 19.

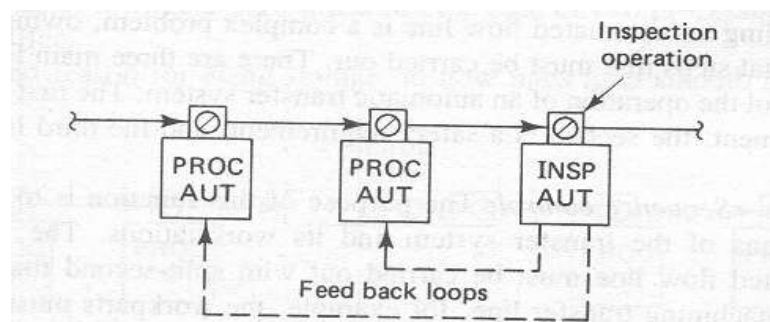


Figure 19 Inspection station with feedback

Conventional thinking on the control of the line has been to stop operation when a malfunction occurred. While there are certain malfunctions representing unsafe conditions that demand shutdown of the line, there are other situations where stoppage of the line is not required and perhaps not even desirable. There are alternative control strategies 1. Instantaneous control and 2. Memory control.

Instantaneous control:

This mode of control stops the operation of the flow line immediately when a malfunction is detected. It is relatively simple, inexpensive, and trouble-free. Diagnostic features are often added to the system to aid in identifying the location and cause of the trouble to the operator so that repairs can be quickly made. However, stopping the machine results in loss of production from the entire line, and this is the system's biggest drawback.

Memory control:

In contrast to instantaneous control, the memory system is designed to keep the machine operating. It works to control quality and/or protect the machine by preventing subsequent stations from processing the particular workpart and by segregating the part as defective at the end of the line. The premise upon which memory-type control is based is that the failures which occur at the stations will be random and infrequent. If, however, the station failures result from cause and tend to repeat, the memory system will not improve production but, rather, degrade it. The flow line will continue to operate, with the consequence that bad parts will continue to be produced. For this reason, a counter is sometimes used so that if a failure occurs at the same station for two or three consecutive cycles, the memory logic will cause the machine to stop for repairs.

BUFFER STORAGE

Automated flow lines are often equipped with additional features beyond the basic transfer mechanisms and workstations. It is not uncommon for production flow lines to include storage zones for collecting banks of workparts along the line. One example of the use of storage zones would be two intermittent transfer systems, each without any storage capacity, linked together with a workpart inventory area. It is possible to connect three, four, or even more lines in this manner. Another example of workpart storage on flow lines is the asynchronous transfer line. With this system, it is possible to provide a bank of workparts for every station on the line.

There are two principal reasons for the use of buffer storage zones. The first is to reduce the effect of individual station breakdowns on the line operation. The continuous or intermittent transfer system acts as a single integrated machine. When breakdowns occur at the individual stations or when preventive maintenance is applied to the machine, production must be halted. In many cases, the proportion of

time the line spends out of operation can be significant, perhaps reaching 50% or more. Some of the common reasons for line stoppages are:

- Tool failures or tool adjustments at individual processing stations
- Scheduled tool changes

- Defective workparts or components at assembly stations, which require that the

- Feed mechanism be cleared

- Feed hopper needs to be replenished at an assembly station

- Limit switch or other electrical malfunction

- Mechanical failure of transfer system or workstation

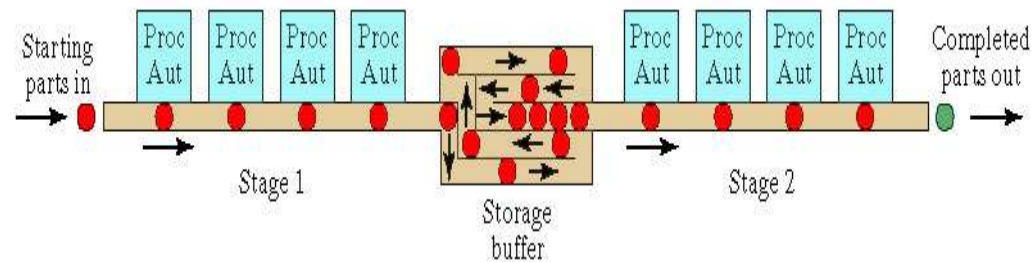


Figure 20 Storage buffer between two stages of a production

When a breakdown occurs on an automated flow line, the purpose of the buffer storage zone is to allow a portion of the line to continue operating while the remaining portion is stopped and under repair. For example, assume that a 20-station line is divided into two sections and connected by a parts storage zone which automatically collects parts from the first section and feeds them to the second section. If a station jam were to cause the first section of the line to stop, the second section could continue to operate as long as the supply of parts in the buffer zone lasts. Similarly, if the second section were to shut down, the first section could continue to operate as long as there is room in the buffer zone to store parts. Hopefully, the average production rate on the first section would be about equal to that of the second section. By dividing the line and using the storage area, the average production rate would be improved over the original 20-station Mow line. Figure 20 shows the Storage buffer between two stages of a production line

Reasons for using storage buffers:

- To reduce effect of station breakdowns
- To provide a bank of parts to supply the line
- To provide a place to put the output of the line
- To allow curing time or other required delay
- To smooth cycle time variations
- To store parts between stages with different production rates

The disadvantages of buffer storage on flow lines are increased factory floor space, higher in-process inventory, more material handling equipment, and greater complexity of the overall flow line system. The benefits of buffer storage are often great enough to more than compensate for these disadvantages.

AUTOMATION FOR MACHINING OPERATIONS

Transfer systems have been designed to perform a great variety of different metal-cutting processes. In fact, it is difficult to think of machining operations that must be excluded from the list. Typical applications include operations such as milling, boring, drilling, reaming, and tapping. However, it is also feasible to carry out operations such as turning and grinding on transfer-type systems.

There are various types of mechanized and automated machines that perform a sequence of operations simultaneously on different work parts. These include dial indexing machines, trunnion machines, and transfer lines. To consider these machines in approximately the order of increasing complexity, we begin with one that really does not belong in the list at all, the single-station machine.

Single-station machine

These mechanized production machines perform several operations on a single workpart which is fixtured in one position throughout the cycle. The operations are performed on several different surfaces by work heads located around the piece. The available space surrounding a stationary workpiece limits the number of machining heads that can be used. This limit on the number of operations is the principal disadvantage of the single-station machine. Production rates are usually low to medium. The single station machine is as shown in figure 21.



Figure 21 single-station machines

Rotary indexing machine

To achieve higher rates of production, the rotary indexing machine performs a sequence of machining operations on several work parts simultaneously. Parts are fixtured on a horizontal circular table or dial, and indexed between successive stations. An example of a dial indexing machine is shown in Figure 22 and 23.



Figure 22 Example of 6 station rotary configuration

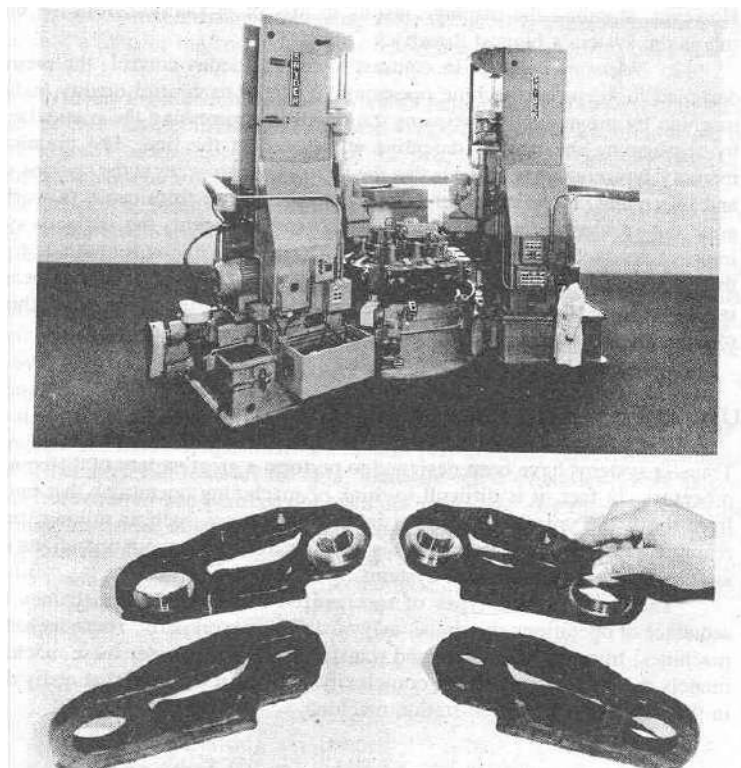


Figure 23 Five station dial index machine showing vertical and horizontal machining centers

Trunnion machine

Trunnion machine is a vertical drum mounted on a horizontal axis, so it is a variation of the dial indexing machine as shown in figure 24. The vertical drum is called a trunnion. Mounted on it are several fixtures which hold the work parts during processing. Trunnion machines are most suitable for small workpieces. The configuration of the machine, with a vertical rather than a horizontal indexing dial, provides the opportunity to perform operations on opposite sides of the workpart. Additional stations can be located on the outside periphery of the trunnion if it is required. The trunnion-type machine is appropriate for work parts in the medium production range.

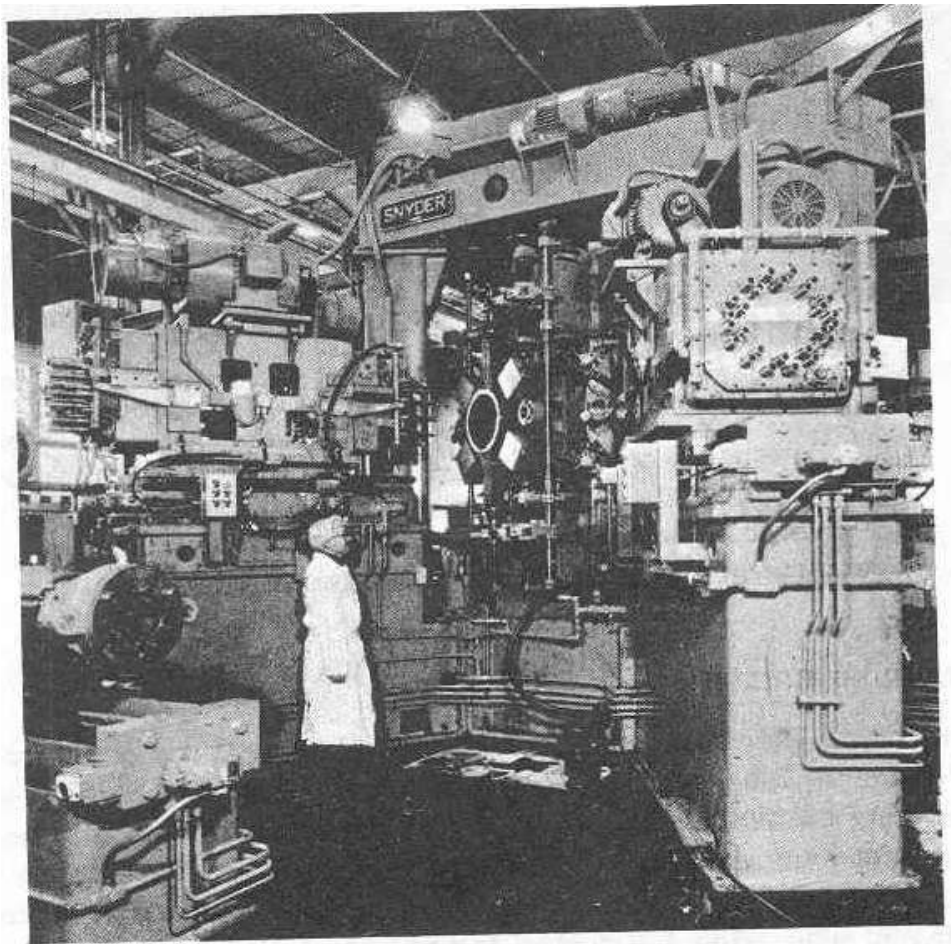


Figure 24 Six station trunnion machine

Center column machine

Another version of the dial indexing arrangement is the center column type, pictured in Figure 25. In addition to the radial machining heads located around the periphery of the horizontal table, vertical units are mounted on the center column of the machine. This increases the number of machining operations that can be performed as compared to the regular dial indexing type. The center column machine is considered to be a high-production machine which makes efficient use of floor space.

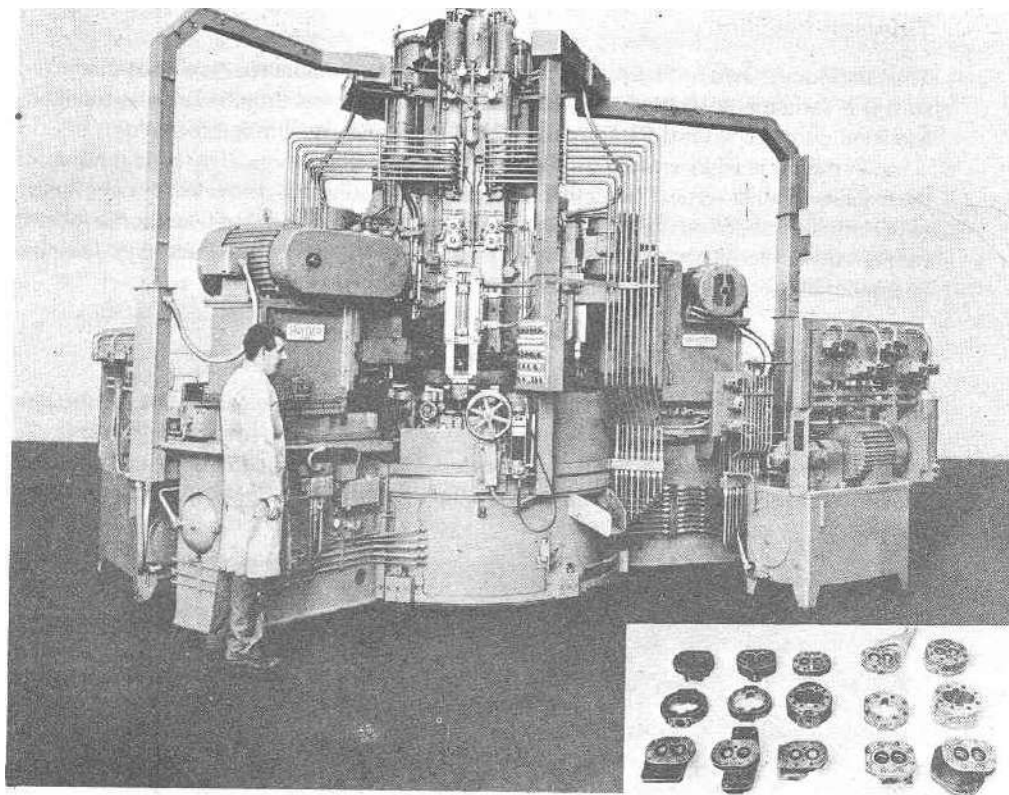


Figure 25 Ten-station center column machine

Transfer machine

The most highly automated and versatile of the machines is the transfer line, as explained earlier the workstations are arranged in a straight-line flow pattern and parts are transferred automatically from station to station. The transfer system can be synchronous or asynchronous, work parts can be transported with or without parallel fixtures, buffer storage can be incorporated into the line operation if desired, and a variety of different monitoring and control features can be used to manage the line. Hence, the transfer machine offers the greatest flexibility of any of the

machines discussed. The transfer line can accommodate larger workpieces than the rotary-type indexing systems. Also, the number of stations, and therefore the number of operations, which can be included on the line is greater than for the circular arrangement. The transfer line has traditionally been used for machining a single product in high quantities over long production runs. More recently, transfer machines have been designed for ease of changeover to allow several different but similar workparts to be produced on the same line. These attempts to introduce flexibility into transfer line design add to the appeal of these high-production systems.



Figure 26 Example of 20 stations Transfer line



Figure 27 Example of Transfer line

UNIT 3:

ANALYSIS OF AUTOMATED FLOW LINE & LINE BALANCING

General Terminology & Analysis:

There are two problem areas in analysis of automated flow lines which must be addressed:

1. Process Technology
2. Systems Technology

Process Technology refers to the body of knowledge about the theory & principles of the particular manufacturing process used on the production line. E.g. in the manufacturing process, process technology includes the metallurgy & machinability of the work material, the correct applications of the cutting tools, chip control, economics of machining, machine tools alterations & a host of other problems. Many problems encountered in machining can be overcome by application of good machining principles. In each process, a technology is developed by many years of research & practice.

Terminology & Analysis of transfer lines with no Internal storage:

There are a few assumptions that we will have to make about the operation of the Transfer line & rotary indexing machines:

1. The workstations perform operations such as machining & not assembly.
2. Processing times at each station are constant though they may not be equal.
3. There is synchronous transfer of parts.
4. No internal storage of buffers.

In the operation of an automated production line, parts are introduced into the first workstation & are processed and transported at regular intervals to the succeeding stations. This interval defines the ideal cycle time, T_c of the production line. T_c is the processing time for the slowest station of the line plus the transfer time; i.e. :

$$T_c = \max (T_{si}) + T_r \text{ ----- (1)}$$

T_c = ideal cycle on the line (min)

T_{si} = processing time at station (min)

T_r = repositioning time, called the transfer time (min)

In equation 1, we use the $\max (T_{si})$ because the longest service time establishes the pace of the production line. The remaining stations with smaller service times will have to wait for the slowest station. The other stations will be idle.

In the operation of a transfer line, random breakdowns & planned stoppages cause downtime on the line.

Common reasons for downtime on an Automated Production line:

1. Tool failures at workstations.
2. Tool adjustments at workstations
3. Scheduled tool changes
4. Limit switch or other electrical malfunctions.

5. Mechanical failure of a workstation.
6. Mechanical failure of a transfer line.
7. Stock outs of starting work parts.
8. Insufficient space for completed parts.
9. Preventive maintenance on the line worker breaks.

The frequency of the breakdowns & line stoppages can be measured even though they occur randomly when the line stops, it is down for a certain average time for each downtime occurrence. These downtime occurrences cause the actual average production cycle time of the line to be longer than the ideal cycle time.

The actual average production time T_p :

$$T_p = T_c + FT_d \text{ ----- 2}$$

F = downtime frequency, line stops / cycle

Td = downtime per line stop in minutes

The downtime Td includes the time for the repair crew to swing back into action, diagnose the cause of failure, fix it & restart the drive.

FT_d = downtime averaged on a per cycle basis

Production can be computed as a reciprocal of T_p

$$R_p = \frac{1}{T_p} \text{ ----- 3}$$

Where, R_p = actual average production rate (pc / min)

T_p = the actual average production time

The ideal production rate is given by

$$R_c = \frac{1}{T_c} \text{ ----- 4}$$

Where R_c = ideal production rate (pc / min)

Production rates must be expressed on an hourly basis on automated production lines.

The machine tool builder uses the ideal production rate, R_c , in the proposal for the automated transfer line & calls it as the production rate at 100% efficiency because of downtime. The machine tool builder may ignore the effect of downtime on production rate but it should be stated that the amount of downtime experienced on the line is the responsibility of the company using the production line.

Line efficiency refers to the proportion of uptime on the line & is a measure of reliability more than efficiency.

Line efficiency can be calculated as follows:

$$E = \frac{T_c}{T_p} = \frac{T_c}{T_c + FT_d} \text{ ----- 5}$$

Where E = the proportion of uptime on the production line.

An alternative measure of the performance is the proportion of downtime on the line which is given by:

$$D = \frac{FT_d}{T_p} = \frac{FT_d}{T_c} + FT_d \text{ ----- 6}$$

Where D = proportion of downtime on the line

$$E + D = 1.0$$

An important economic measure of the performance of an automated production line is the cost of the unit produced. The cost of 1 piece includes the cost of the starting blank that is to be processed, the cost of time on the production line & the cost of the tool consumed. The cost per unit can be expressed as the sum of three factors:

$$C_{pc} = C_m + C_o T_p + C_t \text{ ----- 7}$$

Where C_{pc} = cost per piece (Rs / pc)

C_m = cost per minute to operate the time (Rs / min)

T_p = average production time per piece (min / pc)

C_t = cost of tooling per piece (Rs / pc)

C_o = the allocation of capital cost of the equipment over the service life, labour to operate the line, applicable overheads, maintenance, & other relevant costs all reduced to cost per min.

Problem on Transfer line performance:

A 30 station Transfer line is being proposed to machine a certain component currently produced by conventional methods. The proposal received from the machine tool builder states that the line will operate at a production rate of 100 pc / hr at 100% efficiency. From a similar transfer line it is estimated that breakdowns of all types will occur at a frequency of $F = 0.20$ breakdowns per cycle & that the average downtime per line stop will be 8.0 minutes. The starting blank that is machined on the line costs Rs. 5.00 per part. The line operates at a cost for 100 parts each & the average cost per tool = Rs. 20 per cutting edge. Compute the following:

1. Production rate
2. Line efficiency
3. Cost per unit piece produced on the line

Solution:

1. At 100% efficiency, the line produces 100 pc/hr. The reciprocal gives the unit time or ideal cycle time per piece.

$$T_c = \frac{1}{100} = 0.010 \text{ hr / pc} = 0.6 \text{ mins}$$

The average production time per piece is given by:

$$\begin{aligned}
 T_p &= T_c + FT_d \\
 &= 0.60 + 0.20 (8.0) \\
 &= 0.60 + 1.60 \\
 &= 2.2 \text{ mins / piece} \\
 R_p &= 1 / 2.2\text{m} = 0.45 \text{ pc / min} = 27 \text{ pc / hr}
 \end{aligned}$$

Efficiency is the ratio of the ideal cycle time to actual production time

$$\begin{aligned}
 E &= 0.6 / 2.2 \\
 &= 27 \%
 \end{aligned}$$

Tooling cost per piece

$$\begin{aligned}
 C_t &= \frac{(30 \text{ tools}) (\text{Rs } 20 / \text{tool})}{100 \text{ parts}} \\
 &= \text{Rs. } 6 / \text{piece}
 \end{aligned}$$

The hourly ratio of Rs 100 / hr to operate the line is equivalent to Rs. 1.66 / min.

$$\begin{aligned}
 C_{pc} &= 5 + 1.66 (2.2) + 6 \\
 &= 5 + 3.65 + 6 \\
 &= \text{Rs } 14.65 / \text{piece}
 \end{aligned}$$

Upper Bound Approach:

The upper bound approach provides an upper limit on the frequency on the line stops per cycle. In this approach we assume that the part remains on the line for further processing. It is possible that there will be more than one line stop associated with a given part during its sequence of processing operations. Let

Pr = probability or frequency of a failure at station i where i = 1, 2, η
 Station i where i = 1, 2, η

Since a part is not removed from the line when a station jam occurs it is possible that the part will be associated with a station breakdown at every station. The expected number of lines stops per part passing through the line is obtained by summing the frequencies Pi over the n stations. Since each of the n stations is processing a part of each cycle, then the expected frequency of line stops per cycle is equal to the expected frequency of line stops per part i.e.

$$F = \sum_{i=1}^{\eta} P_i \text{ ----- 8}$$

where F = expected frequency of line stops per cycle

Pi = frequency of station break down per cycle, causing a line stop

η = number of workstations on the line

If all the Pi are assumed equal, which is unlikely but useful for computation purposes, then

$$\begin{aligned}
 F &= \eta \cdot p \text{ where all the } P_i \text{ are equal ----- 9} \\
 p_1 &= p_2 = \dots \dots \dots p_{\eta} = p
 \end{aligned}$$

Lower Bound Approach:

The lower bound approach gives an estimate of the lower limit on the expected frequency of line stops per cycle. Here we assume that a station breakdown results in destruction of the part, resulting in removal of the part from the line & preventing its subsequent processing at the remaining workstations.

Let P_i = the probability that the workpiece will jam at a particular station i .

