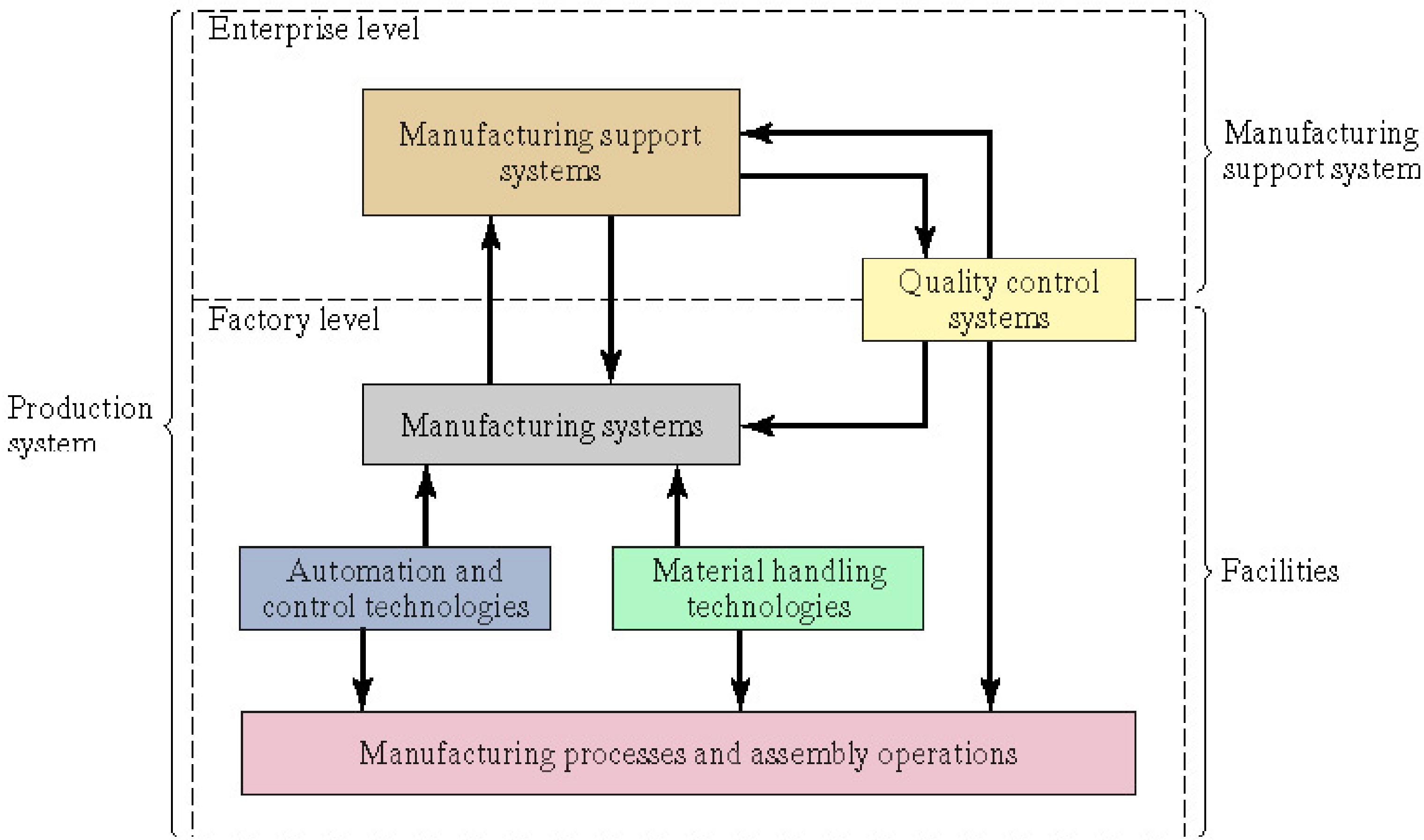
Manufacturing Systems & Single Station Manufacturing

Lecture 2

Manufacturing Systems in Production System



Manufacturing System Defined

A collection of integrated **equipment and human resources**, whose function is to perform one or more processing and/or assembly operations on a starting raw material, part, or set of parts

- **Equipment** includes
  - Production machines and tools
  - Material handling and work positioning devices
  - Computer systems
- **Human resources** are required either full-time or periodically to keep the system running

Examples of Manufacturing Systems

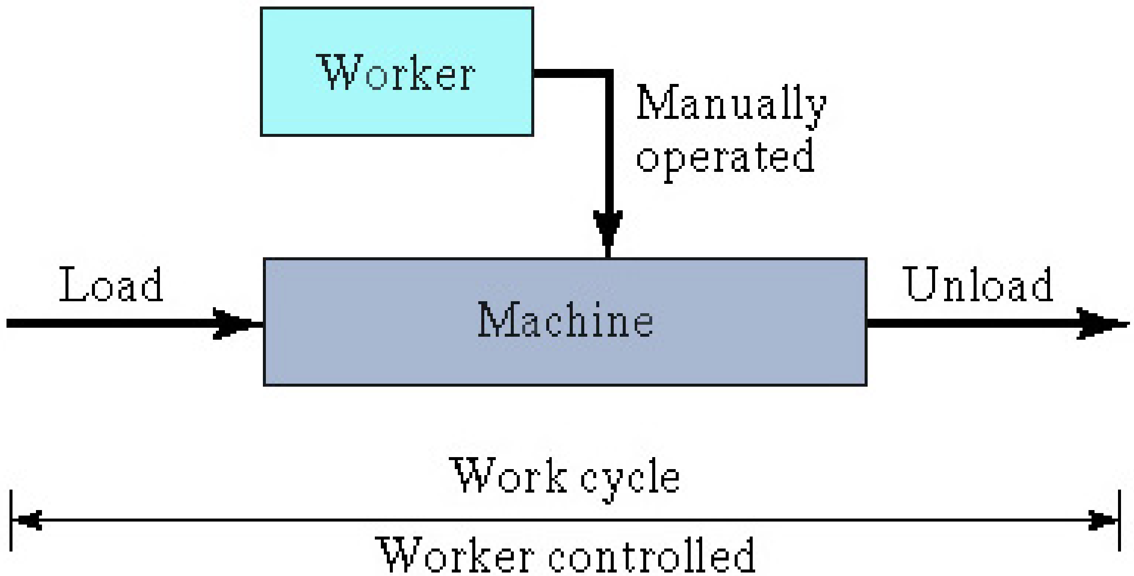
- Single-station cells
- Machine clusters
- Manual assembly lines
- Automated transfer lines
- Automated assembly systems
- Machine cells (cellular manufacturing)
- Flexible manufacturing systems

Components of a Manufacturing System

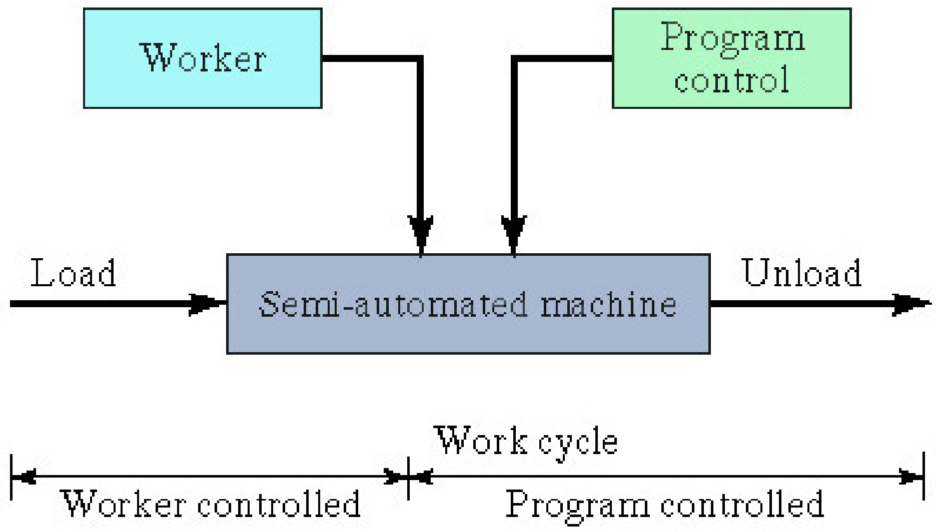
1. Production machines
2. Material handling system
3. Computer system to coordinate and/or control the preceding components
4. Human workers to operate and manage the system