Then considering a given part as it proceeds through the line, P_i = probability that the part will jam at station 1

$(1 - P_i)$ = probability that the part will not jam station 1 & thus will be available for processing at subsequent stations. A jam at station 2 is contingent on successfully making it through station 1 & therefore the probability that the same part will jam at station 2 is given by

$$P_1 (1 - P_2)$$

Generalising the quantity

$$P (1 - P_1) (1 - P_2) = (1 - P_2) (1 - P_1)$$

Where $i = 1, 2, \dots, \eta$

is the probability that a given part will jam at any station i . Summing all these probabilities from $i = 1$ through $i = \eta$ gives the probability or frequency of line stops per cycle.

Probability that the given part will pass through all η stations without a line stop is

$$\prod_{i=1}^{\eta} (1 - P_i)$$

Therefore the frequency of line stops per cycle is:

$$F = 1 - \prod_{i=1}^{\eta} (1 - P_i) \quad \text{----- 10}$$

If all the probabilities, P_i , are equal, $P_i = P$, then

$$F = 1 - (1 - P)^{\eta}$$

Because of parts removal in the lower bound approach, the number of parts coming off the line is less than the number launched onto the front of the line.

If F = frequency of line stops & a part is removed for every line stop, then the proportion of parts produced is $(1 - F)$. This is the yield of the production line. The production rate equation then becomes:

$$Rap = \frac{1 - F}{T_p} \quad \text{----- 11}$$

where Rap = average actual production rate of acceptable parts from the line

T_p = average cycle rate of the transfer machine

$Rp = \frac{1}{T_p}$ = average cycle rate of the system

Example 2 Upper Bound v/s Lower Bound Approach

A 2 station transfer line has an ideal cycle time of $T_c = 1.2$ mins. The probability of station breakdown per cycle is equal for all stations & $P = 0.005$ breakdowns / cycle. For each of the upper bound & lower bound determine:

- a) frequency of line stops per cycle
- b) average actual production rate
- c) line efficiency

a) For the Upper bound approach

$$\begin{aligned} F &= 20 (0.005) = 0.10 \text{ lines per cycle} \\ F &= 1 - (1 - 0.005)^{20} = 1 - (0.995)^{20} \\ &= 1 - 0.0946 \\ &= 0.0954 \text{ line stops per cycle} \end{aligned}$$

For the Upper bound approach the production rate,

$$\begin{aligned} R_p &= \frac{1}{20} \\ &= 0.500 \text{ pc / min} \\ &= 30 \text{ pc / hr} \end{aligned}$$

For the lower bound approach the production time we calculate by using the formula for F

$$\begin{aligned} T_p &= T_c + F (T_d) \\ &= 1.2 + 0.0954 (0.8) \\ &= 1.9631 \text{ mins} \end{aligned}$$

$$\begin{aligned} \text{Production rate} &= \frac{0.9046}{1.9631} \\ &= 0.4608 \text{ pc / min} \\ &= 27.65 \text{ pc / hr} \end{aligned}$$

The production rate is about 8% lower than that we computed by the upper bound approach. We should note that:

$$\begin{aligned} R_p &= \frac{1}{0.9631} \\ &= 0.5094 \text{ cycles / min} \\ &= 30.56 \text{ cycles / hr} \end{aligned}$$

which is slightly higher than in the upper bound case.

c) For the upper bound the line efficiency will be

$$\begin{aligned} E &= \frac{1.2}{2.0} \\ &= 0.6 \\ &= 60 \% \end{aligned}$$

For the lower bound approach we have

$$\begin{aligned} E &= \frac{1.2}{1.9631} \\ &= 0.6113 \\ &= 61.13 \% \end{aligned}$$

Line efficiency is greater with lower bound approach even though production rate is lower. This is because lower bound approach leaves fewer parts remaining on the line to jam.

Analysis of Transfer Lines with Storage Buffers:

In an automated production line with no internal storage of parts, the workstations are interdependent. When one station breaks down all other stations on the line are affected either immediately or by the end of a few cycles of operation. The other stations will be forced to stop for one or two reasons 1) starving of stations 2) Blocking of stations
Starving on an automated production line means that a workstation is prevented from performing its cycle because it has no part to work on. When a breakdown occurs at any workstation on the line, the stations downstream from the affected station will either immediately or eventually become starved for parts.

Blocking means that a station is prevented from performing its work cycle because it cannot pass the part it just completed to the neighbouring downstream station. When a breakdown occurs at a station on the line, the stations upstreams from the affected station become blocked because the broken down station cannot accept the next part for processing from the neighbouring upstream station. Therefore none of the upstream stations can pass their just completed parts for work.

By Adding one or more parts storage buffers between workstations production lines can be designed to operate more efficiently. The storage buffer divides the line into stages that can operate independently for a number of cycles.

The number depending on the storage capacity of the buffer

If one storage buffer is used, the line is divided into two stages.

If two storage buffers are used at two different locations along the line, then a three stage line is formed.

The upper limit on the number of storage buffers is to have a storage between every pair of adjacent stations.

The number of stages will then be equal to the number of workstations.

For an η stage line, there will be $\eta - 1$ storage buffers. This obviously will not include the raw parts inventory at the front of the line or the finished parts inventory that accumulates at the end of the line.

Consider a two – stage transfer line, with a storage buffer separating the stages. If we assume that the storage buffer is half full. If the first stage breaks down, the second stage can continue to operate using parts that are in the buffer. And if the second stage breaks down, the first stage can continue to operate because it has the buffer to receive its output. The reasoning for a two stage line can be extended to production lines with more than two stages.

Limit of Storage Buffer Effectiveness:

Two extreme cases of storage buffer effectiveness can be identified:

1. No buffer storage capacity at all.
2. Infinite capacity storage buffers

If we assume in our Analysis that the ideal cycle time T_c is the same for all stages considered.

In the case of no storage capacity, the production line acts as one stage when a station breaks down the entire line stops. This is the case of a production line with no internal storage.

The line efficiency of a zero capacity storage buffer:

$$E_0 = \frac{T_c}{T_c + F T_d} \text{-----} 12$$

The opposite extreme is the case where buffer zones of infinite capacity are installed between every pair of stages. If we assume that each storage buffer is half full, then each stage is independent of the next. The presence of the internal storage buffer means that then no stage will ever be blocked or starved because of a breakdown at some other stage.

An infinite capacity storage buffer cannot be realized in practice. If it could then the overall line efficiency will be limited by the bottleneck stage.

i.e. production in all other stages would ultimately be restricted by the slowest stage. The downstream stages could only process parts at the output rate of the bottleneck stage.

Given that the cycle time T_c is the same for all the stages the efficiency for any stage k is given by:

$$E_k = \frac{T_c}{T_c + F_k T_{d_k}}$$

where k is used to identify the stage.

The overall line efficiency would be given by:

$$E_\infty = \text{Minimum } (E_k)$$

where the subscript ∞ identifies E_∞ as the efficiency of a line whose storage buffers have infinite capacity.

By including one or more storage buffers in an automated production line, we expect to improve the line efficiency above E_0 , but we cannot expect to achieve E_∞ .

The actual value of line efficiency will fall somewhere between these extremes for a given buffer capacity

$$E_0 < E_b < E_\infty$$

Analysis of a Two stage transfer line:

The two stage line is divided by a storage buffer of capacity b is expressed in terms of the number of work parts that it can store. The buffer receives the output of stage 1 & forwards it to stage 2, temporarily storing any parts not immediately needed by stage 2 upto its capacity b . The ideal cycle time T_c is the same for both stages. We assume the downtime distributions of each stage to be the same with mean downtime = T_d , let F_1 & F_2

be the breakdown rates of stages 1 & 2 respectively.

F_1 & F_2 are not necessarily equal.

Over the long run both stages must have equal efficiencies. If the efficiency of stage 1 is greater than the efficiency of stage 2 then inventory would build up on the storage buffer until its capacity is reached.

Thereafter stage 1 would eventually be blocked when it outproduced stage 2.

Similarly if the efficiency of stage 2 is greater than the efficiency of stage 1 the inventory would get depleted thus stage 2 would be starved.

Accordingly the efficiencies would tend to equalize overtime in the two stages.

The overall efficiency for the two stage line can be expressed as:

$$E_b = E_0 + \{ D_1^1 \eta(b) \} E_2 \text{ ----- 13}$$

where E_b = overall efficiency for a two stage line with a buffer capacity

E_0 = line efficiency for the same line with no internal storage buffer

$\{ D_1^1 \eta(b) \} E_2$ represents the improvement in efficiency that results from having a

storage buffer with $b > 0$

when $b = 0$

$$E_0 = \frac{T_c}{T_c + (F_1 + F_2) T_d} \text{ ----- 14}$$

The term D_1^1 can be thought of as the proportion of total time that stage 1 is down

$$D_1^1 = \frac{F_1 T_d}{T_c + (F_1 + F_2) T_d} \text{ ----- 15}$$

The term $h(b)$ is the proportion of the downtime D_1^1 (when the stage 1 is down) that stage 2 could be up & operating within the limits of storage buffer capacity b . The equations cover several different downtime distributions based on the assumption that both stages are never down at the same time. Four of these equations are presented below:

Assumptions & definitions: Assume that the two stages have equal downtime distributions ($T_{d1} = T_{d2} = T_d$) &

equal cycle times ($T_{c1} = T_{c2} = T_c$).

Let F_1 = downtime frequency for stage 1, & F_2 = downtime frequency for stage 2. Define r to be the ration of breakdown frequencies as follows:

$$r = \frac{F_1}{F_2} \text{ ----- 16}$$

Equations for $h(b)$:

With these definitions & assumptions, we can express the relationships for $h(b)$ for two theoretical downtime distributions :

Constant downtime:

Each downtime occurrence is assumed to be of constant duration T_d , this is a case of no downtime variation. Given buffer capacity b , define B & L as follows:

$$b = B \frac{T_d}{T_c} + L \text{ ----- 17}$$

Where B is the largest integer satisfying the relation : $b \frac{T_c}{T_d} \geq B$,

& L represents the leftover units, the amount by which b exceeds $B \frac{T_d}{T_c}$.

There are two cases:

$$\begin{aligned} \text{Case 1: } r &= 1.0. h(b) \\ &= \frac{B}{B+1} + L \frac{T_c}{T_d} \frac{1}{(B+1)(B+2)} \text{ ----- 18} \end{aligned}$$

$$\begin{aligned} \text{Case 2: } r &\neq 1.0. h(b) \\ &= r \frac{1 - r^B}{1 - r} + L \frac{T_c}{T_d} \frac{r^B (1 - r)^2}{(1 - r^{B+1})(1 - r^{B+2})} \text{ ----- 19} \end{aligned}$$

Geometric downtime distribution:

In this downtime distribution, the probability that repairs are completed during cycle duration T_c , is independent of the time since repairs began. This a case of maximum downtime variation. There are two cases:

$$\begin{aligned} \text{Case 1: } r &= 1.0. h(b) \\ &= \frac{B \frac{T_c}{T_d}}{2 + (b-1) \frac{T_c}{T_d}} \text{ ----- 20} \end{aligned}$$

Case 2: $r \neq 1.0$.

$$\text{Define } K = \frac{1 + r - \frac{T_c}{T_d}}{1 + r - r \frac{T_c}{T_d}} \text{ ----- 21}$$

$$\text{Then } h(b) = \frac{r (1 - K^b)}{1 - r K^b} \text{ ----- 22}$$

Finally, E_2 corrects for the assumption in the calculation of $h(b)$ that both stages are never down at the same time. This assumption is unrealistic. What is more realistic is that when stage 1 is down but stage 2 could be producing because of parts stored in the buffer, there will be times when stage 2 itself breaks down. Therefore E_2 provides an estimate of the proportion of stage 2 uptime when it could be otherwise be operating even with stage 1 being down. E_2 is calculated as:

$$E_2 = \frac{T_c}{T_c + F_2 T_d} \text{ ----- 23}$$

Two-Stage Automated Production Line:

A 20-station transfer line is divided into two stages of 10 stations each. The ideal cycle time of each stage is $T_c = 1.2$ min. All of the stations in the line have the same probability of stopping, $p = 0.005$. We assume that the downtime is constant when a breakdown occurs, $T_d = 8.0$ min. Using the upper-bound approach, compute the line efficiency for the following buffer capacities: (a) $b = 0$, (b) $b = \infty$, (c) $b = 10$, (d) $b = 100$

Solution:

$$F = np = 20(0.005) = 0.10$$

$$E_0 = \frac{1.2}{1.2 + 0.1(8)} = 0.60$$

(a) For a two stage line with 20 stations (each stage = 10 stations) & $b = \infty$, we first compute F :

$$F_1 = F_2 = 10(0.005) = 0.05$$

$$E_\infty = E_1 = E_2 = \frac{1.2}{1.2 + 0.05(8)} = 0.75$$

(b) For a two stage line with $b = 10$, we must determine each of the items in equation 13. We have E_0 from part (a). $E_0 = 0.60$. And we have E_2 from part (b). $E_2 = 0.75$

$$D'_1 = \frac{0.05(8)}{1.2 + (0.05 + 0.05)(8)} = \frac{0.40}{2.0} = 0.20$$

Evaluation of $h(b)$ is from equation 18 for a constant repair distribution. In equation 17, the ratio

$$\frac{T_d}{T_c} = \frac{8.0}{1.2} = 6.667.$$

For $b = 10$, $B = 1$ & $L = 3.333$.

Thus,

$$h(b) = h(10)$$

$$= \frac{1}{1+1} + 3.333 \frac{(1.2)}{(8.0)} \frac{1}{(1+1)(1+2)}$$
$$= 0.50 + 0.8333 = 0.5833$$

We can now use equation 13:

$$E_{10} = 0.600 + 0.20(0.5833)(0.75)$$
$$= 0.600 + 0.0875 = 0.6875$$

- (c) For $b = 100$, the only parameter in equation 13 that is different from part (c) is $h(b)$.
for $b = 100$, $B = 15$ & $L = 0$ in equation 18. Thus, we have:

$$h(b) = h(100) = \frac{15}{15 + 1} \\ = 0.9375$$

Using this value,

$$E_{100} = 0.600 + 0.20 (0.9375) (0.75) \\ = 0.600 + 0.1406 = 0.7406$$

The value of $h(b)$ not only serves its role in equation 13 but also provides information on how much improvement in efficiency we get from any given value of b . note in example 15 that the difference between E_{∞} & $E_0 = 0.75 - 0.60 = 0.15$.

For $b = 10$, $h(b) = h(10) = 0.58333$, which means we get 58.33% of the maximum possible improvement in line efficiency using a buffer capacity of

$$10 \{E_{10} = 0.6875 = 0.60 + 0.5833(0.75 - 0.60)\}.$$

For $b = 100$, $h(b) = h(100) = 0.9375$, which means we get 93.75% of the maximum improvement with $b = 100 \{E_{100} = 0.7406 = 0.60 + 0.9375 (0.75 - 0.60)\}$

We are not only interested in the line efficiencies of a two stage production line. We also want to know the corresponding production rates. These can be evaluated based on knowledge of the ideal cycle time T_c & the definition of line efficiency. According to equation 5, $E = T_c / T_p$. Since R_p = the reciprocal of T_p , then $E = T_c R_p$. Rearranging this we have:

$$R_p = \frac{E}{T_c} \text{ ----- 24}$$

Production Rates on the Two-Stage Line of the example above:

Compute the production rates for the 4 cases in the above example. The value of $T_c = 1.2$ min is as before.

Solution:

- (a) For $b = 0$, $E_0 = 0.60$. Applying equation 23, we have

$$R_p = 0.60 / 1.2 = 0.5 \text{ pc/min} = 30 \text{ pc /hr.}$$

- (b) For $b = \infty$, $E_{\infty} = 0.75$.

$$R_p = 0.75 / 1.2 = 0.625 \text{ pc / min} = 37.5 \text{ pc /hr}$$

- (c) For $b = 10$, $E_{10} = 0.6875$.

$$R_p = 0.6875 / 1.2 = 0.5729 \text{ pc / min} = 34.375 \text{ pc /hr.}$$

- (d) For $b = 100$, $E_{100} = 0.7406$

$$R_p = 0.7406 / 1.2 = 0.6172 \text{ pc / min} = 37.03 \text{ pc / hr}$$

Effect of High Variability in Downtimes:

Evaluate the line efficiencies for the two-stage line in above example, except that the geometric repair distribution is used instead of the constant downtime distribution.

Solution:

For parts (a) & (b), the values of E_0 & E_∞ will be the same as in the previous example. $E_0 = 0.600$ & $E_\infty = 0.750$.

(c) For $b = 10$, all of the parameters in equation 13 remain the same except $h(b)$.

Using equation 20, we have:

$$h(b) = h(10) = \frac{10(1.2/8.0)}{2 + (10 - 1)(1.2/8.0)} = 0.4478$$

Now using equation 13, we have

$$\begin{aligned} E_{10} &= 0.600 + 0.20 (0.4478)(0.75) \\ &= 0.6672 \end{aligned}$$

(d) For $b = 100$, it will be:

$$h(b) = h(100) = \frac{100(1.2/8.0)}{2 + (100 - 1)(1.2/8.0)} = 0.8902$$

$$\begin{aligned} E_{100} &= 0.600 + 0.20 (0.8902)(0.75) \\ &= 0.7333 \end{aligned}$$

Transfer Lines with More than Two Stages:

If the line efficiency of an automated production line can be increased by dividing it into two stages with a storage buffer between, then one might infer that further improvements in performance can be achieved by adding additional storage buffers. Although we do not have exact formulas for computing line efficiencies for the general case of any capacity b for multiple storage buffers, efficiency improvements can readily be determined for the case of infinite buffer capacity.

Transfer Lines with more than One Storage Buffer:

For the same 20-station transfer line we have been considering in the previous examples, compare the line efficiencies & production rates for the following cases, where in each case the buffer capacity is infinite: (a) no storage buffers, (b) one buffer, (c) three buffers, &

19 buffers. Assume in cases (b) & (c) that the buffers are located in the line to equalise the downtime frequencies; i.e. all F_i are equal. As before, the computations are based on the upper-bound approach.

Solution:

(a) For the case of no storage buffer, $E_{\infty} = 0.60$

$$R_p = 0.60/1.2 = 0.50 \text{ pc/min} = 30 \text{ pc/hr}$$

(b) For the case of one storage buffer
(a two stage line), $E_{\infty} = 0.75$

$$R_p = 0.75/1.2 = 0.625 \text{ pc/min} = 37.5 \text{ pc/hr}$$

(c) For the case of three storage buffers (a four stage line), we have

$$F_1 = F_2 = F_3 = F_4 = 5(0.005) = 0.025$$

$$T_p = 1.2 + 0.025(8) = 1.4 \text{ min / pc.}$$

$$E_{\infty} = 1.2 / 1.4 = 0.8571$$

$$R_p = 0.8571/1.2 = 0.7143 \text{ pc/min} \\ = 42.86 \text{ pc/hr.}$$

(d) For the case of 19 storage buffers (a 20 stage line, where each stage is one station), we have

$$F_1 = F_2 = \dots = F_{20} = 1(0.005) = 0.005$$

$$T_p = 1.2 + 0.005(8) = 1.24 \text{ min / pc.}$$

$$E_{\infty} = 1.2 / 1.24 = 0.9677$$

$$R_p = 0.9677/1.2 = 0.8065 \text{ pc/min} \\ = 48.39 \text{ pc/hr.}$$

This last value is very close to the ideal production rate of $R_c = 50 \text{ pc/hr}$

Problem:

Suppose that a 10 station transfer machine is under consideration to produce a component used in a pump. The item is currently produced by mass conventional means but demand for the item cannot be met. The manufacturing engineering department has estimated that the ideal cycle time will be

$T_c = 1.0 \text{ min}$. From similar transfer lines & that the average downtime for line stop occur with a frequency;

$F = 0.10$ breakdown/cycle & the average downtime per line stop will be 6.0 min. The scrap rate for the current conventional processing method is 5% & this is considered a good estimate for a transfer line. The starting costing for the component costs Rs. 1.50 each & it will cost Rs 60.00 / hr or Rs 1 / min to operate the transfer line. Cutting tools are estimated to cost Rs 0.15/ work part. Compute the following measures of line performance given the foregoing data.

- (a) Production rate
- (b) Number of hours required to meet a demand of 1500 units/week.
- (c) Line efficiency
- (d) Cost per unit produced.

Problem:

If a line has 20 work stations each with a probability of breakdown of 0.02, the cycle time of the line is 1 min & each time a breakdown occurs, it takes exactly 5 minutes to repair. The line is to be divided into two stages by a storage buffer so that each stage will consist of 10 stations. Compute the efficiency of the two stage line for various buffer capacities.

Solution:

Let us compute the efficiency of the line with no buffer

$$F = np = 20(0.02) = 0.4$$

$$E_o = \frac{1.0}{1.0 + 0.4(10)} = 0.20$$

Next dividing the line into equal stages by a buffer zone of infinite capacity each stage would have an efficiency given by

$$F_1 = F_2 = 10(0.02) = 0.2$$

$$E_1 = E_2 = \frac{T_c}{T_c + (F_1 + F_2)T_d} = \frac{1.0}{1.0 + 0.2(10)} = 0.333$$

- d) The cost per product can be computed except that we must account for the scrap rate.

$$C_{pc} = \frac{1}{0.95} (1.50 + 1.00 \times 1.60 + 0.15) = \text{Rs. } 3.42/\text{good unit}$$

The Rs.3.42 represents the average cost per acceptable product under the assumption that we are discarding the 5% bad units with no salvage value and no disposal cost. Suppose that we could repair these parts at a cost of Rs.5.00/unit. To compute the cost per piece the repair cost would be added to other components.

$$C_{pc} = 1.50 + 1.00 \times 1.60 + 0.15 + 0.05 (5.00) = \text{Rs. } 3.50/\text{unit.}$$

The policy of scrapping the 5% defects ,yields a lower cost per unit rather than repairing them.

Problem:

An eight station rotary indexing machine operates with an ideal cycle time of 20 secs. The frequency of line stop occurrences is 0.06 stop / cycle on the average. When a stop occurs it takes an average of 3 min to make repairs. Determine the following:

1. Average production time
2. Proportion of downtime
3. Line efficiency
4. Average production rate

Solution

$$\begin{aligned}T_p &= T_c + F (T_d) \\&= 0.33 + 0.06(3) \\&= 0.5133 \text{ minutes.}\end{aligned}$$

$$R_p = \frac{1}{0.5133} = 1.94 \text{ pieces /minutes}$$

$$\text{Line efficiency} = \frac{T_c}{T_p} = \frac{0.333}{0.51} = 0.491$$

$$\text{Proportion of downtime can be calculated by } D = \frac{F T_d}{T_p} = \frac{0.06(3)}{0.5133} = 0.35$$

Partial Automation:

Many assembly lines in industry contain a combination of automated & manual work stations. These cases of partially automated production lines occur for two main reasons:

1. **Automation is introduced gradually on an existing manual line.** Suppose that demand for the product made on a manually operated line increases, & it is desired to increase production & reduce labour costs by automating some or all of the stations. The simpler operations are automated first, & the transition toward a fully automated line is accomplished over a long period of time. Meanwhile, the line operates as a partially automated system.
2. **Certain manual operations are too difficult or too costly to automate.** Therefore, when the sequence of workstations is planned for the line, certain stations are designed to be automated, whereas the others are designed as manual stations.

Examples of operations that might be too difficult to automate are assembly procedures or processing steps involving alignment, adjustment, or fine-tuning of the work unit. These operations often require special human skills and/or senses to carry out. Many inspection procedures also fall into this category. Defects in a product or a part that can be easily perceived by a human inspector are sometimes extremely difficult to identify by an automated inspection device. Another problem is that the automated inspection device can only check for the defects for which it was designed, whereas a human inspector is capable of sensing a variety of unanticipated imperfections & problems.

To analyze the performance of a partially automated production line, we build on our previous analysis & make the following assumptions:

1. Workstations perform either processing or assembly operations;

2. Processing & assembly times at automated stations are constant, though not necessarily equal at all stations;
3. Synchronous transfer of parts;
4. No internal buffer storage ;
5. The upper bound approach is applicable &
6. Station breakdowns occur only at automated stations.

Breakdowns do not occur at manual workstations because the human workers are flexible enough, we assume, to adapt to the kinds of disruptions & malfunctions that would interrupt the operation of an automated workstation. For example, if a human operator were to retrieve a defective part from the parts bin at the station, the part would immediately be discarded & replaced by another without much lost time. Of course, this assumption of human adaptability is not always correct, but our analysis is based on it.

The ideal cycle time T_c is determined by the slowest stations on the line, which is generally one of the manual stations. If the cycle time is in fact determined by a manual station, then T_c will exhibit a certain degree of variability simply because there is a random variation in any repetitive human activity. However, we assume that the average T_c remains constant over time. Given our assumption that breakdowns occur only at automated stations, let n_a = the number of automated stations & T_d = average downtime per occurrence. For the automated stations that perform processing operations, let p_i = the probability (frequency) of breakdowns per cycle; & for automated stations that perform assembly operations, let q_i & m_i equal, respectively, the defect rate & probability that the defect will cause station i to stop. We are now in a position to define the average actual production time:

$$T_p = T_c + \sum_{i \in n_a} p_i T_d \text{ ----- } 25$$

where the summation applies to the n_a automated stations only. For those automated stations that perform assembly operations in which a part is added,

$$p_i = m_i q_i$$

If all p_i , m_i , & q_i are equal, respectively to p , m , & q , then the preceding equations reduce to the following:

$$T_p = T_c + n_a p T_d \text{ ----- } 26$$

and $p = mq$ for those stations that perform assembly consisting of the addition of a part.

Given that n_a is the number of automated stations, then n_w = the number of stations operated by manual workers, & $n_a + n_w = n$, where n = the total station count. Let C_{asi} = cost to operate the automatic workstation i (\$ / min), C_{wi} = cost to operate manual workstation i (\$ / min), C_{at} = cost to operate the automatic transfer mechanism. Then the total cost to operate the line is given by:

$$C_o = C_{at} + \sum_{i \in n_a} C_{asi} + \sum_{i \in n_w} C_{wi} \text{ ----- } 27$$

where C_o = cost of operating the partially automated production system (\$ / min).
 For all $C_{asi} = C_{as}$ & all
 $C_{wi} = C_w$, then
 $C_o = C_{at} + n_a C_{as} + n_w C_w$ ----- 28

Now the total cost per unit produced on the line can be calculated as follows:

$$C_{pc} = \frac{C_m + C_o T_p + C_t}{P_{ap}} \text{ ----- 29}$$

Where C_{pc} = cost per good assembly (\$ / pc), C_m = cost of materials & components being processed & assembled on the line (\$ / pc),
 C_o = cost of operating the partially automated production system by either of the equations 27 or 28 (\$ / min), T_p = average actual production time (min / pc), C_t = any cost of disposable tooling (\$ / pc), & P_{ap} = proportion of good assemblies.

Problem On Partial Automation:

It has been proposed to replace one of the current manual workstations with an automatic work head on a ten-station production line. The current line has six automatic stations & four manual stations. Current cycle time is 30 sec. The limiting process time is at the manual station that is proposed for replacement. Implementing the proposal would allow the cycle time to be reduced to 24 sec. The new station would cost \$0.20/min. Other cost data: $C_w = \$0.15/\text{min}$, $C_{as} = \$0.10/\text{min}$, & $C_{at} = \$0.12/\text{min}$. Breakdowns occur at each automated station with a probability $p = 0.01$. The new automated station is expected to have the same frequency of breakdowns. Average downtime per occurrence $T_d = 3.0\text{min}$, which will be unaffected by the new station. Material costs & tooling costs will be neglected in the analysis. It is desired to compare the current line with the proposed change on the basis of production rate & cost per piece. Assume a yield of 100% good product.

Solution:

For the current line,

$$\begin{aligned} T_c &= 30 \text{ sec} = 0.50\text{min.} \\ T_p &= 0.50 + 6(0.01)(3.0) = 0.68 \text{ min.} \\ R_p &= 1/0.68 = 1.47 \text{ pc/min} = 88.2\text{pc/hr} \\ C_o &= 0.12 + 4(0.15) + 6(0.10) \\ &= \$1.32 / \text{min} \\ C_{pc} &= 1.32 (0.68) = \$0.898 / \text{pc} \end{aligned}$$

For the proposed line,

$$\begin{aligned} T_c &= 24 \text{ sec} = 0.4 \text{ min.} \\ R_p &= 1/0.61 = 1.64 \text{ pc/min} = 98.4\text{pc/hr} \\ C_o &= 0.12 + 3(0.15) + 6(0.10) + 1(0.20) \end{aligned}$$

$$= \$1.37/\text{min}$$

$$C_{pc} = 1.67(0.61) = \$0.836 / \text{pc}$$

Even though the line would be more expensive to operate per unit time, the proposed change would increase production rate & reduced piece cost.

Storage Buffers:

The preceding analysis assumes no buffer storage between stations. When the automated portion of the line breaks down, the manual stations must also stop for lack of work parts (either due to starving or blocking, depending on where the manual stations are located relative to the automated stations). Performance would be improved if the manual stations could continue to operate even when the automated stations stop for a temporary downtime incident. Storage buffers located before & after the manual stations would reduce forced downtime at these stations.

Problem On Storage Buffers on a Partially Automated Line:

Considering the current line in the above example, suppose that the ideal cycle time for the automated stations on the current line $T_c = 18$ sec. The longest manual time is 30 sec. Under the method of operation assumed in the above example both manual & automated stations are out of action when a breakdown occurs at an automated station. Suppose that storage buffers could be provided for each operator to insulate them from breakdowns at automated stations. What effect would this have on production rate & cost per piece?

Solution:

Given $T_c = 18\text{sec} = 0.3\text{min}$, the average actual production time on the automated stations is computed as follows:

$$T_p = 0.30 + 6(0.01)(3.0) = 0.48\text{min}$$

Since this is less than the longest manual time of 0.50, the manual operation could work independently of the automated stations if storage buffers of sufficient capacity were placed before & after each manual station. Thus, the limiting cycle time on the line would be

$T_c = 30\text{sec} = 0.50$ min, & the corresponding production rate would be:

$$R_p = R_c = 1/0.50 = 2.0\text{pc/min}$$

$$= 120.0 \text{ pc/hr}$$

Using the line operating cost from the previous example, $C_o = \$1.32/\text{min}$, we have a piece cost of

$$C_{pc} = 1.32 (0.50) = \$0.66 / \text{pc}$$

Comparing with the previous example, we can see that a dramatic improvement in production rate & unit cost is achieved through the use of storage buffers.

Problem On Partial Automation:

A partially automated production line has a mixture of three mechanized & three manual workstations. There are a total of six stations, & the ideal cycle time $T_c = 1.0$ min, which includes a transfer time $T_r = 6$ sec. Data on the six stations are listed in the following table. Cost of the transfer mechanism $C_{at} = \$0.10/\text{min}$, cost to run each automated station $C_{as} = \$0.12/\text{min}$, & labour cost to operate each manual station $C_w = \$0.17/\text{min}$. It has been proposed to substitute an automated station in place of station 5. The cost of this station is estimated at $C_{as5} = \$0.25/\text{min}$, & its breakdown rate $P_5 = 0.02$, but its process time would be only 30 sec, thus reducing the overall cycle time of the line from 1.0 min to 36 sec. Average downtime per breakdown of the current line as well as the proposed configuration is $T_d = 3.5$ min. Determine the following for the current line & the proposed line: (a) production rate, (b) proportion uptime, & (c) cost per unit. Assume the line operates without storage buffers, so when an automated station stops, the whole line stops, including the manual stations. Also, in computing costs, neglect material & tooling costs.

Station	Type	Process Time (sec)	p_i
1	Manual	36	0
2	Automatic	15	0.01
3	Automatic	20	0.02
4	Automatic	25	0.01
5	Manual	54	0
6	Manual	33	0

Solution : $T_c = 1.0$ min

$T_p = 1.0 + 2(0.01) \times 3.5 + 1(0.02) \times 3.5 = 1.14$ mins

$R_p = \frac{1}{1.14} = 0.877$ pcs /min $\times 60 = 52.65$ pcs / hr

$C_p = 0.12 + 3(0.17) + 3(0.10) = \$0.93/\text{mins}$

$C_{pc} = 0.93 \times 1.14 = \$1.062/\text{piece}$

For the proposed line $T_c = 36$ secs = 0.6 mins

$T_p = 0.6 + 2(0.01) \times 3.5 + 2(0.02) \times 3.5 = 0.81$ mins

$R_p = 1.234$ pieces / min = 74.07 pieces/hr

$C_p = 0.12 + 2(0.17) + 3(0.10) + 1(0.25) = \$0.902/\text{min}$

$C_{pc} = 0.90 \times 0.81 \text{ mins} = \$0.73062/\text{piece}$

Transfer of Work between Work Stations:

There are two basic ways in which the work (the subassembly that is being built up) is moved on the line between operator workstations.

1. Nonmechanical Lines. In this arrangement, no belt or conveyor is used to move the parts between operator workstations. Instead, the parts are passed from station to station by hand. Several problems result from this mode of operation:
 - Starving at stations, where the operator has completed his or her work but must wait for parts from the preceding station.

- Blocking of stations, where the operator has completed his or her work but must wait for the next operator to finish the task before passing along the part.

As a result of these problems, the flow of work on a nonmechanical line is usually uneven. The cycle times vary, and this contributes to the overall irregularity. Buffer stocks of parts between workstations are often used to smooth out the production flow.

- Moving conveyor lines. These flow lines use a conveyor (e.g., a moving belt, conveyor, chain-in-the-floor, etc.) to move the subassemblies between workstations. The transport system can be continuous, intermittent (synchronous), or asynchronous. Continuous transfer is most common in assembly lines, although asynchronous transfer is becoming more popular. With the continuously moving conveyor, the following problems can arise:
 - Starving can occur as with non mechanical lines.
 - Incomplete items are sometimes produced when the operator is unable to finish the current part & the next part travels right by on the conveyor. Blocking does not occur.

Again, buffer stocks are sometimes used to overcome these problems. Also stations overlaps can sometimes be allowed, where the worker is permitted to travel beyond the normal boundaries of the station in order to complete work.

In the moving belt line, it is possible to achieve a higher level of control over the production rate of the line. This is accomplished by means of the feed rate, which refers to the reciprocal of the time interval between work parts on the moving belt. Let f_p denote this feed rate. It is measured in work pieces per time & depends on two factors: the speed with which the conveyor moves, & the spacing of work parts along the belt. Let V_c equal the conveyor speed (feet per minute or meters per second) & s_p equal the spacing between parts on the moving conveyor (feet or meters per work piece). Then the feed rate is determined by

$$f_p = \frac{V_c}{s_p} \quad \text{----- 1}$$

To control the feed rate of the line, raw work parts are launched onto the line at regular intervals. As the parts flow along the line, the operator has a certain time period during which he or she begin work on each piece. Otherwise, the part will flow past the station. This time period is called the tolerance time T_t . It is determined by the conveyor speed & the length of the workstation. This length we will symbolize by L_s , & it is largely determined by the operator's reach at the workstation. The tolerance time is therefore defined by

$$T_t = \frac{L_s}{V_c} \quad \text{----- 2}$$

For example, suppose that the desired production rate on a manual flow line with moving conveyor were 60 units/h. this would necessitate a feed rate of 1 part/min. This could be achieved by a conveyor speed of 0.6m/min & a part spacing of 0.5m. (Other combinations of V_c & s_p would also provide the same feed rate.) If the length of each workstation were 1.5m. the tolerance time available to the operators for each work piece

would be 3 min. It is generally desirable to make the tolerance time large to compensate for worker process time variability.

Mode Variations:

In both nonmechanical lines & moving conveyor lines it is highly desirable to assign work to the stations so as to equalize the process or assembly times at the workstations. The problem is sometimes complicated by the fact that the same production line may be called upon to process more than one type of product. This complication gives rise to the identification of three flow line cases (and therefore three different types of line balancing problems).

The three production situations on flow lines are defined according to the product or products to be made on the line. Will the flow line be used exclusively to produce one particular model? Or, will it be used to produce several different models, & if so how will they be scheduled on line? There are three cases that can be defined in response to these questions:

1. Single-model line. This is a specialized line dedicated to the production of a single model or product. The demand rate for the product is great enough that the line is devoted 100% of the time to the production of that product.
2. Batch-model line. This line is used for the production of two or more models. Each model is produced in batches on the line. The models or products are usually similar in the sense of requiring a similar sequence of processing or assembly operations. It is for this reason that the same line can be used to produce the various models.
3. Mixed-model lines. This line is also used for the production of two or more models, but the various models are intermixed on the line so that several different models are being produced simultaneously rather than in batches. Automobile & truck assembly lines are examples of this case.

To gain a better perspective of the three cases, the reader might consider the following. In the case of the batch-model line, if the batch sizes are very large, the batch-model line approaches the case of the single-model line. If the batch sizes become very small (approaching a batch size of 1), the batch-model line approximates to the case of the mixed-model line.

In principle, the three cases can be applied in both manual flow lines & automated flow lines. However, in practice, the flexibility of human operators makes the latter two cases more feasible on the manual assembly line. It is anticipated that future automated lines will incorporate quick changeover & programming capabilities within their designs to permit the batch-model, & eventually the mixed-model, concepts to become practicable.

Achieving a balanced allocation of work load among stations of the line is a problem in all three cases. The problem is least formidable for the single-model case. For the batch-model line, the balancing problem becomes more difficult; & for the mixed-model case, the problem of line balancing becomes quite complicated.

In this chapter we consider only the single-model line balancing problem, although the same concepts & similar terminology & methodology apply for the batch & mixed model cases.

The Line Balancing Problem:

In flow line production there are many separate & distinct processing & assembly operations to be performed on the product. Invariably, the sequence of processing or assembly steps is restricted, at least to some extent, in terms of the order in which the operations can be carried out. For example, a threaded hole must be drilled before it can be tapped. In mechanical fastening, the washer must be placed over the bolt before the nut can be turned & tightened. These restrictions are called *precedence constraints* in the language of line balancing. It is generally the case that the product must be manufactured at some specified production rate in order to satisfy demand for the product. Whether we are concerned with performing these processes & assembly operations on automatic machines or manual flow lines, it is desirable to design the line so as to satisfy all of the foregoing specifications as efficiently as possible.

The line balancing problem is to arrange the individual processing & assembly tasks at the workstations so that the total time required at each workstation is approximately the same. If the work elements can be grouped so that all the station times are exactly equal, we have perfect balance on the line & we can expect the production to flow smoothly. In most practical situations it is very difficult to achieve perfect balance. When the workstations times are unequal, the slowest station determines the overall production rate of the line.

In order to discuss the terminology & relationships in line balancing, we shall refer to the following example. Later, when discussing the various solution techniques, we shall apply the techniques to this problem.

UNIT 4 :

Minimum Rational Work Element:

In order to spread the job to be done on the line among its stations, the job must be divided into its component tasks. The minimum rational work elements are the smallest practical indivisible tasks into which the job can be divided. These work elements cannot be subdivided further. For example, the drilling of a hole would normally be considered as a minimum rational work element. In manual assembly, when two components are fastened together with a screw & nut, it would be reasonable for these activities to be taken together. Hence, this assembly task would constitute a minimum rational work element. We can symbolize the time required to carry out this minimum rational work element T_{ej} , where j is used to identify the element out of the n_e elements that make up the total work or job. For instance, the element time T_{ej} , for element 1 in the table above is 0.2 min.

The time T_{ej} of a work element is considered a constant rather than a variable. An automatic work head most closely fits this assumption, although the processing time could probably be altered by making adjustments in the station. In a manual operation, the time required to perform a work element will, in fact, vary from cycle to cycle.

Another assumption implicit in the use of T_e values is that they are additive. The time to perform two work elements is the sum of the times of the individual elements. In practice, this might not be true. It might be that some economy of motion could be achieved by combining two work elements at one station, thus violating the additivity assumption

Problem:

A new small electrical appliance is to be assembled on a production flow line. The total job of assembling the product has been divided into minimum rational work elements. The industrial engineering department has developed time standards based on previous similar jobs. This information is given in the table below. In the right hand column are the immediate predecessors for each element as determined by precedence requirements. Production demand will be 120,000 units/yr. At 50 weeks/yr & 40 h/week, this reduces to an output from the line of 60 units/h or 1 unit/min.

No.	Element description	T_{ej}	Must be preceded by:
1	Place frame on work holder & clamp	0.2	-----
2	Assemble plug, grommet to power cord	0.4	-----
3	Assemble brackets to frame	0.7	1
4	Wire power cord to motor	0.1	1, 2
5	Wire power to switch	0.3	2
6	Assemble mechanism plate to bracket	0.11	3
7	Assemble blade to bracket	0.32	3
8	Assemble motor to brackets	0.6	3, 4
9	Align blade & attach to motor	0.27	6, 7, 8
10	Assemble switch to motor bracket	0.38	5, 8
11	Attach cover, inspect, & test	0.5	9, 10
12	Place in tote pan for packing	0.12	11

Total Work Content:

This is the aggregate of all the work elements to be done on the line. Let T_{wc} be the time required for the total work content. Hence,

$$T_{wc} = \sum_{j=1}^{n_c} T_{ej} \text{-----} 3$$

For the example, $T_{wc} = 4.00$ min.

Workstation Process Time:

A workstation is a location along the flow line where work is performed, either manually or by some automatic device. The work performed at the station consists of one or more of the individual work elements & the time required is the sum of the times of the work elements done at the station. We use T_{si} to indicate the process time at station i of an n - station line. It should be clear that the sum of the station process times should equal the sum of the work element times.

$$\sum_{i=1}^n T_{si} = \sum_{j=1}^{ne} T_{ej} \text{-----} 4$$

Cycle Time:

This is the ideal or theoretical cycle time of the flow line, which is the time interval between parts coming off the line. The design value of T_c would be specified according to the required production rate to be achieved by the flow line. Allowing for downtime on the line, the value of T_c must meet the following requirement:

$$T_c \leq \frac{E}{R_p} \text{----- 5}$$

Where E is the line efficiency & R_p the required production rate.

The line efficiency of an automated line will be somewhat less than 100%. For a manual line, where mechanical malfunctions are less likely the efficiency will be closer to 100%.

In the above example, the required production rate is 60 units/h or 1 unit/min. at a line efficiency of 100%, the value T_c of would be 1.0 min. At efficiencies less than 100%, the ideal cycle time must be reduced (or what is the same thing, the ideal production rate R_c must be increased) to compensate for the downtime.

The minimum possible value T_c of is established by the bottleneck station, the one with the largest of T_s . That is

$$T_c \geq \max T_{si} \text{----- 6}$$

If $T_c = \max T_{si}$, there will be idle time at all stations whose T_s values are less than T_c .

Finally, since the station times are comprised of element times,

$$T_c \geq T_{ej} \text{ (for all } j = 1, 2, \dots, n_e) \text{----- 7}$$

This equation states the obvious: that the cycle time must be greater than or equal to any of the element times.

Precedence Constraints:

These are also referred to as “technological sequencing requirements”. The order in which the work elements can be accomplished is limited at least to some extent. In the problem above, the switch must be mounted onto the motor bracket before the cover of the appliance can be attached. The right hand column in the table above gives a complete listing of the precedence constraints for assembling the hypothetical electrical appliance. In nearly every processing or assembly job, there are precedence requirements that restrict the sequence in which the job can be accomplished.

In addition to the precedence constraints described above, there may be other types of constraints on the line balancing solution. These concern the restrictions on the arrangement of the stations rather than the sequence of work elements. The first is called a *zoning constraint*. A zoning constraint may be either a positive constraint or a negative constraint. A *positive* zoning constraint means that certain work elements should be placed near each other, preferably at the same workstation. For example, all the spray-painting elements should be performed together since a special semienclosed workstation has to be utilized. A *negative* zoning constraint indicates that work elements might interfere with one another & should therefore not be located in close proximity. As an illustration, a work element requiring fine adjustments or delicate coordination should not be located near a station characterized by loud noises & heavy vibrations.

Another constraint on the arrangement of workstations is called a *position constraint*. This would be encountered in the assembly of large products such as automobiles or major appliances. The product is too large for one worker to perform work on both sides. Therefore, for the sake of facilitating the work, operators are located on both sides of the flow line. This type of situation is referred to as a position constraint.

In the example there are no zoning constraints or position constraints given. The line balancing methods are not equipped to deal with these constraints conveniently. However, in real-life situations, they may constitute a significant consideration in the design of the flow line.

Precedence Diagram:

This is a graphical representation of the sequence of work elements as defined by the precedence constraints. It is customary to use nodes to symbolize the work elements, with arrows connecting the nodes to indicate the order in which the elements must be performed. Elements that must be done first appear as nodes at the left of the diagram. Then the sequence of processing and/or assembly progresses to the right. The element times are recorded above each node for convenience.

Balance Delay:

Sometimes also called balancing loss, this is a measure of the line inefficiency which results from idle time due to imperfect allocation of work among stations. It is symbolized as d & can be computed for the flow line as follows:

$$d = \frac{nT_c - T_{wc}}{nT_c} \text{----- 8}$$

The balance delay is often expressed as a percent rather than as a decimal fraction in Eq. 8.

The balance delay should not be confused with the proportion downtime, D , of an automated flow line. D is a measure of the inefficiency that results from line stops. The balance delay measures the inefficiency from imperfect line balancing.

Considering the data given in the previous problem, the total work content $T_{wc} = 4.00$ min.

We shall assume that $T_c = 1.0$ min. If it were possible to achieve perfect balance with $n = 4$ workstations, the balance delay would be

$$d = \frac{4(1.0) - 4.0}{4(1.0)} = 0$$

If the line could only be balanced with $n = 5$ stations for the 1.0 min cycle, the balance delay would be

$$d = \frac{5(1.0) - 4.0}{5(1.0)} = 0.20 \text{ or } 20\%$$

Both of these solutions provide the same theoretical production rate. However, the second solution is less efficient because an additional workstation, & therefore an additional assembly operator, is required. One possible way to improve the efficiency of the five station line is to decrease the cycle time T_c . To illustrate, suppose that the line could be balanced at a cycle time of $T_c = 0.80$ min. The corresponding measure of inefficiency would be

$$d = \frac{5(0.80) - 4.0}{5(0.80)} = 0$$

This solution (if it were possible) would yield a perfect balance. Although five workstations are required, the theoretical production rate would be $R_c = 1.25$ units/min, an increase over the production rate capability of the four-station line. The reader can readily perceive that there are many combinations of n & T_c that will produce a theoretically perfect balance. Each combination will give a different production rate. In general, the balance delay d will be zero for any values n & T_c that satisfy the relationship

$$nT_c = T_{wc} \text{----- 9}$$

Unfortunately, because of precedence constraints & because the particular values of T_c usually do not permit it, perfect balance might not be achievable for every nT_c combinations that equals the total work content time. In other words, the satisfaction of Eq. 9 is a necessary condition for perfect balance, but not a sufficient condition.