Production Machines

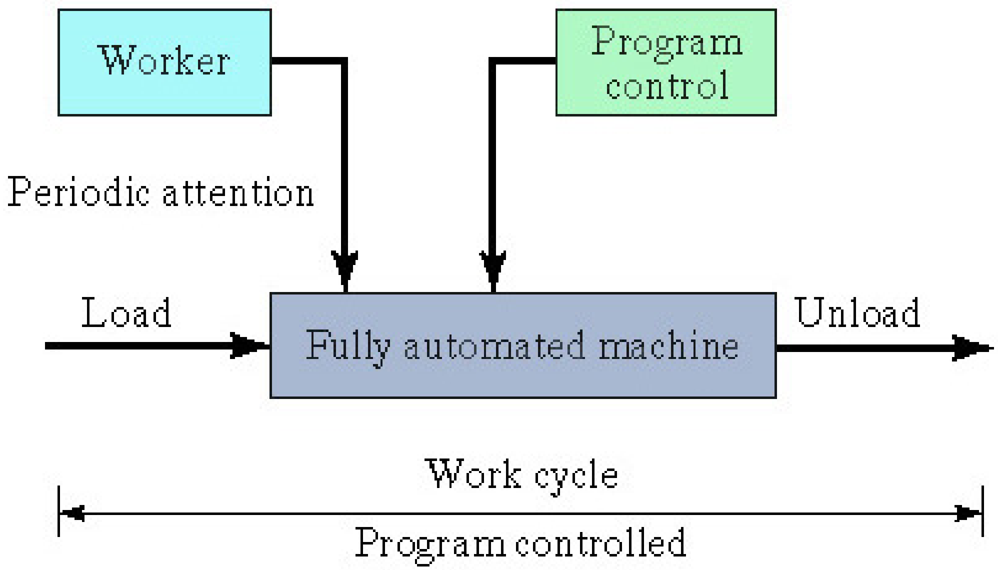
- In virtually all modern manufacturing systems, most of the actual processing or assembly work is accomplished by machines or with the aid of tools
- Classification of production machines:
  1. Manually operated machines are controlled or supervised by a human worker
  2. Semi-automated machines perform a portion of the work cycle under some form of program control, and a worker tends the machine the rest of the cycle
  3. Fully automated machines operate for extended periods of time with no human attention



Manually Operated Machines



Semi Automatic Machines



Fully Automatic Machines

Material Handling System

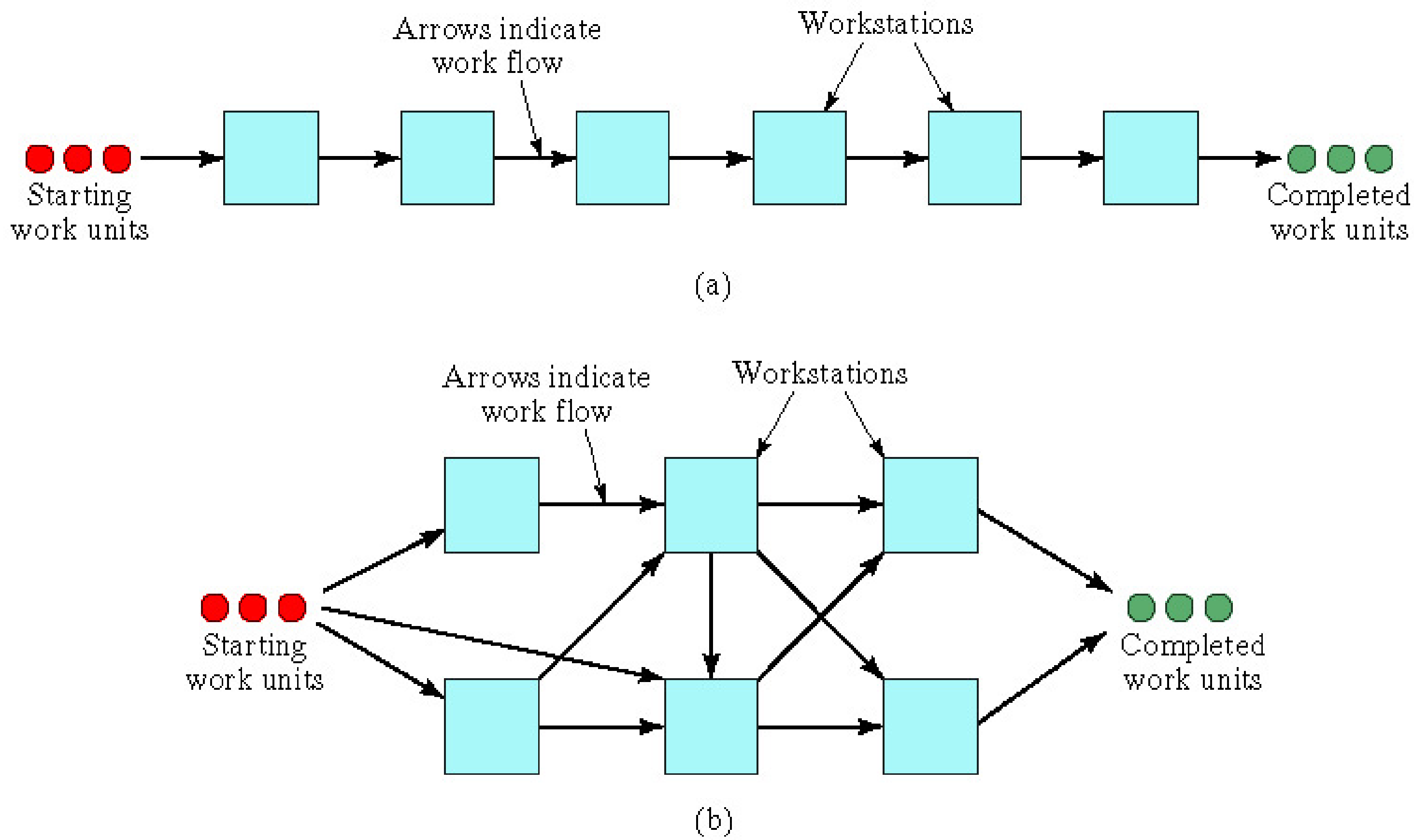
- In most manufacturing systems that process or assemble discrete parts and products, the following material handling functions must be provided:
  1. Loading work units at each station
  2. Positioning work units at each station
  3. Unloading work units at each station
  4. Transporting work units between stations in multi-station systems
  5. Temporary storage of work units

Work Transport Between Stations

- Two general categories of work transport in multi-station manufacturing systems:

1. **Fixed routing**
   - Work units always flow through the same sequence of workstations
   - Most production lines exemplify this category
2. **Variable routing**
   - Work units are moved through a variety of different station sequences
   - Most job shops exemplify this category

(a) Fixed Routing and (b) Variable Routing



Computer Control System

- Typical computer functions in a manufacturing system:
  - Communicate instructions to workers
  - Download part programs to computer-controlled machines
  - Control material handling system
  - Schedule production
  - Failure diagnosis when malfunctions occur
  - Safety monitoring
  - Quality control
  - Operations management

Classification of Manufacturing Systems

- Factors that **define and distinguish** manufacturing systems:
  1. Types of operations
  2. **Number of workstations**
  3. **System layout**
  4. **Automation and manning level**
  5. **Part or product variety**

Types of Operations Performed

- **Processing Vs assembly operations**
- **Type(s) of materials processed**
- **Size** and **weight** of work units
- **Part or product <u>complexity</u>**
  - For assembled products, <u>number of components per product</u>
  - For individual parts, <u>number of distinct operations to complete processing</u>
- **Part geometry**
  - For machined parts, **rotational vs. non-rotational**

Number of Workstations

- Convenient measure of the size of the system
  - Let ***n* = number of workstations**
  - Individual workstations can be identified by **subscript *i*,** where $i = 1, 2, ..., n$
- Affects **performance factors** such as workload capacity, production rate, and reliability
  - As ***n*** increases, this usually means greater workload capacity and higher production rate
  - There must be a synergistic effect that derives from ***n* multiple stations working together vs. *n* single stations**