As indicated by Eq 5, the desired maximum value of T_c is specified by the production rate required of the flow line. Therefore Eq 9 can be cast in a different form to determine the theoretical minimum number of workstations required to optimize the balance delay for a specified T_c . Since n must be an integer, we can state:

minimum n is the smallest integer $\geq \frac{T_{wc}}{T_c}$ --- 10

Applying this rule to our example with

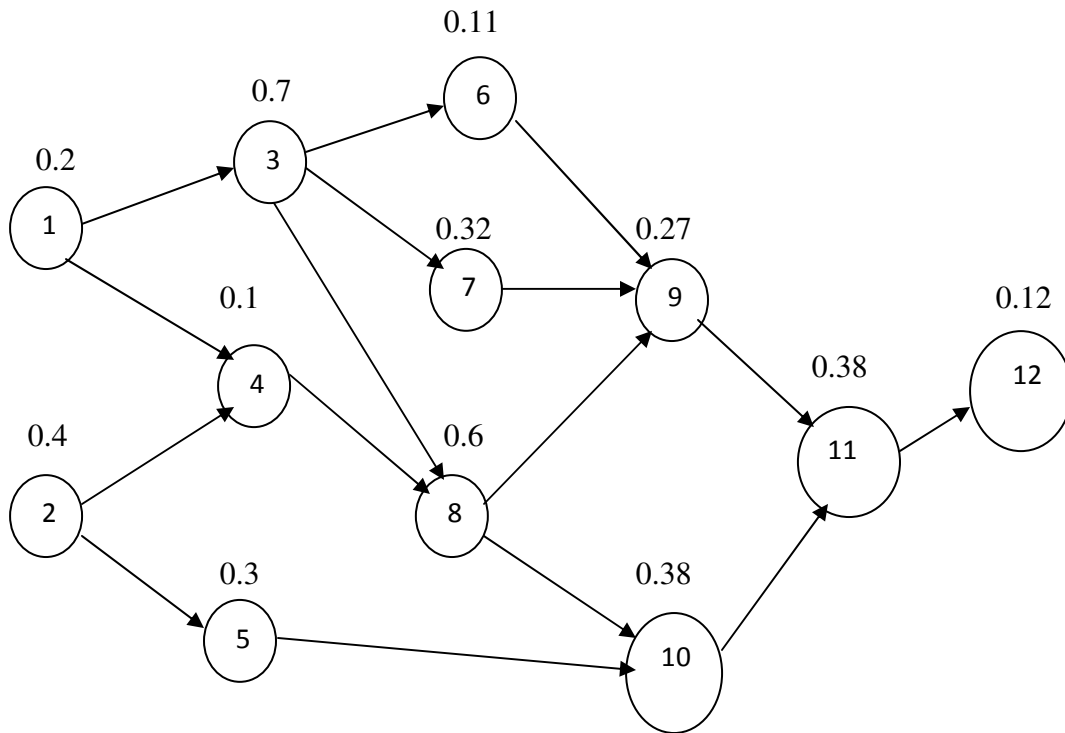
$T_{wc} = 4.0$ min & $T_c = 1.0$ min, the minimum $n = 4$ stations.

Problem:1

A new small electrical appliance is to be assembled on a production flow line. The total job of assembling the product has been divided into minimum rational work elements. The industrial engineering department has developed time standards based on previous similar jobs. This information is given in the table below. In the right hand column are the immediate predecessors for each element as determined by precedence requirements. Production demand will be 120,000 units/yr. At 50 weeks/yr & 40 h/week, this reduces to an output from the line of 60 units/h or 1 unit/min.

No	Element Description	Tek (mins)	Must be preceded by
1	Place frame on work holder & clamp	0.2	-----
2	Assemble plug, grommet to power cord	0.4	-----
3	Assemble brackets to frame	0.7	1
4	Wire power cord to motor	0.1	1 ,2
5	Wire power to switch	0.3	2
6	Assemble mechanism plate to bracket	0.11	3
7	Assemble blade to bracket	0.32	3
8	Assemble motor to brackets	0.6	3 , 4
9	Align blade & attach to motor	0.27	6 , 7 , 8
10	Assemble switch to motor bracket	0.38	5 , 8
11	Attach cover, inspect, & test	0.5	9 , 10
12	Place in tote pan for packing	0.12	11

Step 1:



Solution by Largest Candidate Rule

Step 2:

The Table below is according to the descending order of the Element Times.

Work Element	T_{ek} (min)	Preceded By
3	0.7	1
8	0.6	3, 4
11	0.5	9, 10
2	0.4	----
10	0.38	5, 8
7	0.32	3
5	0.3	2
9	0.27	6, 7, 8
1	0.2	----
12	0.12	11
6	0.11	3
4	0.1	1, 2

Step 3:

Station	Work Element	T _{ek} (min)	Station time (min)
1	2	0.4	
	5	0.3	
	1	0.2	
	4	0.1	0.1
2	3	0.7	
	6	0.11	0.81
3	8	0.6	
	10	0.38	0.98
4	7	0.32	
	9	0.27	0.59
5	11	0.5	
	12	0.12	0.62

$$E_b = \frac{4.0}{5 (0.98)} = 0.816$$

$$\text{Cycle Time (T}_c\text{)} = T_s + T_r = 0.98 + 0.08 = 1.06 \text{ min}$$

$$R_c = \frac{60}{1.06} = 56.66 \text{ cycles/hr}$$

$$R_p = 57 \times 0.96 = 54.72 \text{ units/hr}$$

KILBRIDGE & WESTER METHOD

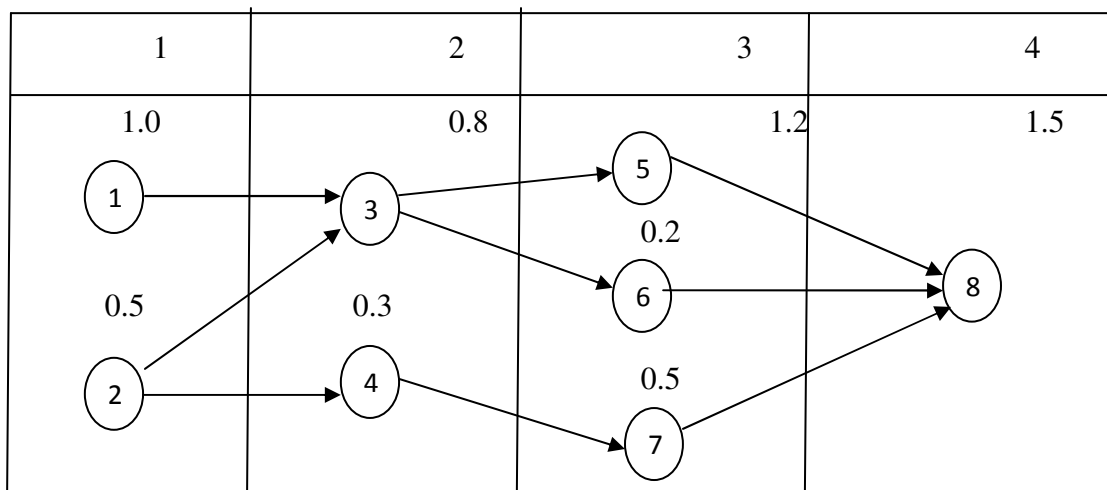
Problem 2:

The following list defines the precedence relationships & element times for a new model toy:

Element	1	2	3	4	5	6	7	8
T_c min	1.0	0.5	0.8	0.3	1.2	0.2	0.5	1.5
Immediate Predecessor	---	---	1, 2	2	3	3, 4	4	5, 6, 7

- I. Construct the precedence diagram.
- II. If the ideal cycle is 1.5 mins, what is the theoretical minimum number of stations required to minimize the balance delay?
- III. Compute the balance delay.

Step 1:



Step 2:

Work Element	Column	T (mins)	Preceded by
1	i	1.0	-
2	i	0.5	-
3	ii	0.8	1,2
4	ii	0.3	2
5	iii	0.2	3
6	iii	0.2	3
7	iii, iv	0.5	4
8	iv	1.5	6,7,8

Step 3:

Station	Work Element	Column	Tc (min)	Station Time
1	1	i	1.0	1.5
	2	i	0.5	
2	3	ii	0.8	1.3
	4	ii	0.3	
3	5	iii	0.2	1.2
	6	iii	1.2	
4	7	iii, iv	0.5	0.5
5	8	iv	1.5	1.5

$$E_b = \frac{6}{5(1.5)} = 0.80$$

$$R_c = \frac{60}{1.5} = 40 \text{ cycles/hr}$$

$$R_p = 40 \times 0.96 = 38.4 \text{ pieces/hr}$$

Ranked Positional Weight Method:

Step 1:

The Ranked positional weights method is applied to the second problem in the following steps

$$\text{RPW1} = 0.8 + 1.2 + 0.2 + 1.5 = 4.7 \text{ mins}$$

$$\text{RPW2} = 0.5 + 0.8 + 0.3 + 1.2 + 0.2 + 0.5 + 1.5 = 5 \text{ mins}$$

$$\text{RPW3} = 0.8 + 0.2 + 1.2 + 1.5 = 3.7 \text{ mins}$$

$$\text{RPW4} = 0.3 + 0.2 + 0.5 + 1.5 = 2.5 \text{ mins}$$

$$\text{RPW5} = 1.2 + 1.5 = 2.7 \text{ mins}$$

$$\text{RPW6} = 0.2 + 1.5 = 1.7 \text{ mins}$$

$$\text{RPW7} = 0.5 + 1.5 = 2 \text{ mins}$$

$$\text{RPW8} = 1.5 \text{ mins}$$

Step 2

Work Element	RPW	T (mins)	Preceded by
2	5	0.5	-
1	4.7	1.0	-
3	3.7	0.8	1,2
5	2.5	1.2	3
4	2.7	0.3	2
6	1.7	0.2	3, 4
7	2	0.5	4
8	1.5	1.5	5,6,7

Step 3:

Station	Work Element	Tc (min)	Station Time
1	2	0.5	1.5
	1	1.0	
2	3	0.8	1.3
	4	0.3	
	6	0.2	1.2
3	5	1.2	
4	7	0.5	0.5
5	8	1.5	1.5

$$E_b = \frac{6}{5(1.5)} = 0.80$$

$$\text{Cycle Time} = T_c + T_v = 1.5 + 0.8 = 1.58 \text{ mins}$$

$$R_c = \frac{60}{1.58} = 38 \text{ cycles / hr}$$

$$R_p = 38 \times 0.96 = 36.48 \text{ pieces/hr}$$

UNIT-5:

AUTOMATED ASSSEMBLY SYSTEMS

Automated Assembly Systems

Assembly involves the joining together of two or more separate parts to form new entity which may be assembly or subassembly.

Automated assembly refers to the use of mechanized and automated devices to perform the various functions in an assembly line or cell.

Automated assembly system performs a sequence of automated operations to combine multiple components in to a single entity which can be a final product or sub assembly.

Automated assembly technology should be considered when the following condition exists.

- ✓ High product demand
- ✓ Stable product design
- ✓ The assembly consists of no more than a limited number of components.
- ✓ The product is designed for automated assembly.

Automated assembly system involves less investment compared to transfer lines because

1. Work part produced are smaller in size compared to transfer lines.
2. Assembly operations do not have the large mechanical forces and power requirement
3. Size is very less compared to transfer lines.

DESIGNS FOR AUTOMATED ASSEMBLY

Recommendations and principles that can be applied in product design to facilitate automated assembly

- ☞ ***Reduce the amount of assembly required:*** This principle can be realized during design by combining functions within the same part that were previously accomplished by separate components in the product. The use of plastic molded parts to substitute for sheet metal parts is an example of this principle. A more complex geometry molded into a plastic part might replace several metal parts.

Although the plastic part may seem to be more costly, the savings-in assembly time probably justify the substitution in many cases.

- ☞ ***Use modular design:*** In automated assembly, increasing the number of separate assembly steps that are done by a single automated system will result in an increase in the downtime of the system. To reduce this effect, Riley suggests that the design of the product be modular, with perhaps each module requiring a maximum of 12 or 13 parts to be assembled on a single assembly system. Also, the subassembly should be designed around a base part to which other components are added.
- ☞ ***Reduce the number of fasteners required:*** Instead of using separate screws and nuts, and similar fasteners, design the fastening mechanism into the component design using snap fits and similar features. Also, design the product modules so that several components are fastened simultaneously rather than each component fastened separately.
- ☞ ***Reduce the need for multiple components to lie handled at once:*** The preferred practice in automated assembly machine design is to separate the operations at different stations rather than to handle and fasten multiple components simultaneously at the same workstation. (It should be noted that robotics technology is causing a rethinking of this practice since robots can be programmed to perform more complex assembly tasks than a single station in a mechanized assembly system.
- ☞ ***Limit the required directions of access:*** This principle simply means that the number of directions in which new components are added to the existing subassembly should be minimized. If all of the components can be added vertically from above, this is the ideal situation. Obviously, the design of the subassembly module determines this.
- ☞ ***Require high quality in components:*** High performance of the automated assembly system requires consistently good quality of the components that are added at each workstation. Poor-quality components cause jams in the feeding and assembly mechanisms which cause downtime in the automated system.
- ☞ ***Implement hopperability:*** This is a term that is used to identify the ease with which a given component can be fed and oriented reliably for delivery from the parts hopper to the assembly workhead.

TYPES OF AUTOMATED ASSEMBLY SYSTEMS

Based on the type of work transfer system that is used in the assembly system:

- Continuous transfer system
- Synchronous transfer system
- Asynchronous transfer system
- Stationary base part system

The first three types involve the same methods of workpart transport described in automated flow line. In the stationary base part system, the base part to which the other components are added is placed in a fixed location, where it remains during the assembly work.

Based on physical configuration:

- Dial-type assembly machine
- In-line assembly machine
- Carousel assembly system
- Single-station assembly machine

The *dial-type machine*, the base part are indexed around a circular table or dial. The workstations are stationary and usually located around the outside periphery of the dial. The parts ride on the rotating table and are registered or positioned, in turn, at each station a new component is added to base part. This type of equipment is often referred to as an *indexing machine* or *dial index machine* and the configuration is shown in Figure 1 and example of six station rotary shown in figure 2.

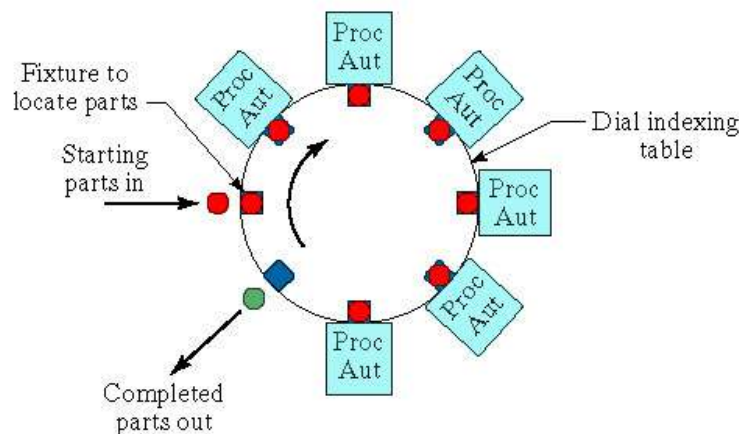


Figure 1 Rotary configuration



Figure 2 Example of 6 station rotary configuration for assembly

In-line type configuration

The *in-line* configuration assembly system consists of a sequence of workstations in a more-or-less straight-line arrangement as shown in figure 3. An example of an in-line transfer machine used for metal-cutting operations is illustrated in Figure 4. The *in-line assembly machine* consists of a series of automatic workstations located along an in-line transfer system. It is the automated version of the manual assembly line. Continuous, synchronous, or asynchronous transfer systems can be used with the in-line configuration.

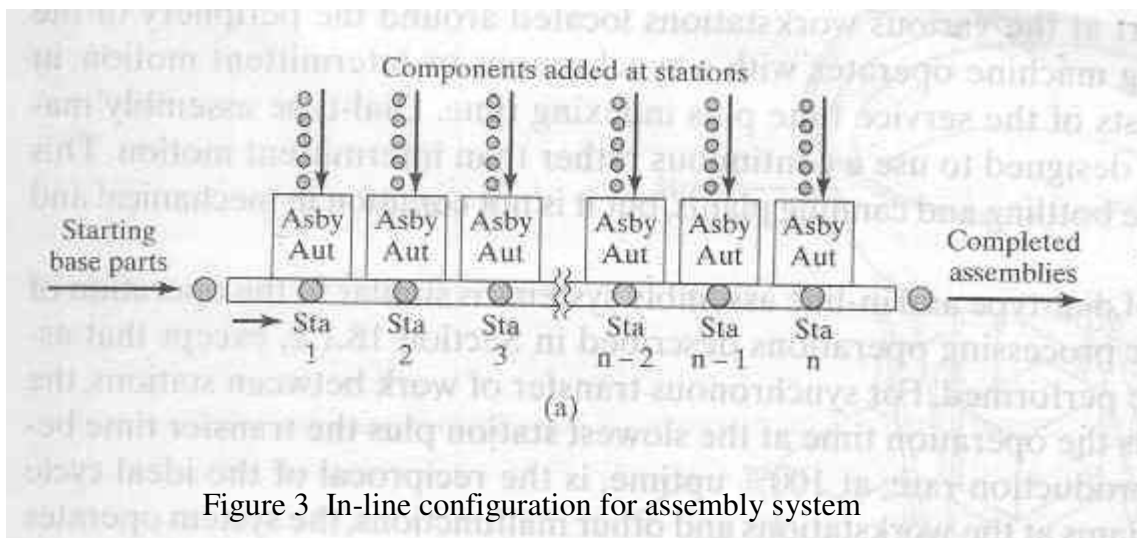


Figure 3 In-line configuration for assembly system

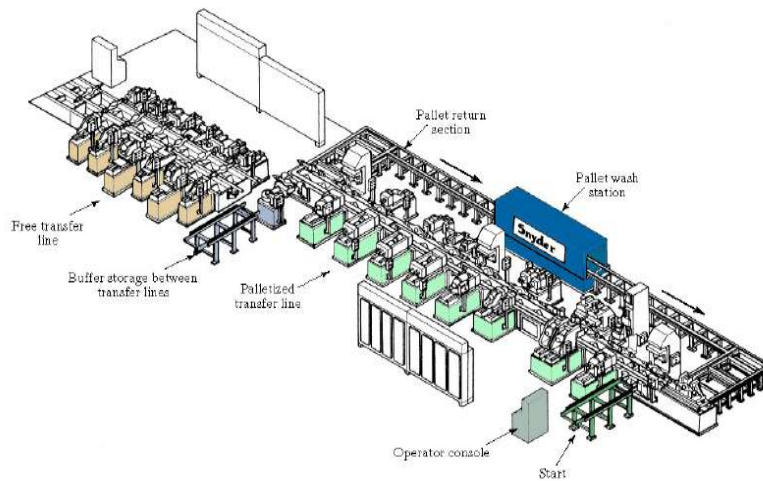


Figure 4 Example of 20 stations In-line configuration

Segmented In-line type

The segmented *in-line* configuration consists of two or more straight-line arrangement which are usually perpendicular to each other with L-Shaped or U-shaped or Rectangular shaped as shown in figure 5-7. The flow of work can take a few 90° turns, either for workpieces reorientation, factory layout limitations, or other reasons, and still qualify as a straight-line configuration.

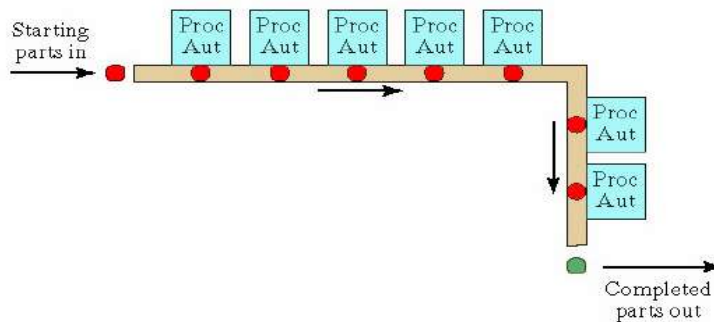


Figure 5 L-shaped configuration

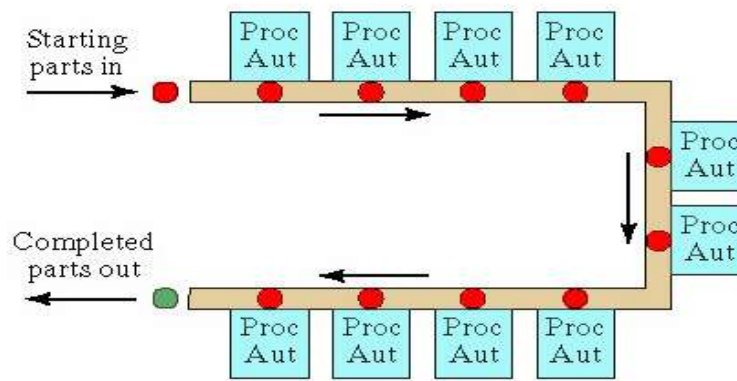


Figure 6 U-shaped configuration

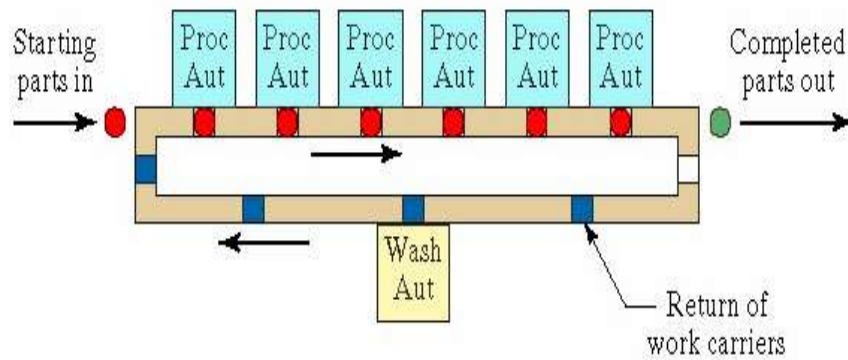


Figure 7 Rectangular-shaped configuration

Carousel assembly system

It represents a hybrid between the circular flow of work provided by the dial assembly machine and straight work flow of the in-line. It is as shown in the figure 8

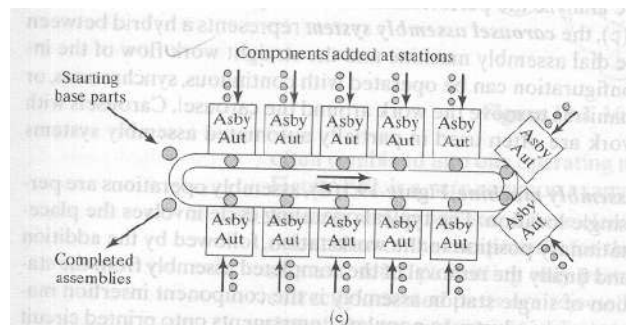


Figure 8 configuration of a carousel assembly system

Single-station assembly machine

In the single-station assembly machine, the assembly operations are performed at a single location (stationary base part system) as shown in figure 9. The typical operation involves the placement of the base part at the workstation where various components are added to the base. The components are delivered to the station by feeding mechanisms, and one or more workheads perform the various assembly and fastening operations.

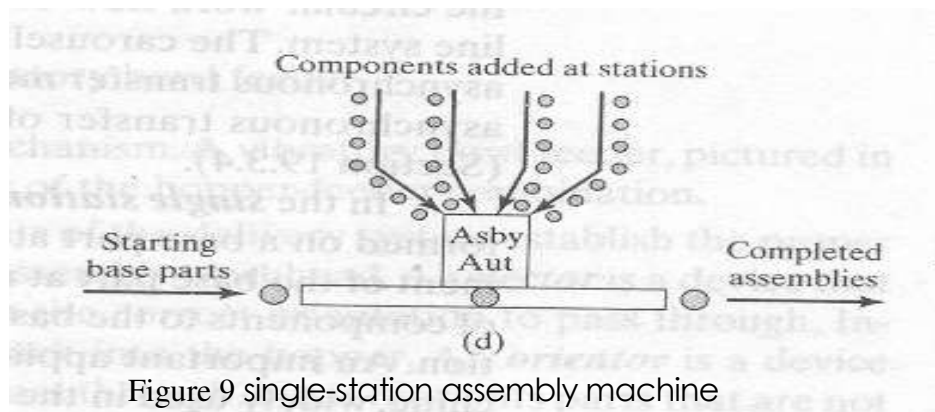


Figure 9 single-station assembly machine

PARTS FEEDING DEVICES

In each of the configurations described above, a means of delivering the components to the assembly workhead must be designed. In this section we discuss these devices and their operation.