System Layout

- Applies mainly to multi-station systems
- Fixed routing vs. variable routing
  - In systems with **fixed routing**, workstations are usually **arranged linearly**
  - In systems with **variable routing**, a variety of layouts are possible
- System layout is an important factor in determining the most appropriate type of material handling system

Automation and Manning Levels

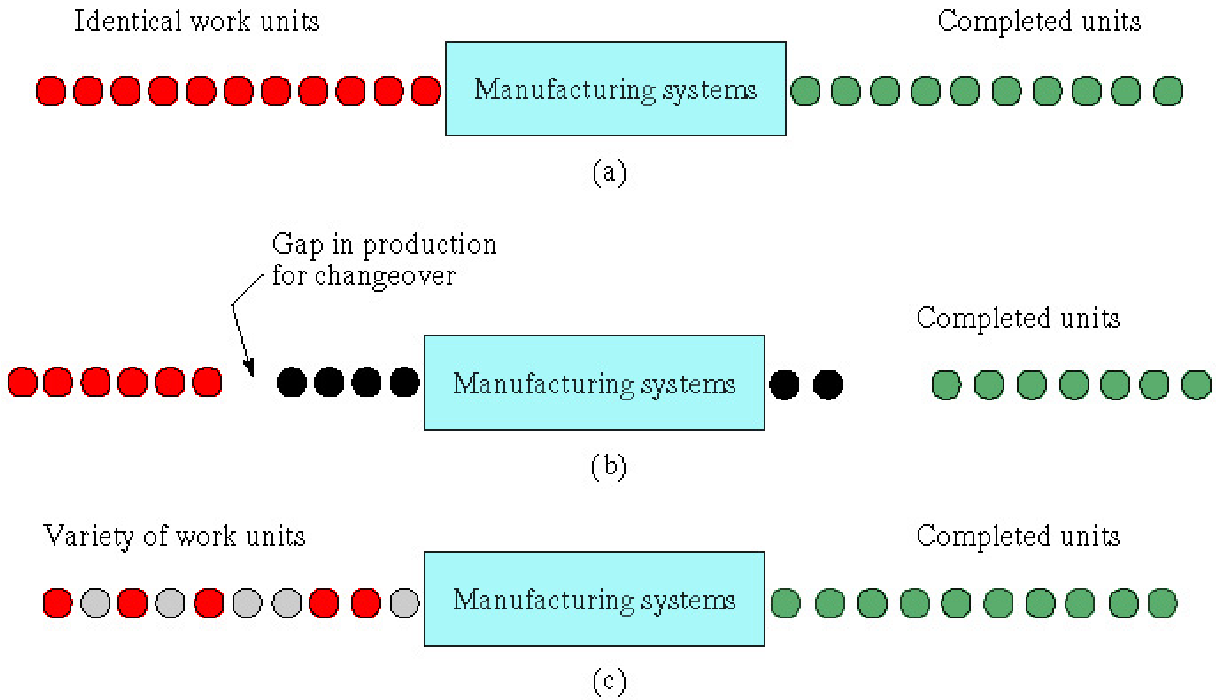
- Level of workstation automation
  - Manually operated
  - Semi-automated
  - Fully automated
- Manning level M_i **= proportion of time worker is in attendance at station *i***
  - $M_i = 1$ means that one worker must be at the station continuously
  - $M_i \geq 1$ indicates manual operations
  - $M_i < 1$ usually denotes some form of automation

Part or Product Variety: Flexibility

The degree to which the system is capable of dealing with variations in the parts or products it produces

- Three cases:
  1. Single-model case - all parts or products are identical
  2. Batch-model case - different parts or products are produced by the system, but they are produced in batches because changeovers are required
  3. Mixed-model case - different parts or products are produced by the system, but the system can handle the differences without the need for time-consuming changes in setup

Three Cases of Product Variety in Manufacturing Systems



(a) Single-model case, (b) batch model case, and (c) mixed-model case

Enablers of Flexibility

- **Identification of the different work units**
  - The system must be able to identify the differences between work units in order to perform the correct processing sequence
- **Quick changeover of operating instructions**
  - The required work cycle programs must be readily available to the control unit
- **Quick changeover of the physical setup**
  - System must be able to change over the fixtures and tools required for the next work unit in minimum time

Manufacturing Systems for Medium or High Product Complexity

Product variety (P) \ Annual production quantity (Q)	Low	Medium	High
Hard	Job shop with multiple single-station cells, manned	(Multiple systems required)	(Multiple systems required)
Soft	Job shop with multiple single-station cells, manned	Multi-station system with variable routing, manned or automated	Multi-station system with fixed routing, manned or automated
None	(Craft shop)	Job shop with multiple single-station cells, manned or automated	Multi-station system with fixed routing, manned or automated

Manufacturing Systems for Low Product Complexity

Product variety (P)	Low	Medium	High
Hard	Single-station cell, manned, batch production	Single-station cell, manned or automated, batch production	(Reverts to multiple single stations dedicated to each part or product)
Soft	Single-station cell, manned, batch- or mixed-model production	Single-station cell, manned or automated, mixed-model production	(Reverts to multiple single stations dedicated to each part or product)
None	(Not feasible, system would be grossly underutilized)	Single-station cell, manned (system would be underutilized)	Single-station or multi-station system, automated, single model production

Annual production quantity (Q)

Product variety (P)

Overview of Classification Scheme

- **Single-station cells**
  - $n = 1$
  - Manual or automated
- **Multi-station systems with fixed routing**
  - $n > 1$
  - Typical example: production line
- **Multi-station systems with variable routing**
  - $n > 1$

Single-Station Cells

- $n = 1$
- Two categories:
  1. **Manned workstations** - manually operated or semi-automated production machine ($M = 1$)
  2. **Fully automated** machine ($M < 1$)
- Most widely used manufacturing system - reasons:
  - Easiest and least expensive to implement
  - Most adaptable, adjustable, and flexible system
  - Can be converted to automated station if demand for part or product justifies

Multi-Station Systems with Fixed Routing

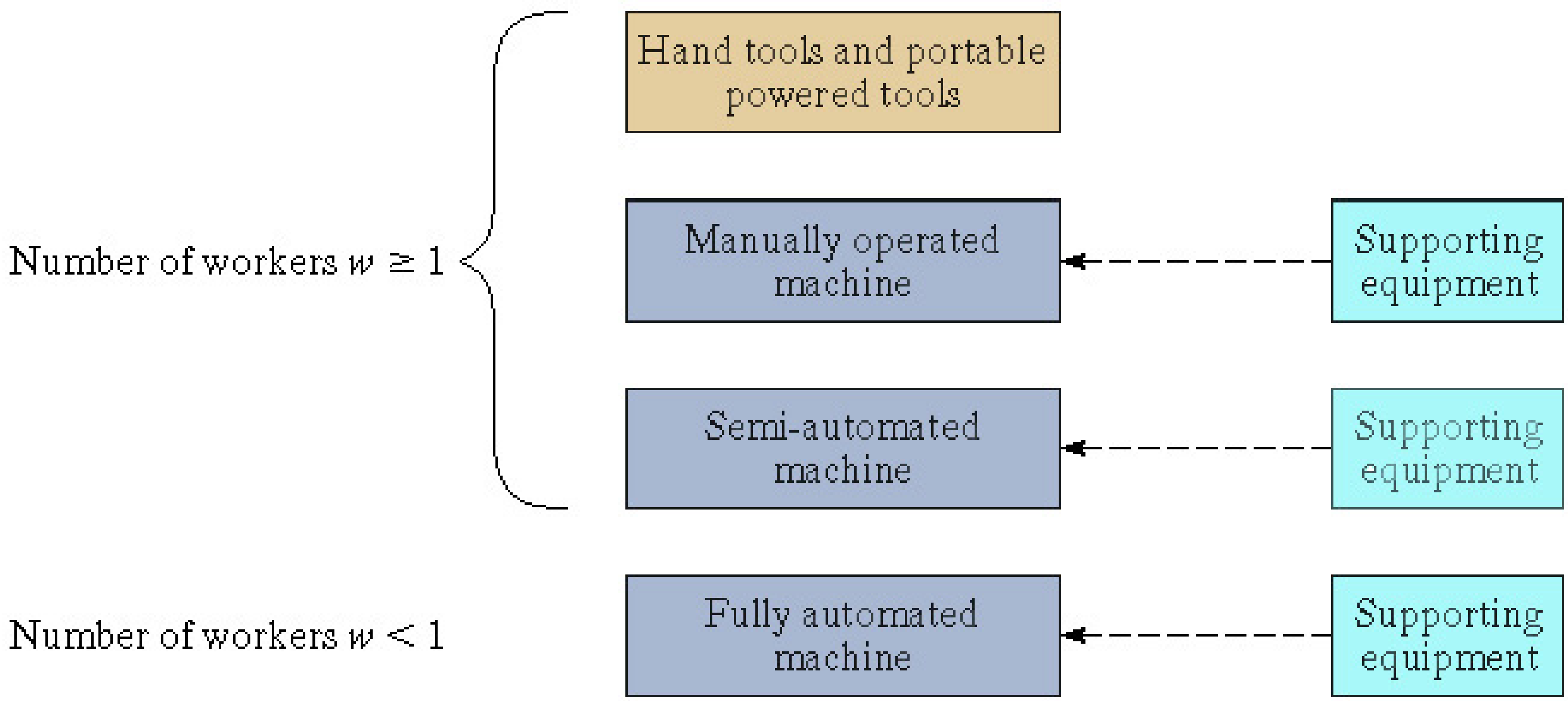
- $n > 1$
- Common example = production line - a series of workstations laid out so that the part or product moves through each station, and a portion of the total work content is performed at each station
- Conditions favoring the use of production lines:
  - Quantity of work units is high
  - Work units are similar or identical, so similar operations are required in the same sequence
  - Total work content can be divided into separate tasks of approximately equal duration