Elements of the parts delivery system

The hardware system that delivers components to the workhead in an automated assembly system typically consists of the following elements as shown in figure 10:

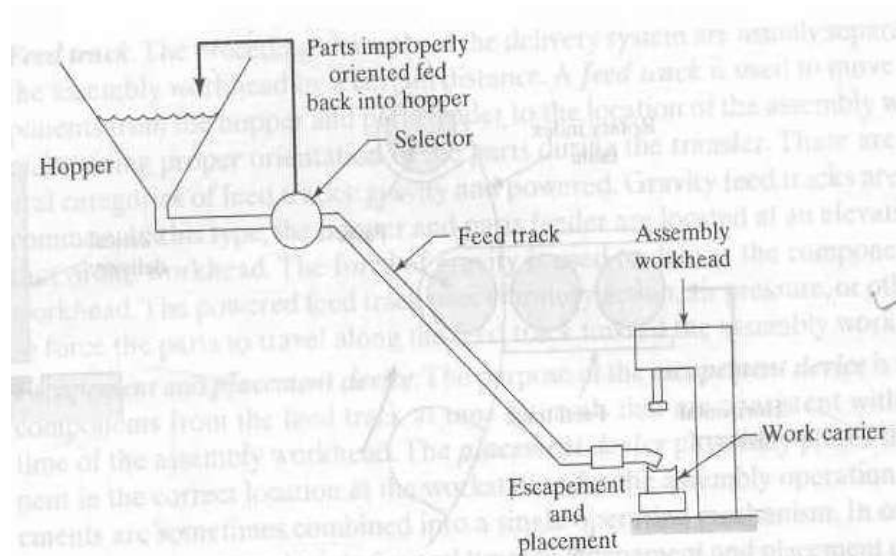


Figure 10 elements of part delivery system

☞ **Hopper:** This is the container into which the components are loaded at the workstation. A separate hopper is used for each component type. The components are usually loaded into the hopper in bulk. This means that the parts are randomly oriented initially in the hopper.

☞ **Parts feeder:** This is a mechanism that removes the components from the hopper one at a time for delivery to the assembly workhead. The hopper and parts feeder are often combined into one operating mechanism. The vibratory bowl feeder, pictured in Figure 11, is a very common example of the hopper-feeder combination.

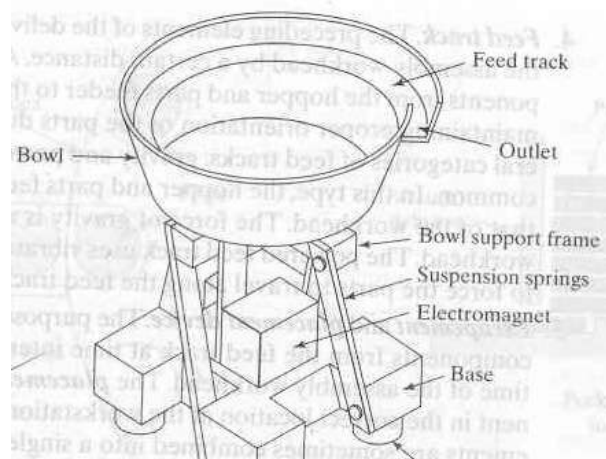


Figure 11 vibratory bowl feeder

☞ **Selector and/or orienter:** These elements of the delivery system establish the proper orientation of the components for the assembly workhead. A selector is a device that acts as a filter, permitting only parts that are in the correct orientation to pass through. Components that are not properly oriented are rejected back into the hopper. An orienter is a device that allows properly oriented parts to pass through but provides a reorientation of components that are not properly oriented initially. Several selector and orienter schemes are illustrated in Figure 12. Selector and orienter devices are often combined and incorporated into one hopper-feeder system.

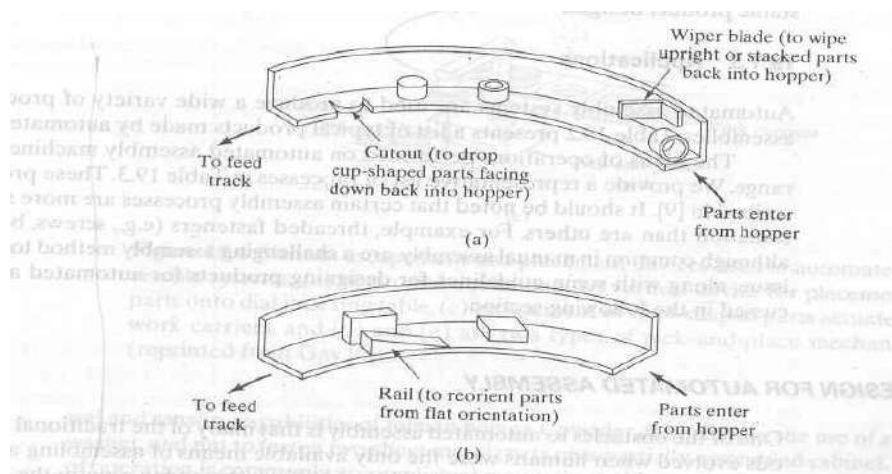


Figure 12 selector (a) and orienter (b)

☞ **Feed track:** The preceding elements of the delivery system are usually located some distance from the assembly workhead. A feed track is used to transfer the components from the hopper and parts feeder to the location of the assembly workhead, maintaining proper orientation of the parts during the transfer. There are two general categories of feed tracks: gravity and powered. The gravity feed track is most common. In this type the hopper and parts feeder are located at an elevation that is above the elevation of the workhead. The force of gravity is used to deliver the components to the workhead. The powered feed track uses vibratory action, air pressure, or other means to force the parts to travel along the feed track toward the assembly workhead.

☞ **Escapement and placement device:** The purpose of the escapement device is to remove components from the feed track at time intervals that are consistent with the cycle time of the assembly workhead. The placement device physically places the component in the correct location at the workstation for the assembly operation by the workhead. Several types of escapement and placement devices are shown in Figure 13.

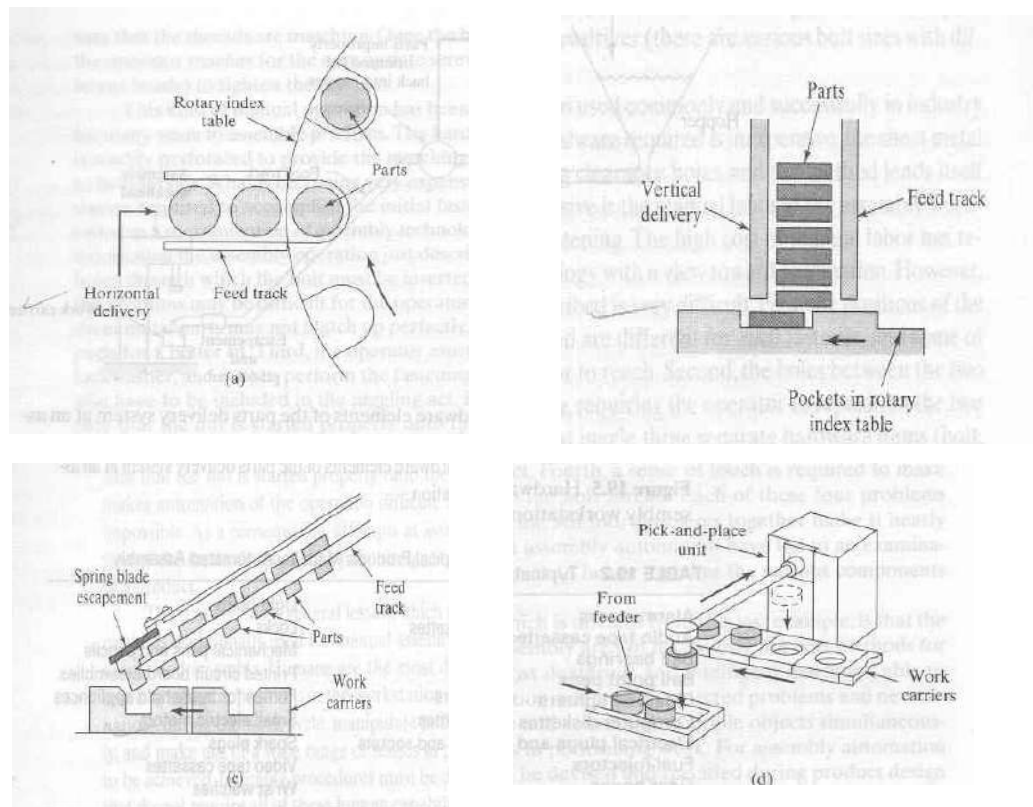


Figure 13 various escapement and placement devices

Quantitative analysis of the delivery system operation

The parts feeding mechanism is capable of removing parts from the hopper at a certain rate f . These parts are assumed to be in random orientation initially, and must be presented to the selector or orientor to establish the correct orientation. In the case of the selector, a certain proportion of the parts will be correctly oriented initially and these will be allowed to pass through. The remaining proportion, which is incorrectly oriented, will be rejected back into the hopper. In the case of the orientor, the parts that are incorrectly oriented will be reoriented, resulting ideally in a 100% rate of parts passing through the orientor device. In many delivery system designs, the functions of the selector and the orientor will be combined. Let us define θ to be the proportion of components that pass through the selector-orientor process and are correctly oriented for delivery into the feed track. Hence the effective rate of delivery of components from the hopper into the feed track will be $f\theta$. The remaining proportion, $(1 - f\theta)$, will be recirculated back into the hopper.

Assuming that the delivery rate of components $f\theta$ is greater than the cycle rate R_c of the assembly machine, a means of limiting the size of the queue in the feed track must be established. This is generally accomplished by placing a sensor (e.g., limit switch, optical sensor, etc.) near the top of the feed track, which is used to turn off the feeding mechanism when the feed track is full. This sensor is referred to as the high-level sensor, and its location defines the active length L_{f2} of the feed track. If the length of a component in the feed track is L_c , the number of parts that can be held in the feed track is $n_{f2} = L_{f2}/L_c$. The length of the components must be measured from a point on a given component to the corresponding point on the next component in the queue to allow for possible overlap of parts. The value of n_{f2} is the capacity of the feed track.

Another sensor is placed along the feed track at some distance from the first sensor and is used to restart the feeding mechanism-again. Defining the location of this low-level sensor as L_{f1} , the number of components in the feed track at this point is $n_{f1} = L_{f1}/L_c$.

The rate at which the quantity of parts in the buffer will be reduced when the high-level sensor is actuated $= R_c$, where R_e is the theoretical cycle rate of the assembly machine. On average, the rate at which the quantity of parts will increase upon actuation of the low-level sensor is $f\theta - R_c$. However, the rate of increase will not be uniform due to the random nature of the feeder-selector operation.

Accordingly, the value of n_{f1} must be made large enough to virtually eliminate the probability of a stockout after the low-level sensor has turned on the feeder.

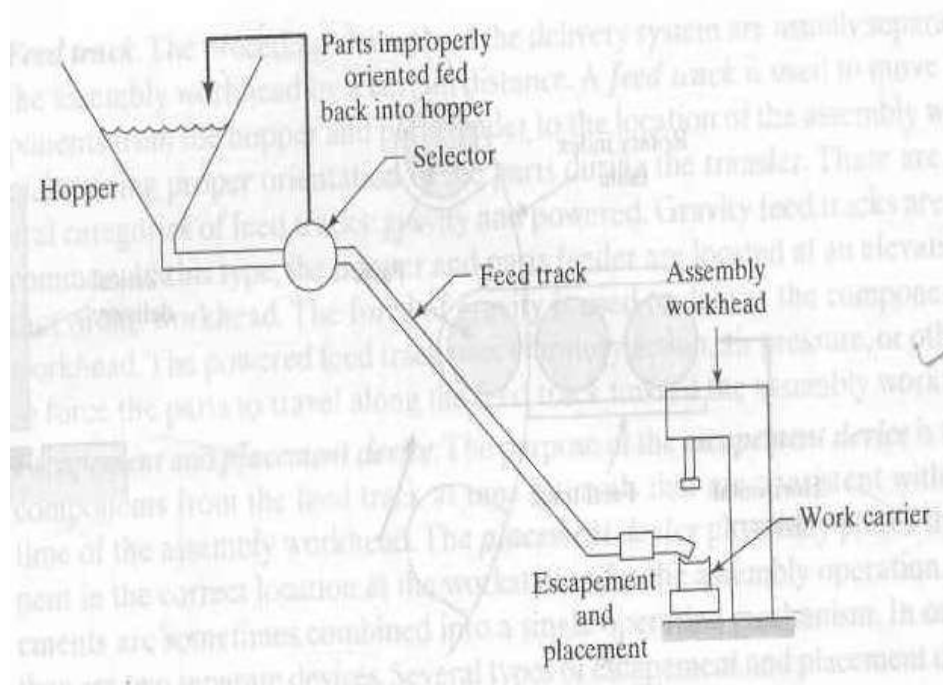


Figure 14 elements of the parts delivery system at an assembly workstation

$$\begin{aligned}
 R_C &\rightarrow \text{Cycle rate of Assembly System} & n_{f_2} &= \frac{L_{f_2}}{L_C} \rightarrow \text{Number of component in feed track} \\
 L_C &\rightarrow \text{Length of component} & n_{f_1} &= \frac{L_{f_1}}{L_C} \rightarrow \text{Number of components at low level sensors} \\
 L_{f_2} &\rightarrow \text{Length of feed track (High level sensors)} \\
 L_{f_1} &\rightarrow \text{Length of low level sensors} \\
 f &\rightarrow \text{The rate at which parts are removed from hopper} \\
 \theta &\rightarrow \text{Proportionate of components that passes through selector-orientor} \\
 f\theta &\rightarrow \text{Effective rate of delivery of components} \\
 f\theta - R_C &\rightarrow
 \end{aligned}$$

In this section we examine the operation and performance of automated assembly machines that have several workstations and use a synchronous transfer system. The types include the dial indexing machine, many in-line assembly systems, and certain carousel systems. The measures of performance are production rate, uptime efficiency, and cost. The analysis of an automated assembly machine with multiple stations shares much in common with the upper-bound approach used for metal machining transfer lines. Some modifications in the analysis must be made to account for the fact that components are being added at the various workstations in the assembly system. The general operation of the assembly system is pictured in Figure 15. In developing the equations that govern the operation of the system, we shall follow the general approach suggested by Boothroyd and Redford.

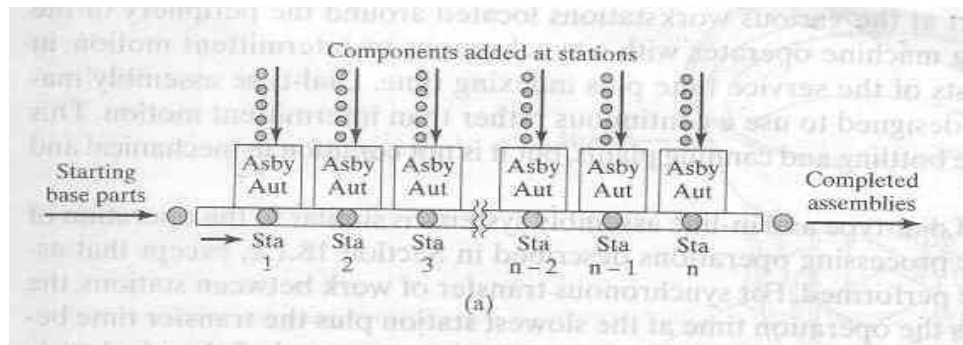


Figure 15 Multistation assembly line

We assume that the typical operation occurring at a workstation of an assembly machine is one in which a component is added or joined in some fashion to an existing assembly. The existing assembly consists of a base part plus the components assembled to it at previous stations. The base part is launched onto the line either at or before the first workstation. The components that are added must be clean, uniform in size and shape, of high quality, and consistently oriented. When the feed mechanism and assembly workhead attempt to join a component that does not meet these specifications, the station can jam. When this occurs, it can result in the shutdown of the entire machine until the fault is corrected. Thus, in addition to the other mechanical and electrical failures that interrupt the operation of a flow line, the problem of defective components is one that specifically plagues the operation of an automatic assembly machine. This is the problem we propose to deal with.

The assembly machine as a game of chance

Defective parts are a fact of manufacturing life. Defects occur with a certain fraction defective rate, q . In the operation of an assembly workstation, q can be considered as the probability that the next component is defective. When an attempt is made to feed and assemble a defective component, the defect might or might not cause the station to jam. Let m equal the probability that a defect will result in the malfunction and stoppage of the workstation. Since the values of q and m may be different for different stations, we subscript these terms as q_i and m_i , where $i = 1, 2, \dots, n$ the number of stations on the assembly machine.

Considering what happens at a particular workstation, station i , there are three possible events that might occur when the feed mechanism attempts to feed the component and the assembly device attempts to join it to the existing assembly:

1. The component is defective and causes a station jam,
2. The component is defective but does not cause a station jam.
3. The component is not defective.

The probability of the first event is the product of the fraction defective rate for the station, q_i , multiplied by the probability that a defect will cause the station to stop, m_i , the probability that a part will jam at station i . For an assembly machine,

$$P_i = m_i q_i$$

The second possible event, when the component is defective but does not cause a station jam, has a probability given by

$$P_i = (1 - m_i) q_i$$

With this outcome, a bad part is joined to the existing assembly, perhaps rendering the entire assembly defective.

The third possibility is obviously the most desirable. The probability that the component is not defective is equal to the proportion of good parts

$$P_i = (1 - q_i)$$

The probabilities of the three possible events must sum to unity.

$$m_i q_i + (1 - m_i) q_i + (1 - q_i) = 1$$

To determine the complete distribution of possible outcomes that can occur on an n-station assembly machine, we can multiply the terms of above Equation together for all stations;

$$\prod_{i=1}^n [m_i q_i + (1 - m_i) q_i + (1 - q_i)] = 1$$

In the special case of Eq., where all m_i are equal and all q_i are equal, then equation becomes

$$[m q + (1 - m) q + (1 - q)]^n = 1$$

Measures of performance

Fortunately, we are not required to calculate every term to make use of the concept of assembly machine operation provided by above Equations. One of the characteristics of performance that we might want to know is the proportion of assemblies that contain one or more defective components. Two of the three terms in above Equation represent events that result in the addition of good components at a given station. The first term is $m_i q_i$, which indicates a line stop but also means that a defective component has not been added to the assembly. The other term is $(1 - q_i)$, which means that a good component has been added at the station. The sum of these two terms represents the probability that a defective component will not be added at station i . Multiplying these probabilities for all stations, we get the proportion of acceptable product coming off the line, P_{ap}

$$P_{ap} = \prod_{i=1}^n [m_i q_i + (1 - q_i)]$$

In the special case where all m_i are equal and all q_i are equal, then equation becomes

$$P_{ap} = [m q + (1 - q)]^n$$

If this is the proportion of assemblies with no defective components, the proportion of assemblies that contain at least one defect is given by

$$P_{qp} = 1 - \prod_{i=1}^n [m_i q_i + (1 - q_i)]$$

In the special case where all m_i are equal and all Q_i are equal, then equation becomes

$$, \quad P_{qp} = 1 - [m_i q_i + (1 - q_i)]^n$$

In addition to the proportions of good and bad assemblies as measures of performance for an assembly machine, we are also interested in the machine's production rate, proportions of uptime and downtime, and average cost per unit produced.

To calculate production rate we must first determine the frequency of downtime occurrences per cycle, f . If each station jam results in a machine downtime occurrence, f can be found by taking the expected number of station jams per cycle.

$$F = \sum_{i=1}^n P_i = \sum_{i=1}^n m_i q_i$$

In the special case where all m_i are equal and all Q_i are equal, then equation becomes

$$F = nm q$$

Average production time per assembly is therefore given by

$$T_P = T_C + \sum_{i=1}^n m_i q_i T_D$$

T_c = ideal cycle time

T_d = average downtime per occurrence

In the special case where all m_i are equal and all Q_i are equal, then equation becomes

$$T_P = T_C + nm q T_D$$

The rate of production of acceptable product is given by equation

$$R_p = \frac{1}{T_p}$$

$$R_{ap} = \frac{\prod_{i=1}^n [m_i q_i + (1 - q_i)]}{T_p} = \frac{P_{ap}}{T_p}$$

In the special case where all m_i are equal and all Q_i are equal, then equation becomes

$$R_{ap} = \frac{(mq + (1 - q))^n}{T_p}$$

The line efficiency is calculated as the ratio of ideal cycle time to average production time.

$$E = \frac{T_C}{T_p} = \frac{T_C}{T_C + nm q T_D}$$

The proportion of downtime, D , is the average downtime per cycle divided by the average production time is given by

$$D = \frac{nm q T_D}{T_p} = \frac{nm q T_D}{T_C + nm q T_D}$$

The cost per assembly produced, is given by

$$C_{pc} = \frac{C_m + C_L \times T_p + C_t}{(mq + (1 - q))^n} = \frac{C_m + C_L \times T_p + C_t}{P_{ap}}$$

1. A 10 station in-line assembly machine has a 6-s ideal cycle time. The base part is automatically loaded prior to the first station. The fraction defect rate at each of 10 stations is equal to 0.01 and the probability that a defect will jam is 0.5. when jam occurs, the average down time is 2 minutes. Determine the average production rate, the yield of good assemblies, and the uptime efficiency of the assembly machine.

$$\text{The average production cycle time} = T_p = T_c + nm q T_D$$

$$T_p = 0.1 + 10 \times 0.5 \times 0.01 \times 2.0 = 0.2 \text{ min}$$

$$R_p = \frac{1}{T_p} = \frac{1}{0.2} = 5 \times 60 = 300 \text{ assemblies / Hr}$$

The yield of good products

$$P_{ap} = \left[m_i q_i + (1 - q_i) \right]^n$$

$$P_{ap} = \left[0.5 \times 0.01 + (1 - 0.01) \right]^{10} = 0.9511$$

Uptime efficiency

$$E = \frac{T_c}{T_p} = \frac{0.1}{0.2} = 0.50 = 50\%$$

7.5 ANALYSIS OF A SINGLE-STATION ASSEMBLY MACHINE

The single-station assembly machine can be pictured as shown in Figure 16. We assume a single workhead, with several components feeding into the station to be assembled. Let us use n to represent the number of distinct assembly elements that are performed on the machine. Each element has an element time, T_{ei} , where $i = 1, 2, \dots, n$. The ideal cycle time for the single-station assembly machine is the sum of the individual element times of the assembly operations to be performed on the machine, plus the handling time to load the base part into position and unload the completed assembly. We can express this ideal cycle time as

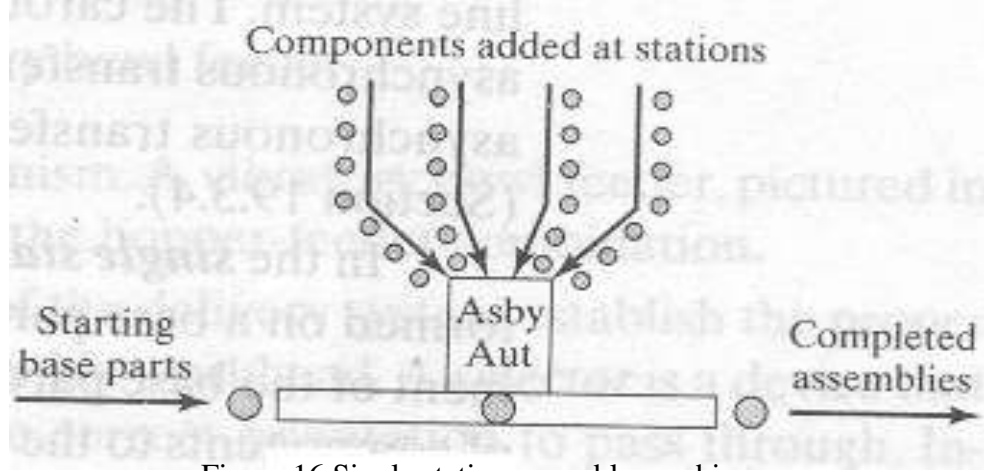


Figure 16 Single station assembly machine

where T_h is the handling time,

$$T_C = T_h + \sum_{i=1}^n T_{ei}$$

Many of the assembly elements involve the addition of a component to the existing subassembly. As in our analysis of the multiple-station assembly system, each component type has a certain fraction defect rate, q_i and there is a certain probability that a defective component will jam the workstation, m_i . When a jam occurs, the assembly machine stops, and it takes an average T_d to clear the jam and restart the system. The inclusion of downtime resulting from jams in the machine cycle time gives.

Average production time per assembly is therefore given by

$$T_P = T_C + \sum_{i=1}^n m_i q_i T_D$$

T_c = ideal cycle time

T_d = average downtime per occurrence

In the special case where all m_i are equal and all Q_i are equal, then equation becomes

$$T_P = T_C + nm q T_D$$

The rate of production of acceptable product is given by equation

$$R_P = \frac{1}{T_P}$$
$$R_{ap} = \frac{\prod_{i=1}^n [m_i q_i + (1 - q_i)]}{T_P} = \frac{P_{ap}}{T_p}$$

In the special case where all m_i are equal and all Q_i are equal, then equation becomes

$$R_{ap} = \frac{(mq + (1 - q))^n}{T_P}$$

The line efficiency is calculated as the ratio of ideal cycle time to average production time.

$$E = \frac{T_C}{T_P} = \frac{T_C}{T_C + nm q T_D}$$

The proportion of downtime, D , is the average downtime per cycle divided by the average production time is given by

$$D = \frac{nm q T_D}{T_P} = \frac{nm q T_D}{T_C + nm q T_D}$$

The cost per assembly produced, is given by

$$C_{pc} = \frac{C_m + C_L \times T_P + C_t}{(mq + (1 - q))^n} = \frac{C_m + C_L \times T_P + C_t}{P_{ap}}$$

AUTOMATED GUIDED VEHICLE SYSTEMS

An automated or automatic guided vehicle system (AGVS) is a materials handling system that uses independently operated, self-propelled vehicles that are guided along defined pathways in the floor. The vehicles are powered by means of on-board batteries that allow operation for several hours (8 to 16 hours is typical) between recharging. The definition of the pathways is generally accomplished using wires embedded in the floor or reflective paint on the floor surface. Guidance is achieved by sensors on the vehicles that can follow the guide wires or paint.

Automated guided vehicles (AGVs) increase efficiency and reduce costs by helping to automate a manufacturing facility or warehouse.

AGVS can carry loads or tow objects behind them in trailers to which they can autonomously attach. The trailers can be used to move raw materials or finished product. The AGV can also store objects on a bed. The objects can be placed on a set of motorized rollers (conveyor) and then pushed off by reversing them. Some AGVs use forklifts to lift objects for storage. AGVs are employed in nearly every industry, including, pulp, paper, metals, newspaper, and general manufacturing. Transporting materials such as food, linen or medicine in hospitals is also done.

There are a number of different types of AGVS all of which operate according to the preceding description. The types can be classified as follows:

- ☞ *Driverless trains*: This type consists of a towing vehicle (which is the AGV) that pulls one or more trailers to form a train. It was the first type of AGVS to be introduced and is still popular. It is useful in applications where heavy payloads must be moved large distances in warehouses or factories with intermediate pickup and drop-off points along the route. Figure 17 illustrates the driverless-train AGVS.

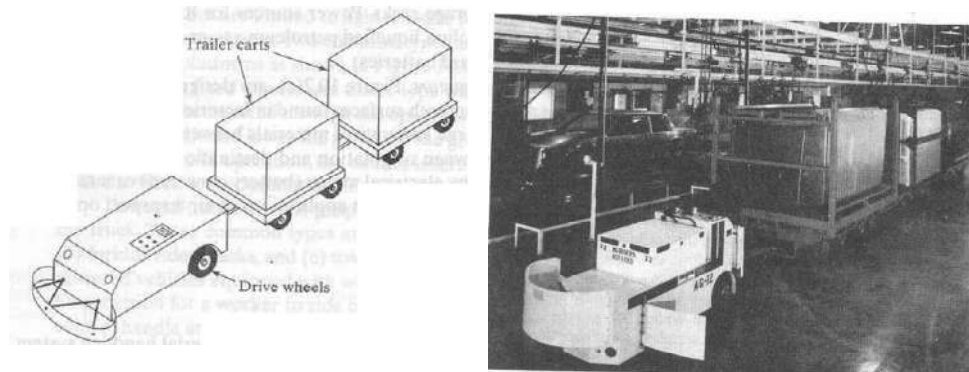


Figure 17 Driverless trains

☞ *AGVS pallet trucks:* Automated guided pallet trucks are used to move palletized loads along predetermined routes. In the typical application the vehicle is backed into the loaded pallet by a human worker who steers the truck and uses its forks to elevate the load slightly. Then the worker drives the pallet truck to the guideway, programs its destination, and the vehicle proceeds automatically to the destination for unloading. The capacity of an AGVS pallet truck ranges up to 6000 lb, and some trucks are capable of handling two pallets rather than one. A more recent introduction related to the pallet truck is the forklift AGV. This vehicle can achieve significant vertical movement of its forks to reach loads on shelves. Figure 18 illustrates this vehicle type.



Figure 19 AGV pallet trucks

☞ *AGVS unit load carriers.* This type of AGVS is used to move unit loads from one station to another station. They are often equipped for automatic loading and unloading by means of powered rollers, moving belts, mechanized lift platforms, or other devices. The unit load carrier is pictured in Figure 20. Variations of the unit load carrier include light-load AGVs and assembly line AGVs. The light-load AGV is a relatively small vehicle with a corresponding light load capacity (typically 500 lb or less). It does not require the same large aisle width as the conventional AGV. Light-load guided vehicles are designed to move small loads (single parts, small baskets or tote pans of parts, etc.) through plants of limited size engaged in light manufacturing. The assembly line AGVS is designed to carry a partially completed subassembly through a sequence of assembly workstations to build the product.



Figure 21 AGV unit load carrier

Vehicle guidance and routing

There are several functions that must be performed to operate any automated guided vehicle system successfully. These functions are:

- 1, Vehicle guidance and routing
- 2, Traffic control and safety
- 3, System management

We describe these functions in this and the following two subsections.

The term *guidance system* refers to the method by which the AGVS pathways are defined and the vehicle control systems that follow the pathways. As indicated above, there are two principal methods currently in use to define the pathways along the floor: embedded guide wires and paint strips. Of the two types, the guide wire system is the more common in warehouse and factory applications.

In the guide wire method the wires are usually embedded in a small channel cut into the surface of the floor. The channel is typically about 1/8 in. wide and 1/2 in. deep. After the guide wires are installed, the channel slot is filled so as to eliminate the discontinuity in the floor surface as shown in figure 22. An alternative but less permanent way to install the guide wires is to tape them to the floor. A frequency generator provides the guidance signal carried in the wire. The signal is of relatively low voltage (less than 40 V), low current (less than 400 mA), and has a frequency in the range 1 to 15 kHz. This signal level creates a magnetic field along the pathway that is followed by sensors on-board each vehicle. The operation of a typical system is illustrated in Figure 22 Two sensors (coils) are mounted on the vehicle on either side of the guide wire. When the vehicle is moving along a course such that the guide wire is directly between the two coils, the intensity of the magnetic field measured by each coil will be equal. If the vehicle strays to one side or the other, or if the guide wire path curves, the magnetic field intensity at the two sensors will be different. This difference is used to control the steering motor, which makes the required changes in vehicle direction to equalize the two sensor signals, thereby tracking the defined pathway.

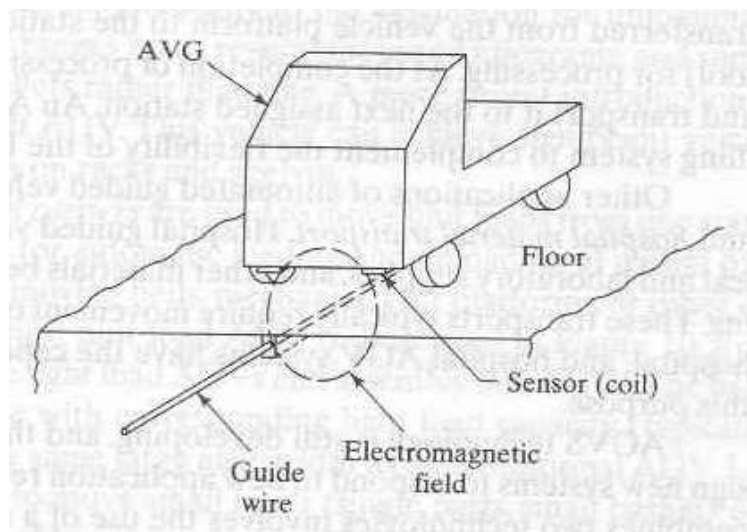


Figure 22 wire guided AGV

When paint strips are used to define the vehicle pathways, the vehicle possesses an optical sensor system that is capable of tracking the paint. The strips can be taped, sprayed, or painted on the floor. One system uses a 1-in.-wide paint strip containing fluorescent particles that reflect an ultraviolet (UV) light source on the vehicle. An on-board sensor detects the reflected light in the strip and controls the steering mechanism to follow it. The paint guidance system is useful in environments where electrical noise would render the guide wire system unreliable or when the installation of guide wires in the floor surface would not be appropriate. One problem with the paint strip guidance method is that the paint strip must be maintained (kept clean and unscratched).

A safety feature used in the operation of most guidance systems is automatic stopping of the vehicle in the event that it accidentally strays more than a few inches (typically 2 to 6 in.) from the guide path. This automatic-stopping feature prevents the vehicle from running wild in the building. Alternatively, in the event that the vehicle is off the guide path (e.g., for manual loading of a pallet truck), it is capable of locking onto the guide wire or paint strip if moved within the same few inches of it. The distance is referred to as the vehicle's *acquisition distance*.

The use of microprocessor controls on-board the vehicles has led to the development of a feature called *dead reckoning*. This term refers to the capability of the vehicle to travel along a route that does not follow the defined pathway in the floor. The microprocessor computes the number of wheel rotations and the operation of the steering motor required to move along the desired path. Dead reckoning might be employed by the vehicle to cross a steel plate in the factory floor (where guide wires cannot be

installed), or to depart from the guide path for positioning at a load/unload station. At the completion of the dead-reckoning maneuver, the vehicle is programmed to return to within (the acquisition distance of the guide path to resume normal guidance control.

Routing in an AGVS is concerned with the problem of selecting among alternative pathways available to a vehicle in its travel to a defined destination point in the system. A typical guided vehicle layout, one that exploits the capabilities of modern AGVS technology, contains features such as multiple loops, branches, side tracks, and spurs, in addition to the required pickup and drop-off stations. Vehicles in the system must decide which path to take to reach a defined destination point.

When a vehicle approaches a branching point in which the guide path splits into two (or more) directions, a decision must be made as to which path the vehicle should take. This is sometimes referred to as a *decision point* for the vehicle. There are two methods used in commercial AGV systems to permit the vehicle to decide which path to take:

1. Frequency select method
2. Path switch select method

In the *frequency select method*, the guide wires leading into the two separate paths at the branch have different frequencies. As the vehicle enters the decision point, it reads an identification code on the floor to identify its location. Depending on its programmed destination, the vehicle selects one of the guide paths by deciding which frequency to track. This method requires a separate frequency generator for each frequency that is used in the guide path layout. This usually means that two or three generators are needed in the system. Additional channels must often be cut into the floor with the frequency select method to provide for bypass channels where only the main channel needs to be powered for vehicle tracking.

The *path switch select method* uses a single frequency throughout the guide path layout. In order to control the path of a vehicle at a decision point, the power is switched off in all branches except the one on which the vehicle is to travel. To accomplish routing by the path switch select method, the guide path layout must be divided into blocks that can be independently turned on and off by means of controls mounted on the floor near their respective blocks. These control units are operated by the vehicles as they move in the various blocks. As a vehicle enters a decision point, it activates a floor-mounted switching device connected to the control unit for the relevant block. The control unit activates the desired guide path and turns off the alternative branch or branches.

Traffic control and safety

The purpose of traffic control for an AGVS is to prevent collisions between vehicles traveling along the same guide path in the layout. This purpose is usually accomplished by means of a control system called the *blocking system*. The term "blocking" suggests that a vehicle traveling along a given guide path is in some way prevented from hitting any vehicle ahead of it. There are several means used in commercial AGV systems to accomplish blocking. They are:

1. On-board vehicle sensing
2. Zone blocking

On-board vehicle sensing and zone blocking are often used in combination to implement a comprehensive blocking system.

On-board vehicle sensing (sometimes called *forward sensing*) involves the use of some form of sensor system to detect the presence of vehicles and carts ahead on the same guide wire. The sensors used on commercial guided vehicles include optical sensors and ultrasonic systems. When the on-board sensor detects an obstacle (e.g., another guided vehicle) in front of it, the vehicle stops. When the obstacle is removed, the vehicle proceeds. Assuming that the sensor system is 100% effective, collisions between vehicles are avoided and traffic is controlled. Unfortunately, the effectiveness of forward sensing is limited by the capability of the sensor system to detect vehicles in front of it on the guide path. Since the sensors themselves are most effective in detecting obstacles directly ahead of the vehicle, these systems are most appropriate on layouts that contain long stretches of straight pathways. They are less effective at turns and convergence points where forward vehicles may not be directly in front of the sensor.

The concept of *zone* control is simple. The AGVS layout is divided into separate zones, and the operating rule is that no vehicle is permitted to enter a zone if that zone is already occupied by another vehicle. The length of a zone is sufficient to hold one vehicle (or a train in driverless train systems) plus an allowance for safety and other considerations. These other considerations include the number of vehicles in the system, the size and complexity of the layout, and the objective of minimizing the number of separate zone controls. When one vehicle occupies a given zone, any trailing vehicle is not allowed into that zone. The leading vehicle must proceed into the next zone before the trailing vehicle can occupy the given zone.

By controlling the forward movement of vehicles in the separate zones, collisions are prevented and traffic in the overall system is controlled. The concept is illustrated in Figure 23 in its simplest form. More complicated zone control schemes separate any two vehicles by a blocked zone.

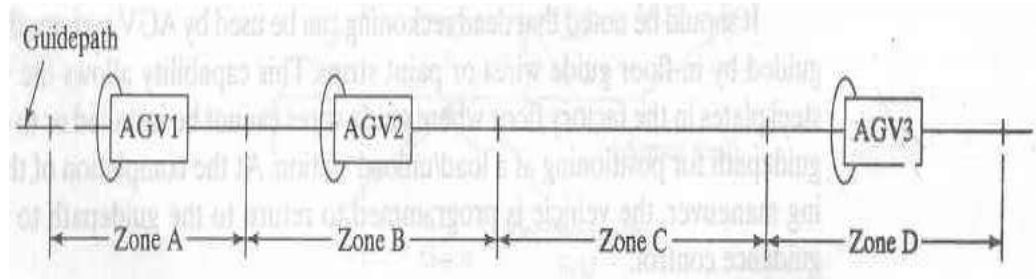


Figure 23 zone control

One means of implementing zone control is to use separate control units for each zone. These controls are mounted along the guide path and are actuated by the vehicle in the zone. When a vehicle enters a given zone, it activates the block in the previous (upstream) zone to block any trailing vehicle from moving forward and colliding with the present vehicle. As the present vehicle moves into the next (downstream) zone, it activates the block in that zone and deactivates the block in the previous zone. In effect, zones are turned on and off to control vehicle movement by the blocking system.

In addition to avoiding collisions between vehicles, a related objective is the safety of human beings who might be located along the route of the vehicles traveling in the system. There are several devices that are usually included on an automatic guided vehicle to achieve this safety objective. One of the safety devices is an obstacle-detection sensor located at the front of each vehicle. This is often the same on-board sensor as that used in the blocking system to detect the presence of other vehicles located in front of the sensor. The sensor can detect not only other vehicles, but also people and obstacles in the path of the vehicle. These obstacle-detection systems are usually based on optical, infrared, or ultrasonic sensors. The vehicles are programmed either to stop when an obstacle is sensed ahead of it, or to slow down. The reason for slowing down is that the sensed object may be located off to the side of the vehicle path, or directly ahead of the vehicle beyond a turn in the guide path. In either of these cases, the vehicle should be permitted to proceed at a slower (safer) speed until it has passed the object or rounded the turn.

Another safety device included on virtually all commercial AG vehicles is an emergency bumper. This bumper surrounds the front of the vehicle and protrudes ahead of it by a distance which can be a foot or more. When the bumper makes contact with an object, the vehicle is programmed to brake immediately. Depending on the speed of the vehicle, its load, and other conditions, the braking distance will vary

from several inches to several feet. Most vehicles are programmed to require manual restarting after an obstacle encounter has occurred with the emergency bumper.

Other safety devices on the vehicles include warning lights (blinking or rotating lights) and/or warning bells. These devices alert people that the vehicle is present.

Finally, another safety feature that prevents runaway vehicles is the inherent operating characteristic of the guidance system: If the vehicle strays by more than a few inches from the defined path, the vehicle is programmed to stop.

System management

Managing the operations of an AGVS deals principally with the problem of dispatching vehicles to the points in the system where they are needed (e.g., to perform pickups and deliveries) in a timely and efficient manner. The system management function depends on reliable operation of the other system functions discussed above (guidance, routing, traffic control). There are a number of methods used in commercial A.GV systems for dispatching vehicles. These methods are generally used in combination to maximize responsiveness and effectiveness of the overall system. The dispatching methods include:

- * On-board control panel
- * Remote call stations
- * Central computer control

Each guided vehicle is equipped with some form of control panel for the purpose of manual vehicle control, vehicle programming, and other functions. Most commercial vehicles have the capacity to be dispatched by means of this control panel to a given station in the AGVS layout. Dispatching with an on-board control panel represents the lowest level of sophistication among the possible methods. Its advantage is that it provides the AGVS with flexibility and responsiveness to changing demands on the handling system. Its disadvantage is that it requires manual attention.

The use of remote call stations is another method that allows the AGVS to respond to changing demand patterns in the system. The simplest form of call station is a press button mounted near the load/unload station. This provides a signal to any passing vehicle to stop at the station in order to accomplish a load transfer operation. The vehicle might then be dispatched to the desired location by means of the on-board control panel.

More sophisticated call stations consist of control panels mounted near the various stations along the layout. This method permits a vehicle to be stopped at a given station, and its next destination to be programmed from the remote call panel. This represents a more automated approach to the dispatching function and is useful in AGV systems that are capable of automatic loading and unloading operations.

Both of the call station methods described here involve a human interface with the AGVS at the load/unload station. It is also possible to automate the call function at an automatic load/unload station. One example is an automated production workstation that receives raw materials and sends completed parts by means of the AGVS. The workstation is interfaced with the AGVS to call for vehicles as needed to perform the loading and unloading procedures.

In large factory and warehouse systems involving a high level of automation, the AGVS servicing the factory or warehouse must also be highly automated to achieve efficient operation of the entire production-storage-handling system. Central computer control is used to accomplish automatic dispatching of vehicles according to a preplanned schedule of pickups and deliveries in the layout and/or in response to calls from the various load/unload stations in the system. In this dispatching method, the central computer issues commands to the vehicles in the system concerning their destinations and operations to perform. To accomplish the dispatching function, the central computer must possess real-time information about the location of each vehicle in the system so that it can make appropriate decisions concerning which vehicles to dispatch to what locations. Hence, the vehicles must continually communicate their whereabouts to the central controller.

There are differences in the way these central computer dispatching systems operate. One of the differences involves the distribution of the decision-making responsibilities between the central controller and the individual vehicles. At one extreme, the central computer makes nearly all the decisions about routing of vehicles and other functions. The central computer plans out the routes for each vehicle and controls the operation of the guide path zones and other functions. At the opposite extreme, each individual vehicle possesses a substantial decision-making capability to make its own routing selections and to control its own operations. The central computer is still needed to control the overall scheduling and determine which vehicles should go to the various demand points in the system. However, the vehicles themselves decide which routes to take and control their own load transfer operations. Vehicles in this second category are often referred to as "smart" vehicles.

To accomplish the system management function, it is helpful to monitor the overall operations of the AGVS by means of some form of graphics display. Even with central computer control it is still desirable for human managers to be able to see the overall system operations, in order to monitor its general status and to spot problems (e.g., traffic jams, breakdowns, etc.). A CRT color graphics display is often used for these purposes in modern guided vehicle systems.

Another useful tool in carrying out the systems management function is a system performance report for each shift (or other appropriate time period) of AGVS operation. These periodic reports of system performance provide summary information about proportion uptime, downtime, number of transactions (deliveries) made during a shift, and more detailed data about each station and each vehicle in the system. Hard-copy reports containing this type of information permit the system managers to compare operations from shift to shift and month to month to maintain a high level of overall system performance.

Applications

Automated Guided Vehicles can be used in a wide variety of applications to transport many different types of material including pallets, rolls, racks, carts, and containers.

AGVs excel in applications with the following characteristics:

- Repetitive movement of materials over a distance
- Regular delivery of stable loads
- Medium throughput/volume
- When on-time delivery is critical and late deliveries are causing inefficiency
- Operations with at least two shifts
- Processes where tracking material is important

Driverless train operations

Storage/distribution

Assembly line operations

FMS

Mail delivery in offices

Hospitals

Raw Material Handling

Work-in-Process Movement

Pallet Handling

Finished Product Handling

Trailer Loading

Roll Handling

Battery Charging

1. ***Driverless train operations:*** These applications involve the movement of large quantities of materials over relatively large distances. For example, the moves are within a large warehouse or factory building, or between buildings in a large storage depot. For the movement of trains consisting of 5 to 10 trailers, this becomes an efficient handling method,
2. ***Storage/distribution systems:*** Unit load carriers and pallet trucks are typically used in these applications. These storage and distribution operations involve the movement of materials in unit loads (sometimes individual items are moved) from or to specific locations. The applications often interface the AGVS with some other automated handling or storage system, such as an automated storage/retrieval system (AS/RS) in a distribution center. The AGVS delivers incoming items or unit loads (contained on pallets) from the receiving dock to the AS/RS, which places the items in storage, and the AS/RS retrieves individual pallet loads or items from storage and transfers them to vehicles for delivery to the shipping dock. When the rates of incoming loads and the outgoing loads are in balance, this mode of operation permits loads to be carried in both directions by the AGVS vehicles, thereby increasing the handling system efficiency.

This type of storage/distribution operation can also be applied in light manufacturing and assembly operations in which work-in-progress is stored in a central storage area and distributed to individual workstations for assembly or processing. Electronics assembly is an example of these types of applications. Components are "kitted" at the storage area and delivered in tote pans or trays by the guided vehicles to the assembly workstations in the plant. Light-load AGV systems are used in these applications.

3. ***Assembly-line operations:*** AGV systems are being used in a growing number of assembly-line applications, based on a trend that began in Europe. In these applications, the production rate is relatively low (perhaps 4 to 10 min per station in the line) and there are a variety of different models made on the production line. Between the work stations, components are kitted and placed on the vehicle for the assembly operations that are to be performed on the partially completed product at the next station. The workstations are generally arranged in parallel configurations to add to the flexibility of the line. Unit load carriers and light-load guided vehicles are the type of AGVS used in these assembly lines.
4. ***Flexible manufacturing systems:*** Another growing application of AGVS technology is in flexible manufacturing systems (FMS). In this application, the guided vehicles are used as the materials handling system in the FMS. The

vehicles deliver work from the staging area (where work is placed on pallet fixtures, usually manually) to the individual workstations in the system. The vehicles also move work between stations in the manufacturing system. At a workstation, the work is transferred from the vehicle platform into the work area of the station (usually, the table of a machine tool) for processing. At the completion of processing by that station a vehicle returns to pick up the work and transport it to the next area. AGV systems provide a versatile material handling system to complement the flexibility of the FMS operation.