Multi-Station Systems with Variable Routing

- $n > 1$
- Defined as a group of workstations organized to achieve some special purpose, such as:
  - Production of a family of parts requiring similar (but not identical) processing operations
  - Assembly of a family of products requiring similar (but not identical) assembly operations
  - Production of a complete set of components used to assemble one unit of a final product
- Typical case in cellular manufacturing

Single-Station Manufacturing Cells

Classification of Single-Station Manufacturing Cells



Single-Station Manufacturing Cells

- Most common manufacturing system in industry
- Operation is independent of other stations
- Perform either processing or assembly operations
- Can be designed for:
  - Single model production
  - Batch production
  - Mixed model production

Single-Station Manned Cell

One worker tending one production machine (most common model)

- Most widely used production method, especially in job shop and batch production
- Reasons for popularity:
  - Shortest time to implement
  - Requires least capital investment
  - Easiest to install and operate
  - Typically, the lowest unit cost for low production
  - Most flexible for product or part changeovers

Single-Station Manned Cell Examples

- Worker operating a standard machine tool
  - Worker loads & unloads parts, operates machine
  - Machine is manually operated
- Worker operating semi-automatic machine
  - Worker loads & unloads parts, starts semi-automatic work cycle
  - Worker attention not required continuously during entire work cycle
- Worker using hand tools or portable power tools at one location

Variations of Single-Station Manned Cell

- Two (or more) workers required to operate machine
  - Two workers required to manipulate heavy forging at forge press
  - Welder and fitter in arc welding work cell
- One principal production machine plus support equipment
  - Drying equipment for a manually operated injection molding machine
  - Trimming shears at impression-die forge hammer to trim flash from forged part

Single-Station Automated Cell

Fully automated production machine capable of operating unattended for longer than one work cycle

- Worker not required except for periodic tending
- Reasons why it is important:
  - Labor cost is reduced
  - Easiest and least expensive automated system to implement
  - Production rates usually higher than manned cell
  - First step in implementing an integrated multi-station automated system

Enablers for Unattended Cell Operation

- For single model and batch model production:
  - Programmed operation for all steps in work cycle
  - Parts storage subsystem
  - Automatic loading, unloading, and transfer between parts storage subsystem and machine
  - Periodic attention of worker for removal of finished work units, resupply of starting work units, and other machine tending
  - Built-in safeguards to avoid self-destructive operation or damage to work units

Enablers for Unattended Cell Operation

- For mixed model production:
  - All of the preceding enablers, plus:
  - Work unit identification:
    - Automatic identification (e.g., bar codes) or sensors that recognize alternative features of starting units
    - If starting units are the same, work unit identification is unnecessary
  - Capability to download programs for each work unit style (programs prepared in advance)
  - Capability for quick changeover of physical setup

Parts Storage Subsystem and Automatic Parts Transfer

- Necessary conditions for unattended operation
- Given a capacity = n_p parts in the storage subsystem, the cell can theoretically operate for a time

$$UT = n_p T_c$$

where UT = unattended time of operation

  – In reality, unattended time will be less than UT because the worker needs time to unload finished parts and load raw work parts into the storage subsystem

Parts Storage Capacity

- Typical objectives in defining the desired parts storage capacity n_p:
  - Make $n_p T_c$ = a fixed time interval that allows one worker to tend multiple machines
  - Make $n_p T_c$ = time between scheduled tool changes
  - Make $n_p T_c$ = one complete shift
  - Make $n_p T_c$ = one overnight ("lights-out operation")

Storage Capacity of One Part

- Example: two-position automatic pallet changer (APC)
- With no pallet changer, work cycle elements of loading/unloading and processing would have to be performed sequentially

$$T_c = T_m + T_s$$

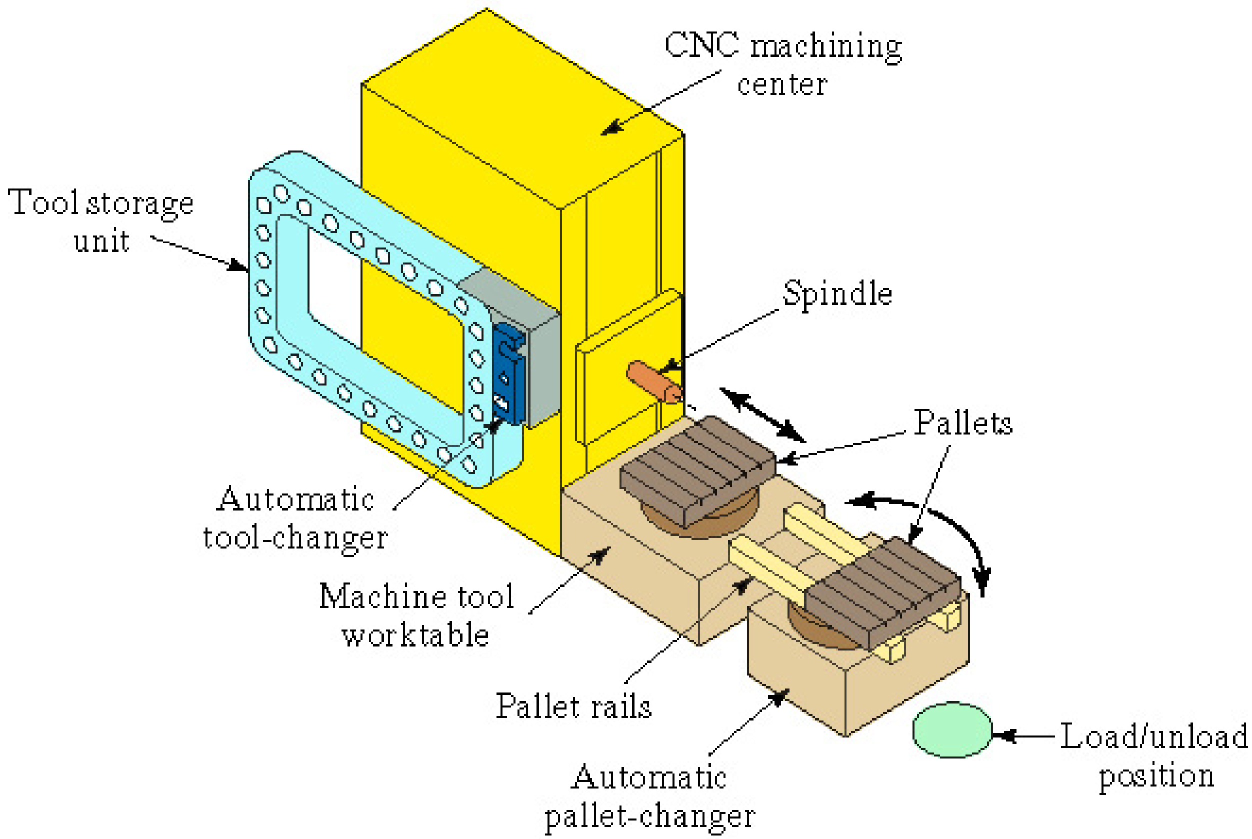
where T_m = machine time and T_s = worker service time

- With pallet changer, work cycle elements can be performed simultaneously

$$T_c = \text{Max}\{T_m, T_s\} + T_r$$

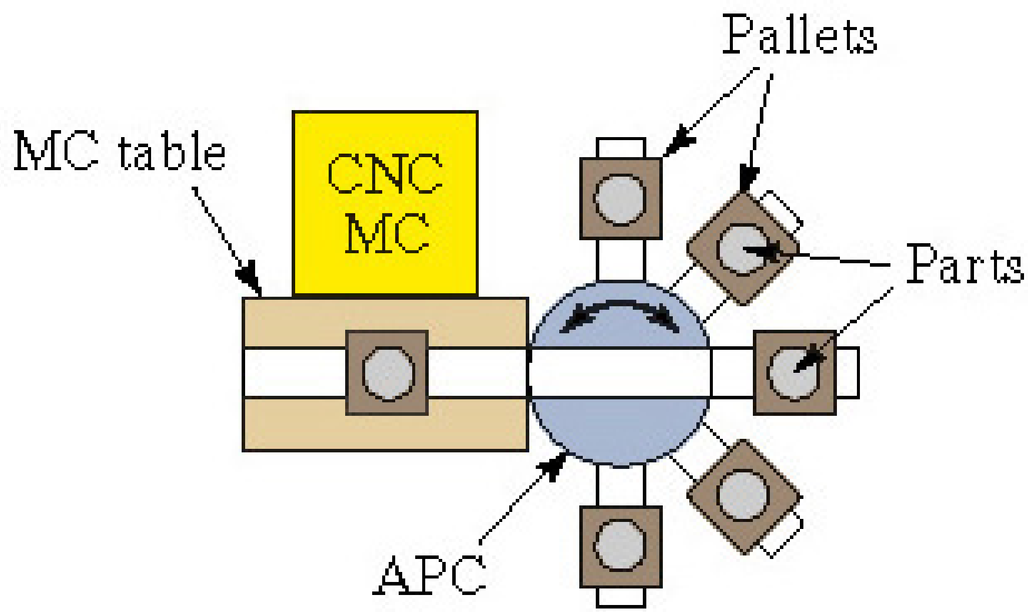
where T_r = repositioning time of pallet changer

CNC Machining Center with Automatic Pallet Changer - Stores One Part

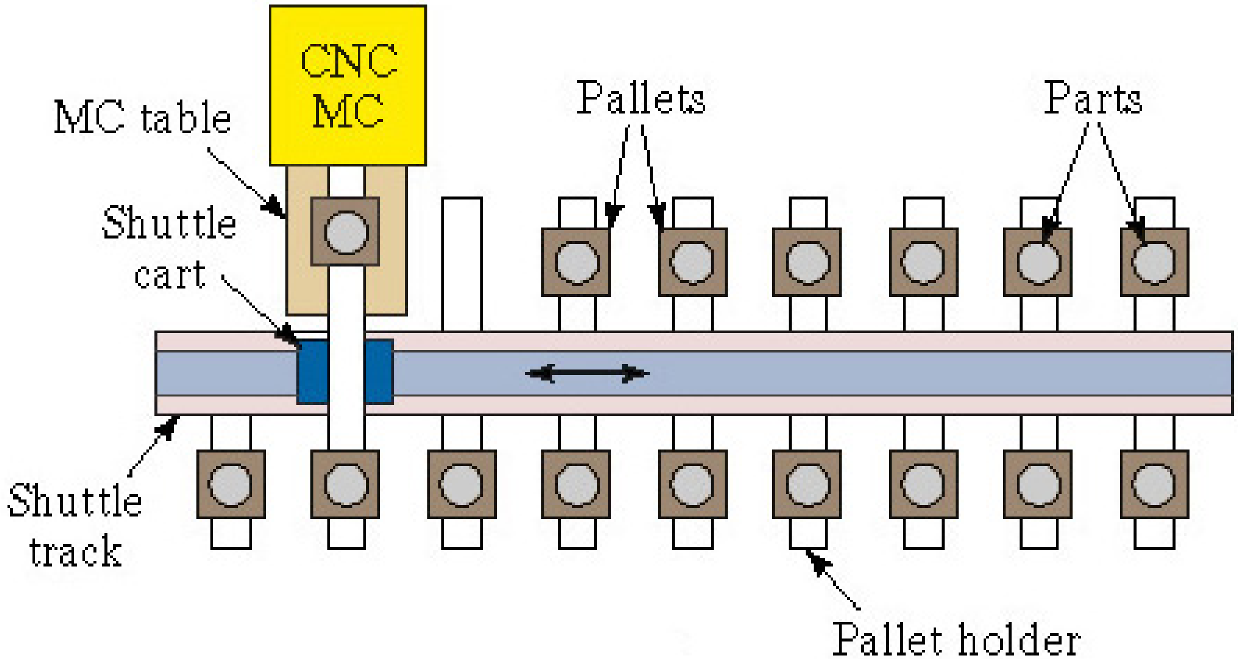


Storage Capacities Greater Than One

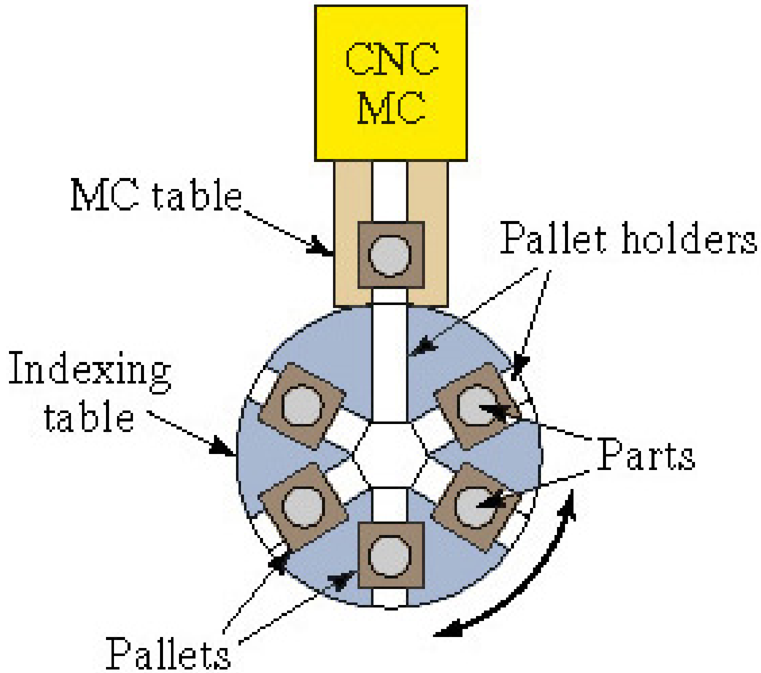
- Machining centers:
  - Various designs of parts storage unit interfaced to automatic pallet changer (or other automated transfer mechanism)
- Turning centers:
  - Industrial robot interface with parts carousel
- Plastic molding or extrusion:
  - Hopper contains sufficient molding compound for unattended operation
- Sheet metal stamping:
  - Starting material is sheet metal coil