5. ***Miscellaneous applications:*** Other applications of automated guided vehicle systems include non manufacturing and non warehousing applications, such as mail delivery in office buildings and hospital material handling operations. Hospital guided vehicles transport meal trays, linen, medical and laboratory supplies, and other materials between various departments in the building. These applications typically require movement of the vehicles between different floors of the hospital, and hospital AGV systems have the capability to summon and use elevators for this purpose.

UNIT 6:

COMPUTERIZED MANUFACTURING PLANNING SYSTEM:

Traditional Process Planning:

There are variations in the level of detail found in route sheets among different companies & industries. In the one extreme, process planning is accomplished by releasing the part print to the production shop with the instructions “make to drawing.” Most firms provide a more detailed list of steps describing each operation and identifying each work center. In any case, it is traditionally the task of the manufacturing engineers or industrial engineers in an organization to write these process plans for new part designs to be produced by the shop. The process planning procedure is very much dependent on the experience and judgement of the planner. It is the manufacturing engineer’s responsibility to determine an optimal routing for each new part design. However, the individual engineers each have their own opinions about what constitutes the best routing. Accordingly, there are differences among the operation sequences developed by various planners. We can illustrate rather dramatically these differences by means of an example.

In one case, a total of 42 different routings were developed for various sizes of a relatively simple part called an “expander sleeve.” There were a total of 64 different sizes & styles, each with its own part number. The 42 routings included 20 different machine tools in the shop. The reason for this absence of process standardization was that many different individuals had worked on the parts: 8 or 9 manufacturing engineers, 2 planners and 25 NC part programmers. Upon analysis, it was determined that only two different routings through 4 machines were needed to process the 64 part numbers. It is clear that there were potentially great differences in the perceptions among process planners as to what constitutes the “optimal” method of production.

In addition to this problem of variability among planners, there are often difficulties in the conventional process planning procedure. New machine tools in the factory render old routings less than optimal. Machine breakdowns force shop personnel to use temporary routings, & these become the documented routings even after the machine is repaired. For these reasons and others, a significant proportion of the total number of process plans used in manufacturing are not optimal.

Automated Process Planning:

Because of the problems encountered with manual process planning, attempts have been made in recent years to capture the logic, judgement, and experience required for this important function and incorporate them into computer programs. Based on the characteristics of a given part, the program automatically generates the manufacturing operation sequence. A computer-aided process planning (CAPP) system offers the potential for reducing the routine clerical work of manufacturing engineers. At the same time, it provides the opportunity to generate production routings which are rational, consistent, and perhaps even optimal. Two alternative approaches to computer-aided process planning have been developed. These are:

1. Retrieval-type CAPP systems (also called variant systems)
2. Generative CAPP systems

The two types are described as below:

Retrieval-type Process Planning systems:

Retrieval-type CAPP systems use parts classification & coding & group technology as a foundation. In this approach, the parts produced in the plant are grouped into part families, distinguished according to their manufacturing characteristics. For each part family, a standard process plan is established. The standard process plan is stored in computer files & then retrieved for new workparts which belong to that family. Some form of parts classification & coding system is required to organize the computer files & to permit efficient retrieval of the appropriate process plan for a new workpart. For some new parts, editing of the existing process plan may be required. This is done when the manufacturing requirements of the new part are slightly different from the standard. The machine routing may be the same for the new part, but the specific operations required at each machine may be different. The complete process plan must document the operations as well as the sequence of machines through which the part must be routed. Because of the alterations that are made in the retrieved process plan, these CAPP systems are sometimes also called by the name “variant system”.

The figure illustrated further will help to explain the procedure used in a retrieval process planning system. The user would initiate the procedure by entering the part code number at a computer terminal. The CAPP program then searches the part family matrix file to determine if a match exists. If the file contains an identical code number, the standard machine routing & operation sequence are retrieved from the respective computer files for display to the user. The standard process plan is examined by the user to permit any necessary editing of the plan to make it compatible with the new part design. After editing, the process plan formatter prepares the paper document in the proper form.

If an exact match cannot be found between the code numbers in the computer file & the code number for the new part, the user may search the machine routing file & the operation sequence file for similar parts that could be used to develop the plan for the new part. Once the process plan for a new part code number has been entered, it becomes the standard process for future parts of the same classification.

In the figure illustrated in the previous slide, the machine routing file is distinguished from the operation sequence file to emphasize that the machine routing may apply to a range of different part families & code numbers. It would be easier to find a match in the machine routing file than in the operation sequence file. Some CAPP retrieval systems would use only one such file which would be a combination of operation sequence file & machine routing file.

The process plan formatter may use other application programs. These could include programs to compute machining conditions, work standards, & standard costs. Standard cost programs can be used to determine total product costs for pricing purposes.

A number of retrieval-type computer-aided process planning systems have been developed. These include MIPLAN, one of the MICLASS modules, the CAPP system developed by Computer-Aided Manufacturing --- International, COMCAPP V by MDSI, & systems by individual companies. We will use MIPLAN as an example to illustrate these industrial systems.

MIPLAN is a computer-aided process planning package available from the Organization for Industrial Research, Inc., of Waltham, Massachusetts. It is basically a retrieval-type CAPP system with some additional features. The MIPLAN system consists of several modules which are used in an interactive, conversational mode.

To operate the system, the user can select any of the four different options to create the process plan for a new part:

1. The first option is a retrieval approach in which the user inputs a part code number & a standard process plan is retrieved from the computer file for possible editing. To generate the part code number, the planner may elect to use the MICLASS interactive parts classification & coding system.
2. In the second option, a process plan is retrieved from the computer files by entering an existing part number (rather than a part code number). Again, the existing process plan can be edited by the user if required.
3. A process plan can be created from scratch, using standard text material stored in computer files. This option is basically a specialized word-processing system in which the planner selects from a menu of text related to machines & processes. The process plan is assembled from text passages subject to editing for the particular requirements of the new part.
4. The user can call up an incomplete process plan from the computer file. This may occur when the user is unable to complete the process plan for a new part at one sitting. For example, the planner may be interrupted in the middle of the procedure to solve some emergency problem. When the procedure is resumed, the incomplete plan can be retrieved & finished.

After the process plan has been completed using one of the four MIPLAN options, the user can have a paper document printed out by the computer. A typical MIPLAN output is shown in the figure in the next slide. It is also possible for the user to store the completed process plan (or the partially completed plan as with the option 3) in the computer files, or to purge an existing plan from the files. This might be done, for example, when an old machine tool is replaced by a more productive machine, & this necessitates changes in some of the standard process plans.

Computer graphics can be utilized to enhance the MIPLAN output. This possibility is illustrated in the next slide, which shows a tooling setup for the machining operation described. With this kind of pictorial process planning, drawings of workpart details, tool paths, & other information can be presented visually to facilitate communication to the manufacturing shops.

Generative Process Planning Systems:

Generative Process Planning involves the use of computer to create an individual process plan from scratch, automatically & without human assistance. The computer would employ a set of algorithms to progress through the various technical & logical decisions toward a final plan for manufacturing. Inputs to the system would include a comprehensive description of the workpart. This may involve the use of some form of part code number to summarise the workpart data, but it does not involve the retrieval of existing standard plans. Instead, the generative CAPP system synthesizes the design of the optimum process sequence, based on an analysis of part geometry, material & other factors which would influence manufacturing decisions.

In the ideal generative process planning package, any part design could be presented to the system for creation of the optimal plan. In practice, current generative-type systems are far from universal in their applicability. They tend to fall short of a truly generative capability, and they are developed for a somewhat limited range of manufacturing processes.

We will illustrate the generative process planning by means of a system called GENPLAN developed at Lockheed-Georgia Company.

GENPLAN is close to a generative process planning system, but it requires a human planner to assist with some of the manufacturing decisions. Also there are several versions GENPLAN (one for parts fabrication, and another for assembly), which means that it is not a system of universal applicability.

To operate the system, the planner enters a part classification code using a coding scheme developed at Lockheed. GENPLAN then analyses the characteristics of the part based on the code number (e.g., part geometry, work piece material, & other manufacturing-related features) to synthesize an optimum process plan. It does not store standard manufacturing plans. Rather, it stores machine tool capabilities & it employs the logic & technological science of manufacturing. The output is a document specifying the sequence of operations, machine tools, & calculated process times. An example of a computer-generated route sheet produced by GENPLAN is shown in the figure in the next slide. Process plans that previously required several hours to accomplish manually are now done typically by GENPLAN in 15 minutes.

Benefits of CAPP:

Whether it is retrieval system or a generative system, computer-aided process planning offers a number of potential advantages over manually oriented process planning.

1. *Process rationalization.* Computer-automated preparation of operation routings is more likely to be consistent, logical, & optimal than its manual counterpart. The process plans will be consistent because the same computer software is being used by all planners. We avoid the tendency for drastically different process plans from different planners. The process plans tend to be more logical & optimal because the company has presumably incorporated the experience & judgement of its best manufacturing people into the process planning computer software.
2. *Increased productivity of process planners.* With computer-aided process planning, there is reduced clerical effort, fewer errors are made, & the planners have immediate access to the process planning data base. These benefits translate into higher productivity of the process planners. One system was reported to increase productivity by 600% in the process planning function.
3. *Reduced turnaround time.* Working with the CAPP system, the process planner is able to prepare a route sheet for a new part in less time compared to manual preparation. This leads to an overall reduction in manufacturing lead time.
4. *Improved legibility.* The computer prepared document is neater & easier to read than manually written route sheets. CAPP systems employ standard text, which facilitates interpretation of the process plan in the factory.
5. *Incorporation of other application programs.* The process planning system can be designed to operate in conjunction with other software packages to automate many of the time-consuming manufacturing support functions.

Aggregate Production Planning & The Master Production Schedule:

Aggregate planning is a high-level corporate planning activity. The *aggregate production plan* indicates production output levels for the major product lines of the company. The aggregate plan must be coordinated with the plans of the sales & marketing departments. Because the *aggregate production plan* includes products that are currently in production, it must also consider the present & future inventory levels of those products & their component parts. Because new products currently being developed will also be included in the aggregate plan, the marketing plans & promotions for current products & new products must be reconciled against the total capacity resources available to the company.

The production quantities of the major product lines listed in the aggregate plan must be converted into a very specific schedule of individual products, known as the *master production schedule* (MPS). It is a list of products to be manufactured, when they should be completed & delivered, & in what quantities. A hypothetical MPS for a narrow product set is presented in the table, showing how it is derived from the corresponding aggregate plan in the 2nd table. The master schedule must be based on an accurate estimate of demand & a realistic assessment of the company's production capacity.

	Week									
Product Line	1	2	3	4	5	6	7	8	9	10
M model line	200	200	200	150	150	120	120	100	100	100
N model line	80	60	50	40	30	20	10			
P model line							70	130	25	100

(a) Aggregate Production Plan

Product Line models	Week									
	1	2	3	4	5	6	7	8	9	10
Model M3	120	120	120	100	100	80	80	70	70	70
Model M4	80	80	80	50	50	40	40	30	30	30
Model N8	80	60	50	40	30	20	10			
Model P1								50		100
Model P2							70	80	25	

(b) Master Production Schedule

Products included in the MPS divide into 3 categories: (1) firm customer orders, (2) forecasted demand, & (3) spare parts. Proportions in each category vary for different companies, & in some cases one or more categories are omitted. Companies producing assembled products will generally have to handle all three types. In the case of customer orders for specific products, the company is usually obligated to deliver the item by a particular date that has been promised by the sales department. In the second category, production output quantities are based on statistical forecasting techniques applied to previous demand patterns, estimates by the sales staff, & other sources. For many companies forecasted demand constitutes the largest portion of the master schedule. The third category consists of repair parts that either will be stocked in the company's service department or sent directly to the customer. Some companies exclude this third category from the master schedule since it does not represent end products.

The MPS is generally considered to be a medium-range plan since it must take into account the lead times to order raw materials & components, produce parts in the factory, & then assemble the end products. Depending on the product, the lead times can range from several weeks to many months; in some cases, more than a year. The MPS is usually considered to be fixed in the near term. This means that changes are not allowed within about a six week horizon because of the difficulty in adjusting production schedules within such a short period. However, schedule adjustments are allowed beyond six weeks to cope with changing demand patterns or the introduction of new products. Accordingly, we should note that the aggregate production plan is not the only input to the master schedule. Other inputs that may cause the master schedule to depart from the aggregate plan include new customer orders & changes in sales forecast over the near term.

Material Requirements Planning:

Material Requirements Planning (MRP) is a computational technique that converts the master schedule for end products into a detailed schedule for the raw materials & components used in the end products. The detailed schedule identifies the quantities of each raw material & component item. It also indicates when each item must be ordered & delivered to meet the master schedule for final products. MRP is often thought of as a method of inventory control. It is both an effective tool for minimizing unnecessary inventory investment & a useful method in production scheduling & purchasing of materials.

The distinction between independent demand & dependent demand is important in MRP. *Independent demand* means that demand for a product is unrelated to demand for other items. Final products & spare parts are examples of items whose demand is independent. Independent demand patterns must usually be forecasted. *Dependent demand* means that demand for the item is directly related to the demand for some other item, usually a final product. The dependency usually derives from the fact that the item is a component of the other product. Component parts, raw materials, & subassemblies are examples of items subject to dependent demand.

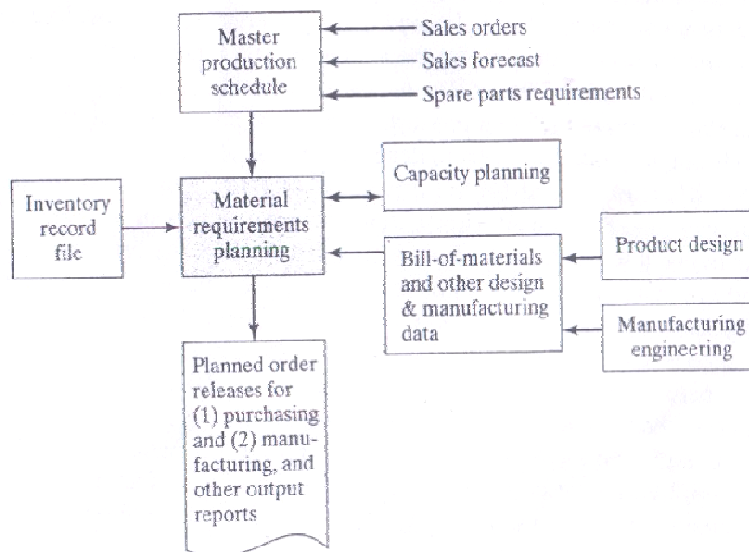
Whereas demand for the firm's end products must often be forecasted, the raw materials & component parts used in the end products should not be forecasted. Once the delivery schedule for the end products is established, the requirements for components & raw materials can be directly calculated. For example, even though demand for automobiles in a given month can only be forecasted, once the quantity is established & production is scheduled, we know that five tires will be needed to deliver the car (don't forget the spare). MRP is the appropriate technique for determining quantities of dependent demand items. These items constitute the inventory of manufacturing: raw materials, work-in-process (WIP), component parts & subassemblies. That is why MRP is such a powerful technique in planning & control of manufacturing inventories. For independent demand items, inventory control is often accomplished using order point systems.

The concept of MRP is relatively straightforward. Its implementation is complicated by the sheer magnitude of the data to be processed. The master schedule provides the overall production plan for the final products in terms of month-by-month deliveries. Each product may contain hundreds of individual components. These components are produced from raw materials, some of which are common among the components. For example, several components may be made out of the same gauge sheet steel. The components are assembled into simple subassemblies, & these subassemblies are put together into more complex subassemblies, & so on, until the final products are assembled. Each step in the manufacturing & assembly sequence takes time. All of these factors must be incorporated into the MRP calculations. Although each calculation is uncomplicated, the magnitude of the data is so large that the application of MRP is practically impossible except by computer processing.

Inputs to the MRP system :

To function, the MRP program needs data contained in several files. These files serve as inputs to the MRP processor. They are (1) the master production schedule, (2) the bill of materials file and other engineering and manufacturing data, and (3) the inventory record file. Figure 1 illustrates the flow of data into the MRP processor and its conversion into useful output report. In a properly implemented MRP system, capacity planning also provides input to ensure that the MRP schedule does not exceed the production capacity of the firm. This concept is elaborated further.

The MPS lists what end products and how many of each are to be produced and when they are to be ready for shipment. Manufacturing firms generally work on monthly delivery schedules, but the master schedule in our figure uses weeks as the time periods. Whatever the duration, these time periods are called *time buckets* in MRP. Instead of treating time as a continuous variable (which of course , it is), MRP makes its computations of materials and parts requirements in terms of the buckets.



The bill of material (BOM) file provides information the product structure by listing the components parts and subassemblies that make up each product, It is use to computer the raw material and components requirement for end products listed in the master schedule. The structure of an assembled product can be illustrated as in Figure 2. This is much simpler than most commercial products, but its simplicity will server for illustration purposes. Product PI is composed of two subassemblies, SI and S@, each of which is made up of components C1,C2 and C3, and C3, and C4,C5 and C6, respectively. Finally, at the the bottom level are the raw materials that go into each component. The items at each successively higher level are called the parents of the items feeding into it form below. For example. SI is the parent of C1 ,C2 and C3. The product structure must also specify the number of each subassembly , component, and raw material that go into respective parent. These numbers are shown in parentheses in our figure.

Period		1	2	3	4	5	6	7
Item : Raw Material M4								
Gross Requirement								
Scheduled receipt				40				
On hand	50	50	50	90				
Net requirement								
Planned order releases								

The inventory record file is referred to as the item master file in a computerize inventory system. The types of data contained in the inventory record are divided into three segments.

1. Item master data : This provides the item's identification (part number) and other data about the part such as order quantity and lead times.
2. Inventory status : This gives a time-phased record of inventory status. In MRP, its is import to know not only the current level of inventory but also any future changes that will occur against the inventory. Therefore , the inventory status segment lists the gross requirements for the item, schedules receipts, on-hand status, and planned order releases, as shown in figure 25.5.
3. Subsidiary data. The third file segment provided subsidiary data such purchase orders, scrap or rejects and engineering changes.

How MRP Works

The MRP processor operates on data contained in the MPS, the BOM file, and the inventory record file. The master schedule specifies the period-by period list of final products required. The BOM define what material and components are needed for each

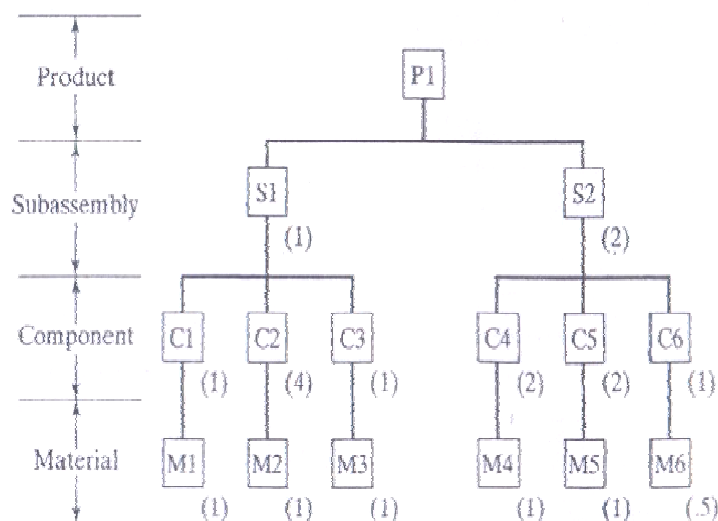


Figure 25.4 Product structure for product P1.

Figure 25.5 Initial inventory status of material M4 in Example 25.2

Product and inventory record files give the current and future inventory status of each product, component, and material. The MRP processor computes how many of each component and raw material are needed each period by “exploding” the end product requirements into successively lower levels in the product structure.

Example 25.1 MRP Gross Quantity Computations

In the master schedule of Figure 25.2, 50 units of product P1 are to be completed in week 8. Explode this product requirement into the corresponding number of subassemblies and components required.

Solution : Referring to the product structure in Figure 25.4, 50 units of P1 explode into 50 units of S1 and 100 units of S2. Similarly, the requirements for these subassemblies explode into 50 units of C1, 200 of C2, 50 of C3, 200 of C5 and 100 of C6. Quantities of raw materials are determined in a similar manner.

Several complicating factors must be considered during the MRP computations. First the quantities of component and subassemblies listed in the solution of Example 25.1 do not account for any of those items that may already be stocked in inventory or are expected to be received as future order. Accordingly, the computed quantities must be adjusted for any inventories on hand or on order, a procedure called netting. For each time bucket, net requirements = gross requirements less on hand inventories and less quantities on order.

Second, quantities of common use items must be combined during parts explosion to determine the total quantities required for each component and raw material in the schedule. Common use items are raw materials and components that are used on more than one product. MRP collects these common use items from different products to achieve economics in ordering the raw materials and producing the components.

Third, lead times for each item must be taken into account. The lead time for a job is the time that must be allowed to complete the job from start to finish. There are two kinds of lead times in MRP: ordering lead time and manufacturing lead times. Ordering lead time for an item is the time required from initiation of the purchase requisition to receipt of the item from the vendor. If the item is raw material that is stocked by the vendor, the ordering lead time should be relatively short, perhaps a few days or a few weeks. If the item is fabricated, the lead time may be substantial, perhaps several months. Manufacturing lead time is the time required to produce the item in the company's own plant, from order release to completion, once the raw material for the item are available. The scheduled delivery of end product must be translated into time-phased requirements for components and materials by factoring in the ordering and manufacturing lead time.

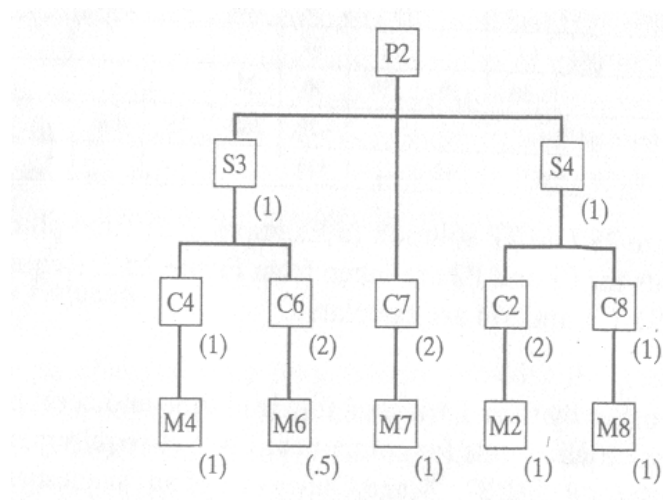
EXAMPLE 25.2 MRP Time Phased Quantity Requirements :

To illustrate these various complicating factors, let us consider the MRP procedure for component C4, which is used in product P1. This part also happens to be used on product P2 of the master schedule in Figure 25.2. The product structure for P2 is shown in figure 5.6. Component C4 is made out of material M4, one unit of M4 for each unit of C4, and the inventory status of M4 is given in figure 25.5. The lead time and inventory status for each of the other items needed in the MRP calculations are shown in the table below. Complete the

MRP calculations to determine the time phased requirements for items S2,S3,C4 and M4, based on the requirements for P1 and P2 given in the MPS of Figure 25.2. we assume that the inventory on hand or on order for P1 , P2,S2,S3 and C4 is zero for all future periods except for the calculated values in this problem solution.