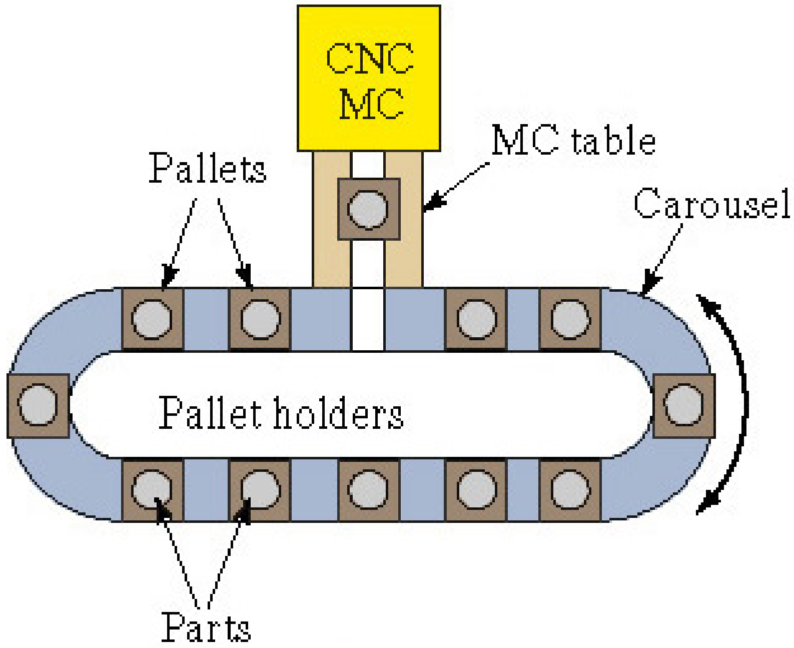
Machining center and automatic pallet changer with pallet holders arranged radially; parts storage capacity = 5



Machining center and in-line shuttle cart system with pallet holders along its length; parts storage capacity = 16



Machining center with pallets held on indexing table; parts storage capacity = 6



Machining center and parts storage carousel with parts loaded onto pallets; parts storage capacity = 12

Applications of Single Station Manned Cells

- CNC machining center with worker to load/unload
- CNC turning center with worker to load/unload
- Cluster of two CNC turning centers with time sharing of one worker to load/unload
- Plastic injection molding on semi-automatic cycle with worker to unload molding, sprue, and runner
- One worker at electronics subassembly workstation inserting components into PCB
- Stamping press with worker loading blanks and unloading stampings each cycle

Applications of Single Station Automated Cells

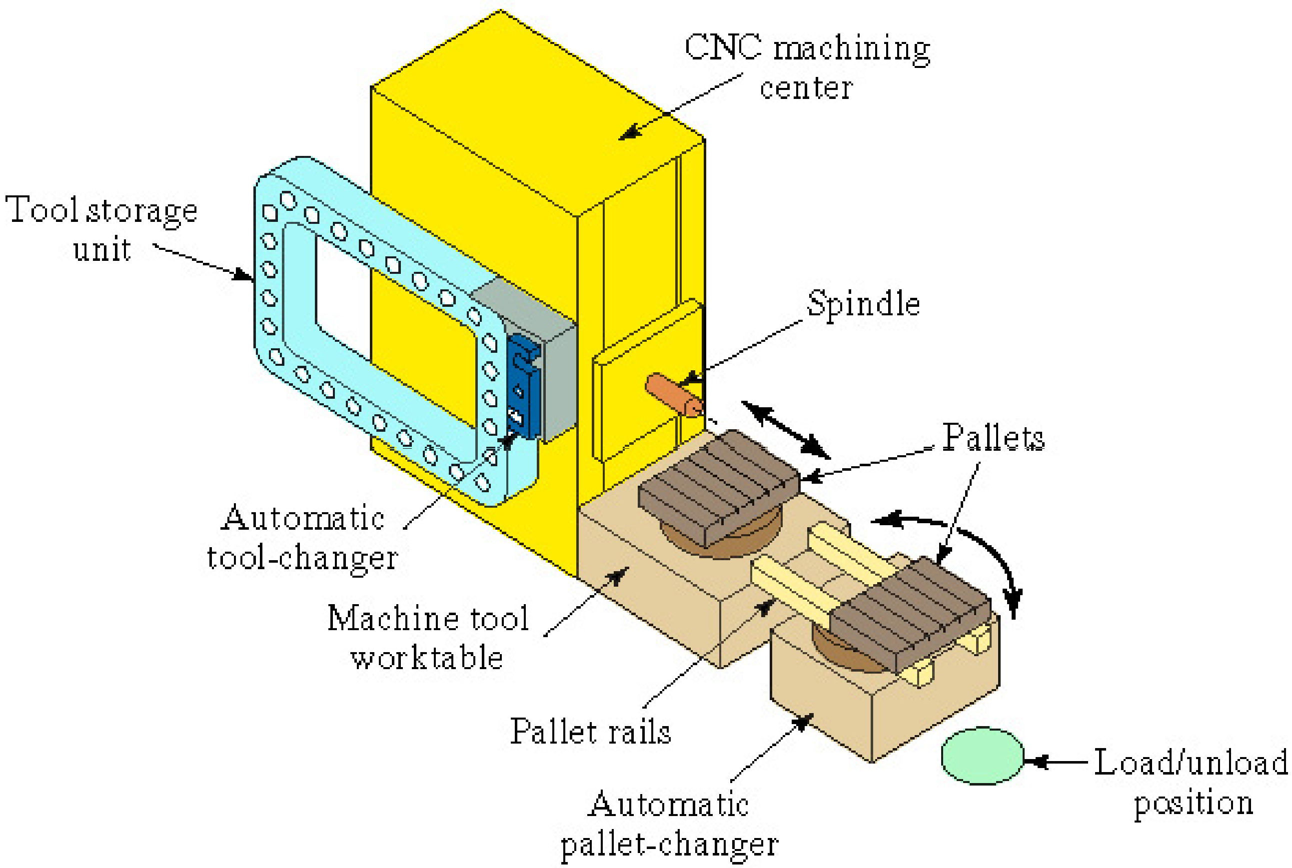
- CNC MC with APC and parts storage subsystem
- CNC TC with robot and parts storage carousel
- Cluster of ten CNC TCs, each with robot and parts storage carousel, and time sharing of one worker to load/unload the carousels
- Plastic injection molding on automatic cycle with robot arm to unload molding, sprue, and runner
- Electronics assembly station with automated insertion machine inserting components into PCBs
- Stamping press stamps parts from long coil

CNC Machining Center

Machine tool capable of performing multiple operations that use rotating tools on a work part in one setup under NC control

- Typical operations: milling, drilling, and related operations
- Typical features to reduce nonproductive time:
  - Automatic tool changer
  - Automatic work part positioning
  - Automatic pallet changer