Item	Lead Time	Inventory
P1	Assembly lead time = 1 wk	No inventory of hand or on order
P2	Assembly lead time = 1 wk	No inventory of hand or on order
S2	Assembly lead time = 1 wk	No inventory of hand or on order
S3	Assembly lead time = 1 wk	No inventory of hand or on order
C4	Manufacturing lead time = 2 wk	No inventory of hand or on order
M4	Ordering lead time = 3 wk	See Figure 25.6

Solution : The result of the MRP calculations are given in figure 25.7. the delivery requirements for P1 and P2 must be offset by their 1 wk assembly lead time to obtain the planned order released. These quantities are then exploded into requirements for subassemblies S2 (for P1) and S3 (for P1) and S3 (for P2). These requirements are offset by their 1 wk assembly lead time and combined in week 6 to obtain gross requirements for component C4. Net requirements equal gross requirements for P1, P2,S2 and C4 because of no inventory on hand and no planned orders. We see the effect of current inventory and planned orders in the time-phased inventory status of M4. The on-hand stock of 50 units plus scheduled receipts of 40 are used to meet gross requirements of 70 units of M4 in week 3, with 20 units remaining that can be applied to the gross requirements of 280 units in week 4. Net requirements in week 4 are therefore 260 units. With an ordering lead time of 3 wk, the order release for 260 units must be planned for week 1.



Period	1	2	3	4	5	6	7	8	9	10
Item: Product P1								50		100
Gross Requirements										
Scheduled receipts										
On Hand 0										
Net requirement								50		100
Planned order releases							50		100	
Item: Product P2							70	80	25	
Gross Requirements										
Scheduled receipts										
On Hand 0	0									
Net requirement							70	80	25	
Planned order releases						70	80	25		
Item: Subassembly S2							100		200	
Gross Requirements										
Scheduled receipts										
On Hand 0	0									
Net requirement							100		200	
Planned order releases						100		200		
Item: Subassembly S3						70	80	25		
Gross Requirements										
Scheduled receipts										
On Hand 0	0									
Net requirement						70	80	25		
Planned order releases					70	80	25			
Item: Component C4					70	280	25	400		
Gross Requirements										
Scheduled receipts										
On Hand 0	0									
Net requirement					70	280	25	400		
Planned order releases			70	280	25	400				
Item: Raw Material M4			70	280	25	400				
Gross Requirements										
Scheduled receipts			40							
On Hand 50	50	50	90	20						
Net requirement			-20	260	25	400				
Planned order releases	260	25	400							

Figure 25.7 MRP solution to Example 25.2. Time –phased requirements for P1 and P2 are taken from Figure 25.2. Requirements for S2,S3,C4 and M4 are calculated..

25.2.3. MRP Output and Benefits :

The MRP program generates a variety of outputs that can be used in planning and managing plant operations. The output includes (1) planned order releases, which provide the authority to place orders that have been planned by the MRP system; (2) report of planned order releases in future periods; (3) rescheduling notices, indicating changes in due dates for open orders; (4) cancellation notices, indicating that certain open orders have been canceled because in the MPS; (5) reports on inventory status; (6) performance reports of various types, indicating costs, item usage, actual versus planned lead times, and so on; (7) exception report, showing deviations from the schedule, orders that are overdue, scrap, and so on; and (8) inventory forecasts, indicating projected inventory levels in future periods.

Of the MRP output listed above, the planned order releases are the most important because they drive the production system. Planned order of two kinds, purchase orders and work orders. Purchase orders provide the authority to purchase raw materials or parts from outside vendors, with quantities and delivery dates specified. Work orders generate the authority to produce parts or assembly subassemblies or products in the company's own factory. Again, quantities to be completed and completion dates are specified.

Benefits reported by users of MRP systems include the following: (1) reduction in inventory, (2) quicker response to changes in demand than is possible with a manual requirements planning system, (3) reduced setup and product changeover costs, (4) better machine utilization, (5) improved capacity to respond to changes in the master schedule, and (6) aid in developing the master schedule.

Notwithstanding these claimed benefits, the success rate in implementing MRP systems throughout industry has been less than perfect. Some MRP systems have not been successful because (1) the application was not appropriate, usually because the product structure did not fit the data requirements of MRP; (2) the MRP computations were based on inaccurate data; and (3) the MPS was not coupled with a capacity planning system, so the MRP program generated an unrealistic schedule of work orders that overloaded the factory.

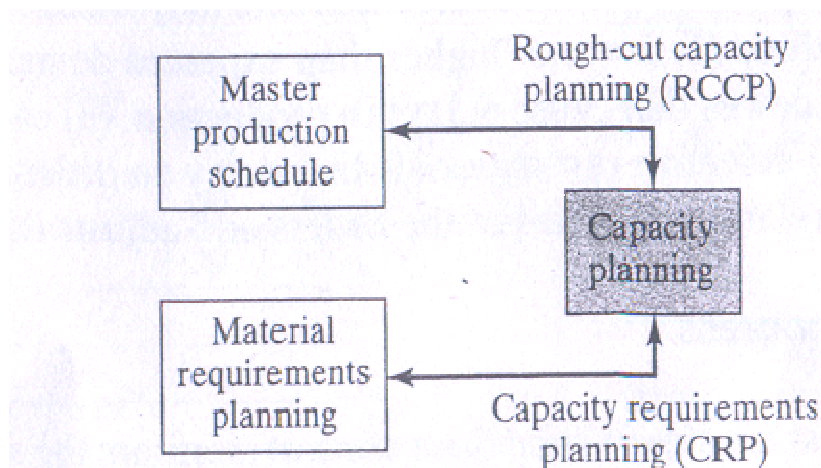
25.3 CAPACITY PLANNING :

The original MRP system that were developed in the 1970s created schedules that were not necessarily consistent with the production capabilities and limitations of the plants that were to produce the products. In many instances, the MRP system developed the detailed schedule based on a master production schedule that was unrealistic. A successful production schedule must consider production capacity. In cases where current capacity is inadequate, the firm must make plans for changes in capacity to meet the changing production requirements specified in the schedule. In chapter 3, we defined production capacity and formulated equations to determine the capacity of a plant. Capacity planning consists of determining what labor and equipment resources are required to meet the current MPS as well as long term future production needs of the firm (see Advanced Manufacturing Planning, Section 24.4). Capacity planning also identifies the limitations of the available production resources to prevent the MRP program from planning an unrealistic master schedule.

Capacity planning is typically accomplished in two stages, as indicated in Figure 25.8: first, when the MPS is established; and second, when the MRP computations are done. In the MPS stage, a rough-cut capacity planning (RCCP) calculation is made to assess the feasibility of the master schedule. Such a calculation indicates whether there is a significant violation of production capacity in the MPS. On the other hand, if the calculation shows no capacity violation, neither does it guarantee that the production schedule can be met. This depends on the allocation of work orders to specific work cells in the plant. Accordingly, a second capacity calculation is made at the time the MRP schedule is prepared. Called capacity requirements planning (CRP), this detailed calculation determines whether there is sufficient production capacity in the individual departments and in the work cells to complete the specific parts and assemblies that have been scheduled by MRP. If the schedule is not compatible with capacity, then either the plant capacity or the master schedule must be adjusted.

Capacity adjustments can be divided into short-term adjustment and long-term adjustments. Capacity adjustments for the short term include the following.

- Employment levels : Employment in the plant can be increase or decrease in response to changes in capacity requirements.
- Number of temporary workers. Increase in employment level can also be achieved by using workers from temporary agency. When the busy period is passed, these workers move to positions at other companies where their services are needed
- Number of work shifts. The numbers of shifts worked per production period can be increased or decreased.
- Number of labor hours. The numbers of labor hours per shift can be increased or decreased, through the use of overtime or reduce hours.
- Inventory stockpiling. This tactic might be used to maintain steady employment level during slow demand periods.
- Order backlogs. : Deliveries of the product to the customer could be delayed during busy period when production resources are insufficient to keep up with demand.
- Workload through subcontracting. This involves the letting of the jobs to other shops during busy periods, or the taking in of extra work during slack periods.



Capacity planning adjustments for the long term include changes in production capacity that generally require long times. These adjustments include the following actions:

- Investing in new equipment. This involves investing in more machines or more productive machines to meet increased future production requirements, or investing in new types of machines to match changes in product design.
- Constructing new plants. Building a new factory represents a major investment for the company. However, it also represents a significant increase in production capacity for the firm.
- Purchasing existing plants from other companies.
- Acquiring existing companies. This may be done to increase productive capacity. However, there are usually more important reasons for taking over an existing company, such as to achieve economies of scale that result from increase market share and reducing staff.
- Closing Plants. This involves the closing of plants that will not be needed in the future.

Unit -7 :

CNC MACHINING CENTERS

INTRODUCTION TO COMPUTER NUMERICAL CONTROL

The variety being demanded in view of the varying tastes of the consumer calls for a very small batch sizes. Small batch sizes will not be able to take advantage of the mass production techniques such as special purpose machines or transfer lines. Hence, the need for flexible automation is felt, where you not only get the benefits of rigid automation but are also able to vary the products manufactured thus bringing in the flexibility. Numerical control fits the bill perfectly and we would see that manufacturing would increasingly be dependent on numerical control in future.

Numerical control

Numerical control of machine tools may be defined as a method of automation in which various functions of machine tools are controlled by letters, numbers and symbols. Basically a NC machine runs on a program fed to it. The program consists of precise instructions about the methodology of manufacture as well as movements. For example, what tool is to be used, at what speed, at what feed and to move from which point to which point in what path. Since the program is the controlling point for product manufacture, the machine becomes versatile and can be used for any part. All the functions of a NC machine tool are therefore controlled electronically, hydraulically or pneumatically. In NC machine tools, one or more of the following functions may be automatic.

- a. Starting and stopping of machine tool spindle.
- b. Controlling the spindle speed.
- c. Positioning the tool tip at desired locations and guiding it along desired paths by automatic control of motion of slides.
- d. Controlling the rate of movement of tool tip (feed rate)
- e. Changing of tools in the spindle.

Functions of a machine tool

The purpose of a machine tool is to cut away surplus material, usually metal from the material supplied to leave a work piece of the required shape and size, produced to an acceptable degree of accuracy and surface finish. The machine tool should possess certain capabilities in order to fulfill these requirements. It must be

- a. Able to hold the work piece and cutting tool securely.
- b. Endowed the sufficient power to enable the tool to cut the work piece material at economical rates.
- c. Capable of displacing the tool and work piece relative to one another to produce the required work piece shape. The displacements must be controlled with a degree of precision which will ensure the desired accuracy of surface finish and size.

Concept of numerical control

Formerly, the machine tool operator guided a cutting tool around a work piece by manipulating hand wheels and dials to get a finished or somewhat finished part. In his procedure many judgments of speeds, feeds, mathematics and sometimes even tool configuration were his responsibility. The number of judgments the machinist had to make usually depended on the type of stock he worked in and the kind of organization that prevailed. If his judgment was an error, it resulted in rejects or at best parts to be reworked or repaired in some fashion.

Decisions concerning the efficient and correct use of the machine tool then depended on the craftsmanship, knowledge and skill of the machinist himself. It is rare that two expert operators produced identical parts using identical procedure and identical judgment of speeds, feeds and tooling. In fact even one craftsman may not proceed in same manner the second time around.

. Process planners and programmers have now the responsibilities for these matters.

It must be understood that NC does not alter the capabilities of the machine tool. The operator. Actual machine tool with a capable operator can do nothing more than it was capable of doing before a MCU was joined to it. New metal removing principles are not involved. Cutting speeds, feeds and tooling principles must still be adhered to. The advantage is idle time is reduced and the actual utilization rate is much higher (compresses into one or two years that a conventional machine receives in ten years).

Historical Development

1947 was the year in which Numerical control was born. It began because of an urgent need. John C Parsons of the parson's corporation, Michigan, a manufacturer of helicopter rotor blades could not make his templates fast enough. so he invented a way of coupling computer equipment with a jig borer.

The US air force realized in 1949 that parts for its planes and missiles were becoming more complex. Also the designs were constantly being improved; changes in drawings were frequently made. Thus in their search for methods of speeding up production, an air force study contract was awarded to the Parson's Corporation. The servomechanisms lab of MIT was the subcontractor.

In 1951, the MIT took over the complete job and in 1952; a prototype of NC machine was successfully demonstrated. The term "Numerical Control" was coined at MIT. In 1955 seven companies had tape controlled machines. In 1960, there were 100 NC machines at the machine tool shown in Chicago and a majority of them were relatively simple point to point application.

During these years the electronics industry was busy. First miniature electronic tubes were developed, then solid state circuitry and then modular or integrated circuits. Thus the reliability of the controls has been greatly increased and they have become most compact and less expensive.

Today there are several hundred sizes and varieties of machines, many options and many varieties of control system available.

Definition:

The simplest definition is as the name implies, "a process a controlled by numbers ". Numerical Control is a system in which the direct insertions of programmed numerical value, stored on some form of input medium are automatically read and decoded to cause a corresponding function on the machine tool which it is controlling.

Advantages of NC machine tools:

1. Reduced lead time:

Lead time includes the time needed for planning, design and manufacture of jigs, etc. This time may amount to several months. Since the need for special jigs and fixtures is often entirely eliminated, the whole time needed for their design and manufacture is saved.

2. Elimination of operator errors:

The machine is controlled by instructions registered on the tape provided the tape is correct and machine and tool operate correctly, no errors will occur in the job. Fatigue, boredom, or inattention by operator will not affect the quality or duration of the machining. Responsibility is transferred from the operator to the tape, machine settings are achieved without the operator reading the dial.

3. Operator activity:

The operator is relieved of tasks performed by the machine and is free to attend to matters for which his skills and ability are essential. Presetting of tools, setting of components and preparation and planning of future jobs fall into this category. It is possible for two work stations to be prepared on a single machine table, even with small batches. Two setting positions are used, and the operator can be setting one station while machining takes place at the other.

4. Lower labor cost

More time is actually spent on cutting the metal. Machine manipulation time ex.:. Gear changing and often setting time are less with NC machines and help reduce the labor cost per job considerably.

5. Smaller batches

By the use of preset tooling and presetting techniques downtime between batches is kept at a minimum. Large storage facilities for work in progress are not required. Machining centers eliminate some of the setups needed for a succession of operation on one job; time spent in waiting until each of a succession of machine is free is also cut. The components circulate round the machine shop in a shorter period, inter department costs are saved and 'program chasing' is reduced.

6. Longer tool life

Tools can be used at optimum speeds and feeds because these functions are controlled by the program.

7. Elimination of special jigs and fixtures

Because standard locating fixtures are often sufficient of work on machines. the cost of special jigs and fixture is frequently eliminated. The capital cost of storage facilities is greatly reduced. The storage of a tape in a simple matter, it may be kept for many years and manufacturing of spare parts, repeat orders or replacements is made much more convenient.

8. Flexibility in changes of component design

The modification of component design can be readily accommodated by reprogramming and altering the tape. Savings are affected in time and cost.

9. Reduced inspection.

The time spent on inspection and in waiting for inspection to begin is greatly reduced. Normally it is necessary to inspect the first component only once the tape is proved; the repetitive accuracy of the machine maintains a consistent product.

10. Reduced scrap

Operator error is eliminated and a proven tape results in accurate component.

11. Accurate costing and scheduling

The time taken in machining is predictable, consistent and results in a greater accuracy in estimating and more consistency in costing.

Evolution of CNC:

With the availability of microprocessors in mid 70's the controller technology has made a tremendous progress. The new control systems are termed as computer numerical control (CNC) which are characterized by the availability of a dedicated computer and enhanced memory in the controller. These may also be termed "soft wired numerical control".

There are many advantages which are derived from the use of CNC as compared to NC.

- Part program storage memory.
- Part program editing.
- Part program downloading and uploading.
- Part program simulation using tool path.
- Tool offset data and tool life management.
- Additional part programming facilities.
- Macros and subroutines.
- Background tape preparation, etc.

The controls with the machine tools these days are all CNC and the old NC control do not exist any more.

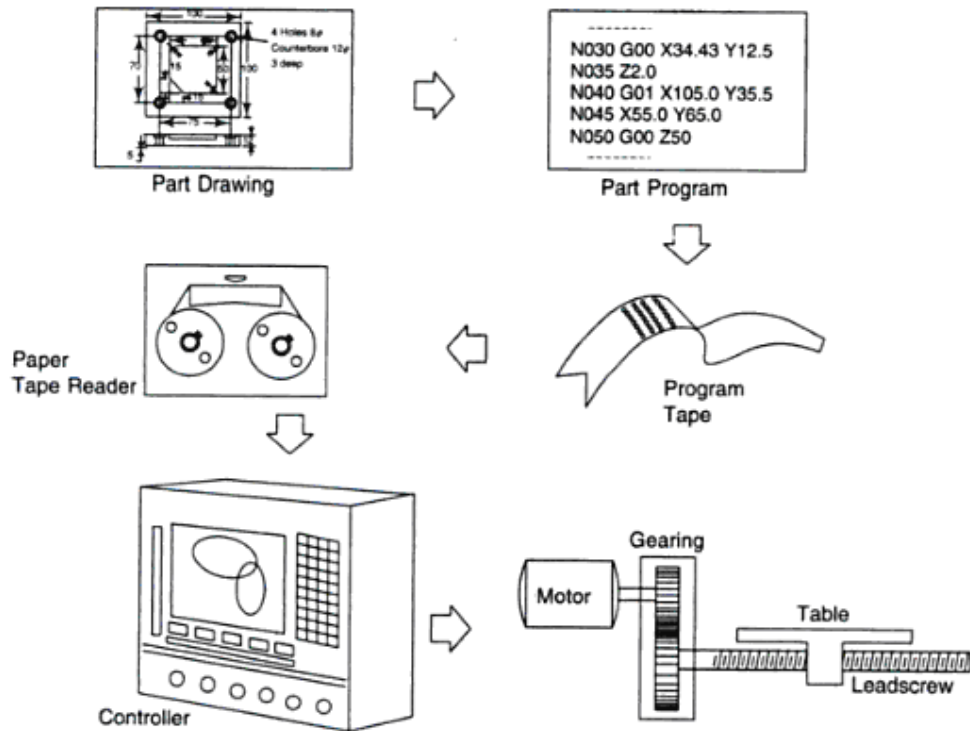


Fig. Elements of NC Machine Tool Operation

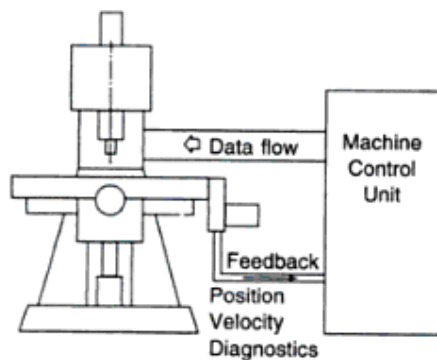


Fig. The Data Processing in a CNC Machine Tool in Closed Loop Control

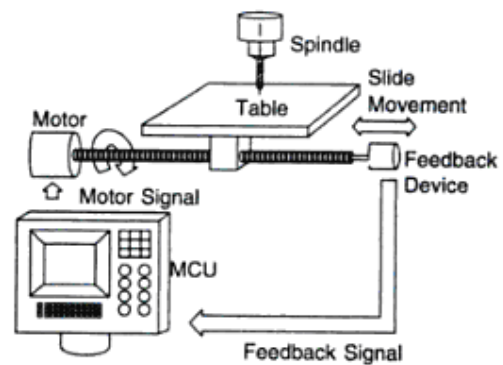


Fig. The Data Processing in a CNC Machine Tool in Closed Loop Control

DEFINITION AND FEATURES OF CNC

Computer Numerical Control (CNC)

CNC refers to a computer that is joined to the NC machine to make the machine versatile. Information can be stored in a memory bank. The programme is read from a storage medium such as the punched tape and retrieved to the memory of the CNC computer. Some CNC machines have a magnetic medium (tape or disk) for storing programs. This gives more flexibility for editing or saving CNC programs. Figure 1 illustrates the general configuration of CNC.

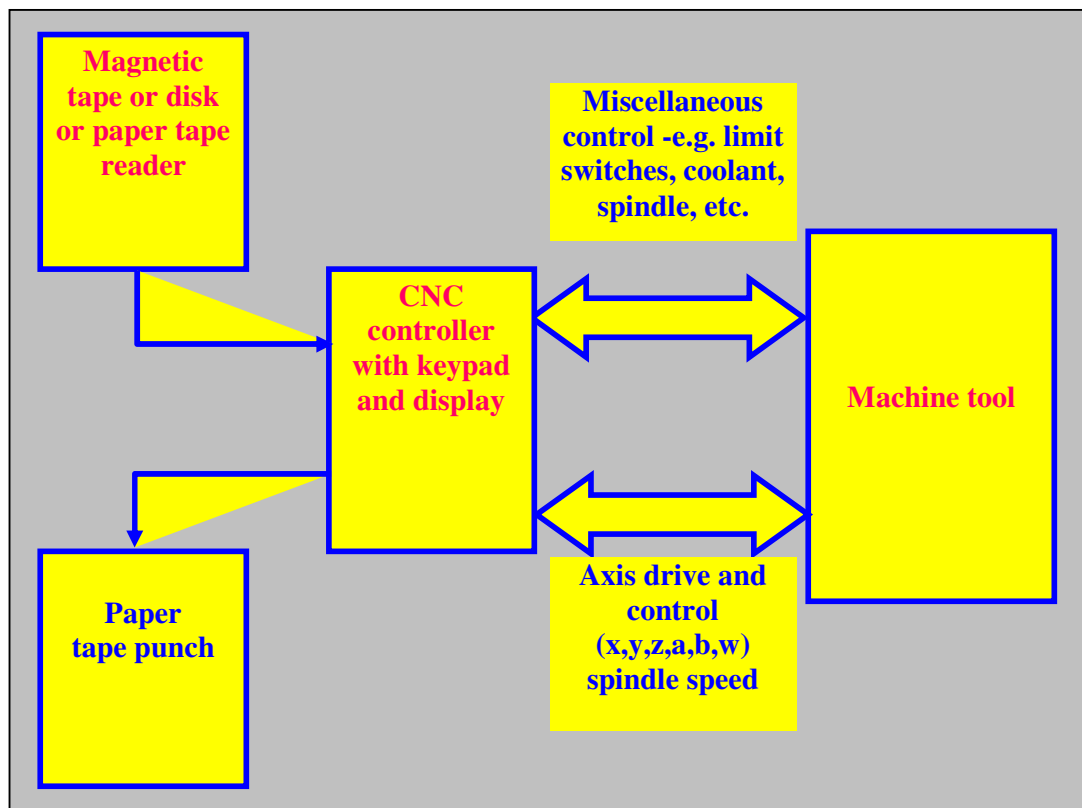


Figure 1 The general configuration of CNC.

Advantages of CNC

1. Increased productivity.
2. High accuracy and repeatability.
3. Reduced production costs.
4. Reduced indirect operating costs.
5. Facilitation of complex machining operations.

6. Greater flexibility.
7. Improved production planning and control.
8. Lower operator skill requirement.
9. Facilitation of flexible automation.

Limitations of CNC:

1. High initial investment.
2. High maintenance requirement.
3. Not cost-effective for low production cost.

Features of CNC

Computer NC systems include additional features beyond what is feasible with conventional hard-wired NC. These features, many of which are standard on most CNC Machine Control units (MCU), include the following:

- **Storage of more than one part program :** With improvements in computer storage technology, newer CNC controllers have sufficient capacity to store multiple programs. Controller manufacturers generally offer one or more memory expansions as options to the MCU
- **Various forms of program input :** Whereas conventional (hard-wired) MCUs are limited to punched tape as the input medium for entering part programs, CNC controllers generally possess multiple data entry capabilities, such as punched tape, magnetic tape, floppy diskettes, RS-232 communications with external computers, and manual data input (operator entry of program).
- **Program editing at the machine tool :** CNC permits a part program to be edited while it resides in the MCU computer memory. Hence, a part program can be tested and corrected entirely at the machine site, rather than being returned to the programming office for corrections. In addition to part program corrections, editing also permits cutting conditions in the machining cycle to be optimized. After the program has been corrected and optimized, the revised version can be stored on punched tape or other media for future use.
- **Fixed cycles and programming subroutines :** The increased memory capacity and the ability to program the control computer provide the opportunity to store frequently used machining cycles as macros, that can be called by the part program. Instead of writing the full instructions for the particular cycle into every program, a programmer includes a call statement in the part program to indicate that the macro cycle should be executed. These cycles often require that certain parameters be defined, for