CNC Horizontal Machining Center

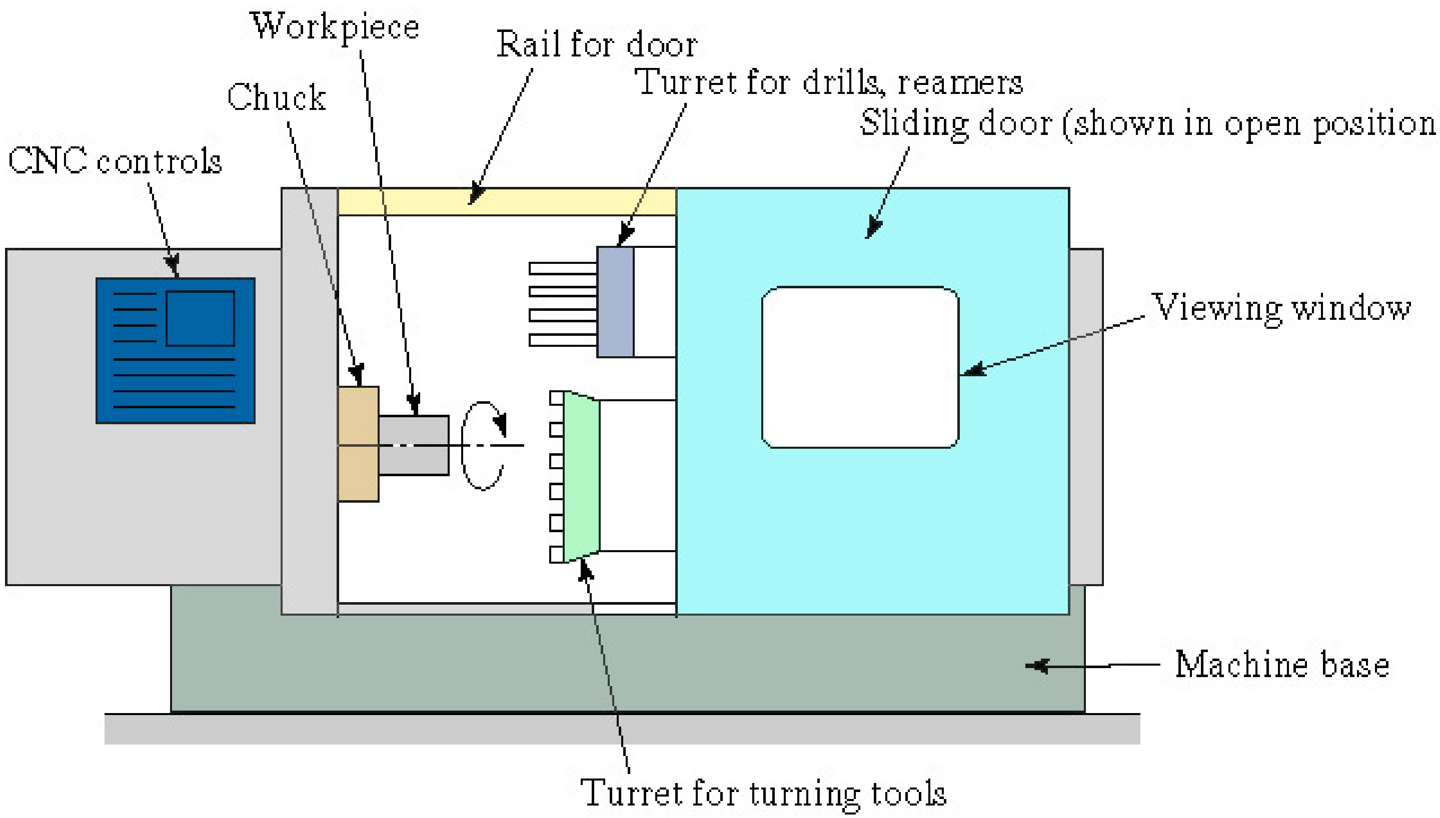


CNC Turning Center

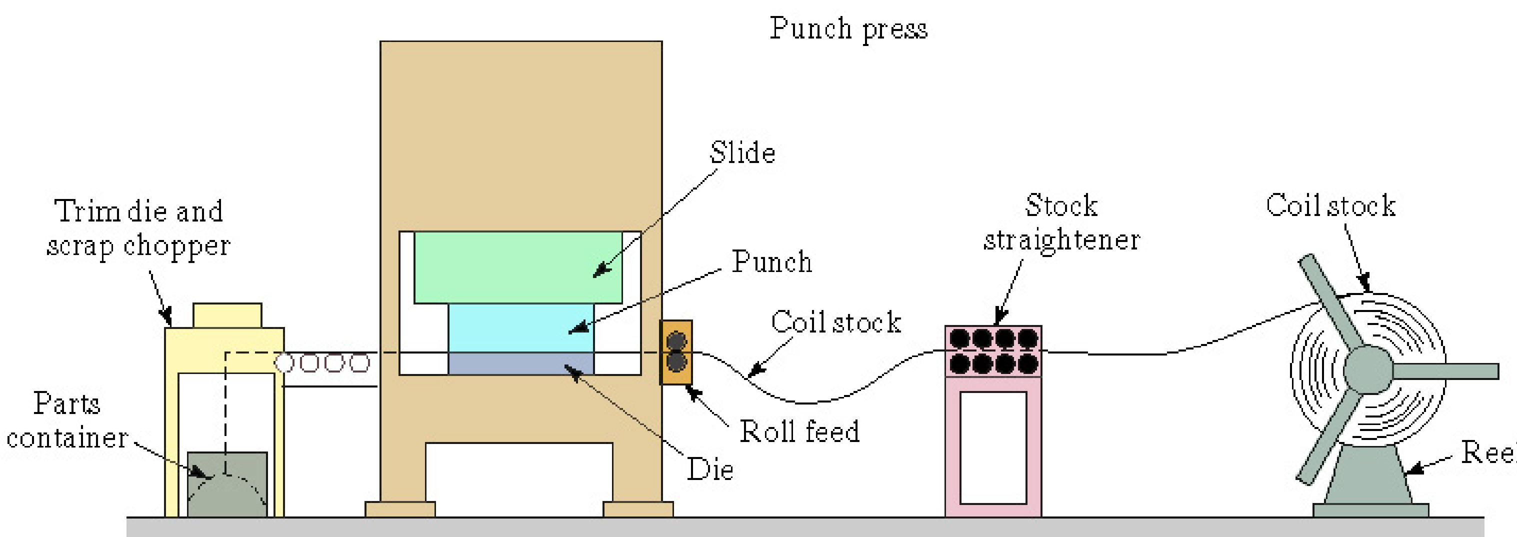
Machine tool capable of performing multiple operations on a rotating work part in one setup under NC control

- Typical operations:
  - Turning and related operations, e.g., contour turning
  - Drilling and related operations along work part axis of rotation

CNC Turning Center



Automated Stamping Press



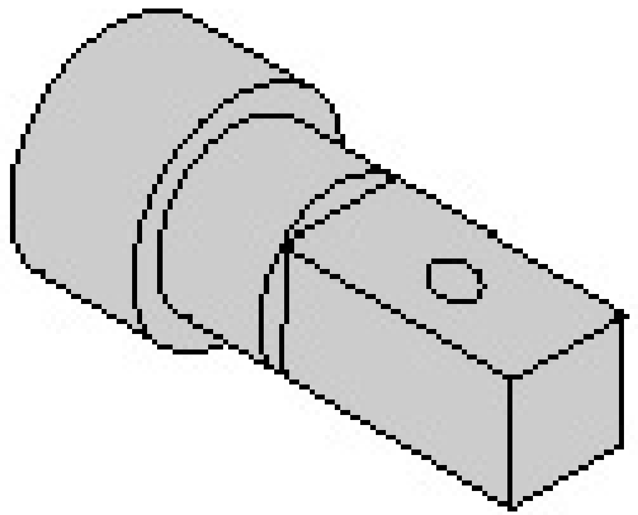
Stamping press on automatic cycle producing stampings from sheet metal coil

CNC Mill-Turn Center

Machine tool capable of performing multiple operations either with single point turning tools or rotating cutters in one setup under NC control

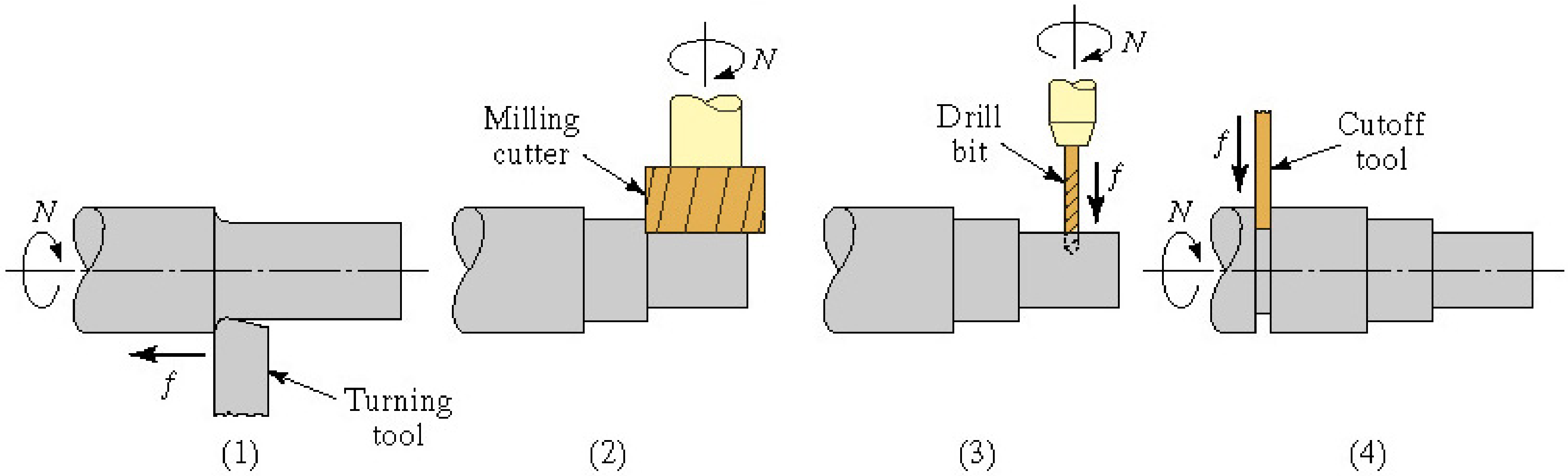
- Typical operations:
  - Turning, milling, drilling and related operations
- Enabling feature:
  - Capability to control position of c-axis in addition to *x*- and *z*-axis control (turning center is limited to *x*- and *z*-axis control)

Part with Mill-Turn Features



Example part with turned, milled, and drilled features

Sequence of Operations of a Mill-Turn Center for Example Part



(1) Turn smaller diameter, (2) mill flat with part in programmed angular positions, four positions for square cross section; (3) drill hole with part in programmed angular position, and (4) cutoff of the machined piece

Analysis of Single Station System

Work Load:

The work load is the quantity of work units produced during the period of interest multiplied by time (hrs) required for each unit

$$WL = QT_c$$

Where WL = work load scheduled; Q = quantity to be produced during period; and T_c = cycle time required /piece (hr/pc)

If work load includes multiple part styles then

$$WL = \sum_i Q_j T_{cj}$$

If n = number of workstations & AT = available time on station in the period (hr/period)

Then

$$n = \frac{WL}{AT}$$

Example:

Suppose a certain facility produce 800 shafts in a lathe section during a particular week. Shafts are identical in shape and requires same machine cycles. T_c = 11.5 min. determine number of lathes if there are 40 hours of available time on each lathe.

$$WL = QT_c$$

$$WL = 800 \times 11.5(\text{min}) = 9200(\text{min}) = 153.33(hrs)$$

Time available is 40 hrs= AT

$$n = \frac{WL}{AT}$$

$$n = \frac{153.33}{40} = 3.82 = 4 lathes$$

Several factors complicates the single model like setup time, availability, utilization, worker efficiency and defect rate

In previous problem suppose setup time is 3.5 hrs. how many lathes are then required?

$$AT = 40 - 3.5 = 36.5 hrs$$

$$n = \frac{153.33}{36.5} = 4.2 = 5 lathes$$

Checking for Utilization U

$$U = \frac{4.2}{5} = 0.84 = 84\%$$

$$OT = \left(3.5 + \frac{153.33}{4}\right) - 40 = 1.83 hr$$

This is a total of 4(1.83 hrs) = 7.33 hrs for 4 m/c operators

Including setup time CASE 2; Shaft type = 20 different in own batch; Average batch size = 40 parts
Batch setup time = 3.5 hrs; Tc = 11.5 min
Computing number of machines again for…..

$$WL = 20(3.5) + 20(40)\left(\frac{11.5}{60}\right) = 223.33 hrs$$

$$n = \frac{223.33}{40} = 5.58 = 6 lathes$$

Available time is

AT = T A U

AT = available time; T = Actual clock time;
A = Availability; U = utilization
it is noted that worker efficiency system is considered in Manual system

Defect rate relationship is also considered here

$$Q = Q_o(1-q)$$

Q= quantity of good units; Q_o= Original or starting units; and q = fraction defect rate

The above equation can be solved for

$$Q_o = \frac{Q}{(1-q)}$$

Combined effects of workers efficiency and fraction defect rate (considered in Work Load)

$$WL = \frac{QT_c}{E_w(1-q)}$$

E_w is worker efficiency

Machine Cluster

A **machine cluster** is defined as a collection of two or more machines producing parts or products with identical cycle times and is serviced by one worker.

Whereas **machine cell** consists of one or more machines organized to produce family of parts/products

Consider a collection of single work station, all products are same in parts and operating on same semi-automatic cycle time

Let T_m = machine cycle time

T_s = Servicing time by worker

If worker is always available when servicing is NEEDED and machine never idle

$T_c = T_m + T_s$

If more than one machine is assigned to the worker, a certain amount of time will; be lost because of walking from one machine to the next called repositioning time T_r.

Time required for operator to service one machine is $T_s + T_r$ and time to service ‘n’ machines is $n(T_s + T_r)$.

For system to be balanced

$$n(T_s + T_r) = T_m + T_s$$

$$n = \frac{T_m + T_s}{T_s + T_r}$$

$n(T_s + T_r)$---------- cannot be balanced with T_c of machine

Scenarios

n_1 and n_2

Introducing cost factors

Let C_L = labor cost rate

C_m = machine cost rate

Case 1: if n_1 = max. integers ≤ n, worker will have idle time and cycle time of machine cluster will be cycle time of machine i.e. $T_c = T_m + T_s$

$$C_{pc}(n_1) = \left(\frac{C_L}{n_1} + C_m\right)(T_m + T_s)$$

Case 2: if n_2 = min. integers > n, machine will have idle time and cycle time of machine cluster will be time it takes for worker to service n_2 machines which is n(Ts + Tr).

$$C_{pc}(n_2) = (C_L + C_m n_2)(T_s + T_r)$$

In absence of cost data workers must have some idle time and machine will be utilized 100%

n_1 = max. integers $\leq \dfrac{T_m + T_s}{T_s + T_r}$

Problem (determining W/stns)

A stamping plant must be designed to supply an automotive engine plant with sheet metal stampings. The plant will operate one 8-hour shift for 250 days per year and must produce 15,000,000 good quality stampings annually. Batch size = 10,000 good stampings produced per batch. Scrap rate = 5%. On average it takes 3.0 sec to produce each stamping when the presses are running. Before each batch, the press must be set up, and it takes 4 hr to accomplish each setup. Presses are 90% reliable during production and 100% reliable during setup. **How many stamping presses** will be required to accomplish the specified production?

Solution

Production: $WL = \frac{15{,}000{,}000(3/3600)}{1-0.05} = 13{,}157.9$ hr/yr

$AT = 250(8)(0.90) = 1800$ hr/yr per press

Setup: number batches/yr = $\frac{15{,}000{,}000}{10{,}000}$ = 1500 batches = 1500 setups

WL = 1500(4) = 6000 hr/yr

AT = 250(8) = 2000 hr/yr per press.

$n = \frac{13{,}157.9}{1800} + \frac{6000}{2000} = 7.31 + 3.0 = 10.31 \rightarrow$ **11 presses**

Problem (M/c Cluster)

A worker is currently responsible for tending two machines in a machine cluster. The service time per machine is 0.35 min and the time to walk between machines is 0.15 min. The machine automatic cycle time is 1.90 min. If the worker's hourly rate = $12/hr and the hourly rate for each machine = $18/hr, determine (a) the current hourly rate for the cluster, and (b) the current cost per unit of product, given that two units are produced by each machine during each machine cycle. (c) What is the % idle time of the worker? (d) What is the optimum number of machines that should be used in the machine cluster, if minimum cost per unit of product is the decision criterion?

Solution

(a) $C_o = \$12 + 2(\$18) =$ **\$48.00/hr**

(b) $T_c = T_m + T_s = 1.90 + 0.35 = 2.25$ min/cycle

$R_c = 2(2)\left(\frac{60}{2.25}\right) = 106.67$ pc/hr

$C_{pc} = \frac{\$48/\text{hr}}{106.67\text{pc}/\text{hr}} =$ **\$0.45/pc**

(c) Worker engagement time/cycle = $2(T_s + T_r) = 2(0.35 + 0.15) = 1.0$ min

Idle time $IT = \frac{2.25 - 1.0}{2.25} = 0.555 =$ **55.5%**

(d) $n = \frac{1.90 + 0.35}{0.35 + 0.15} = 2.25/0.5 =$ **4.5 machines**

$n_1 = 4$ machines: $C_{pc}(4) = 0.5(12/4 + 18(2.25/60) = \$0.394$/pc

$n_2 = 5$ machines: $C_{pc}(5) = 0.5(12 + 18\text{x}5)(0.50/60) = \$0.425$/pc

Use $n_1 =$ **4 machines**