Chapter 2

Product, Process, and Schedule Design

Facilities Planning Process

Facilities Planning Process for manufacturing and assembly facilities can be listed as follows:

- Define the product to be manufactured or assembled
- Specify the required manufactured or assembled
- Determine the interrelationships among all activities
- Determine the space requirement for all activities
- Generate alternative facilities plan
- Evaluate the alternative facilities plan
- Select the preferred facilities plan
- Implement the facilities plan
- Maintain and adopt the facilities plan
- Update the products to be manufactured or redefine the objectives of the facility

Introduction

- Before we start developing alternative facility plans, we should have answers for the following questions:

1. What is to be produced?
2. How are the products to be produced?
3. When are the products to be produced?
4. How much of each product will be produced?
5. For how long will the product be produced?
6. Where will the products be produced?

Answer for the first 5 Questions can be obtained from:
- **Product design**
- **Process design**
- **Schedule design**

Answer for the last question might be obtained from **facility location** determination or it may answered by **schedule design** when the production is to be allocated among several existing factories

Introduction (Contd.)

- Organisations create teams (concurrent engineering team) with:
  - Product planner
  - Process planner
  - Schedule planner (production planner)
  - Facility design planner
  - Personnel from marketing , purchasing and accounting

Why?

To address the design process in an integrated or concurrent way

Introduction (Contd.)

- **Product designers** focus on the end product is to be in terms of its dimensions, material composition, and perhaps packaging.
- **Process planner** determines how the product will be produced.
- **Production planner** specify the production quantities and schedules the production equipment.
- *Facility planner* is dependent on timely *and* accurate input from product, process and schedule designers.

Introduction (Contd.)

- This team approach reduces the design cycle time, improve the design process, and minimising the engineering changes.

- Implementing this integrated approach have reported significant improvement in cost, quality, productivity, sales, customer satisfaction, delivery time, inventories, space and handling requirements, and facilities utilisation.

Introduction (contd.)

- The success of a firm is dependent on having an efficient production system. Hence, it is essential that product designers, process selections, production schedules, and facilities plans to be mutually supportive.

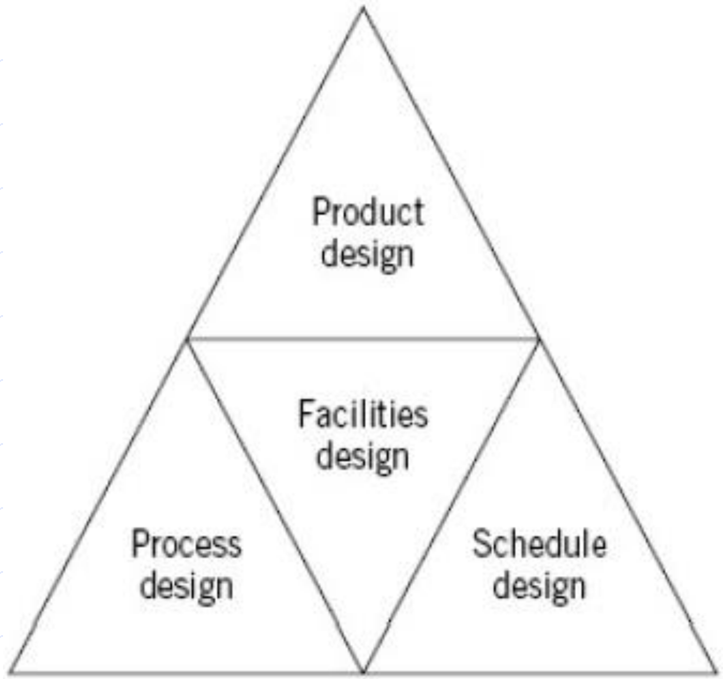


Fig 2.1: The need for close coordination among the four groups

Product Design

- Product design
- Process design
- Schedule design

1. Determination of a product to be produced
2. Detailed design of the product

1. Product Determination

- Product Determination made by upper level management and based on input from:
  - Marketing
  - Manufacturing
  - Finance
  - Etc.

1. Product Determination (contd.)

- Product design
- Process design
- Schedule design

– If changes are likely in facility mission and products:

A high degree of flexibility and a very general space.

– If a high degree of confidence about facility mission and products:

The facility design should optimize the production of those products

- Product design
- Process design
- Schedule design

2. Detailed Design

- The detailed design of the product is influenced by aesthetics, function, materials and manufacturing considerations.
- The product must meet the needs of the customer.

- This challenge can be accomplished by:

Quality Function Deployment (QFD) - Translation of the customers' desires into product design, and subsequently into parts characteristics, process plans and production requirements.

- *Benchmarking*

2. Detailed Design (contd.)

- **Product design**
- **Process design**
- **Schedule design**

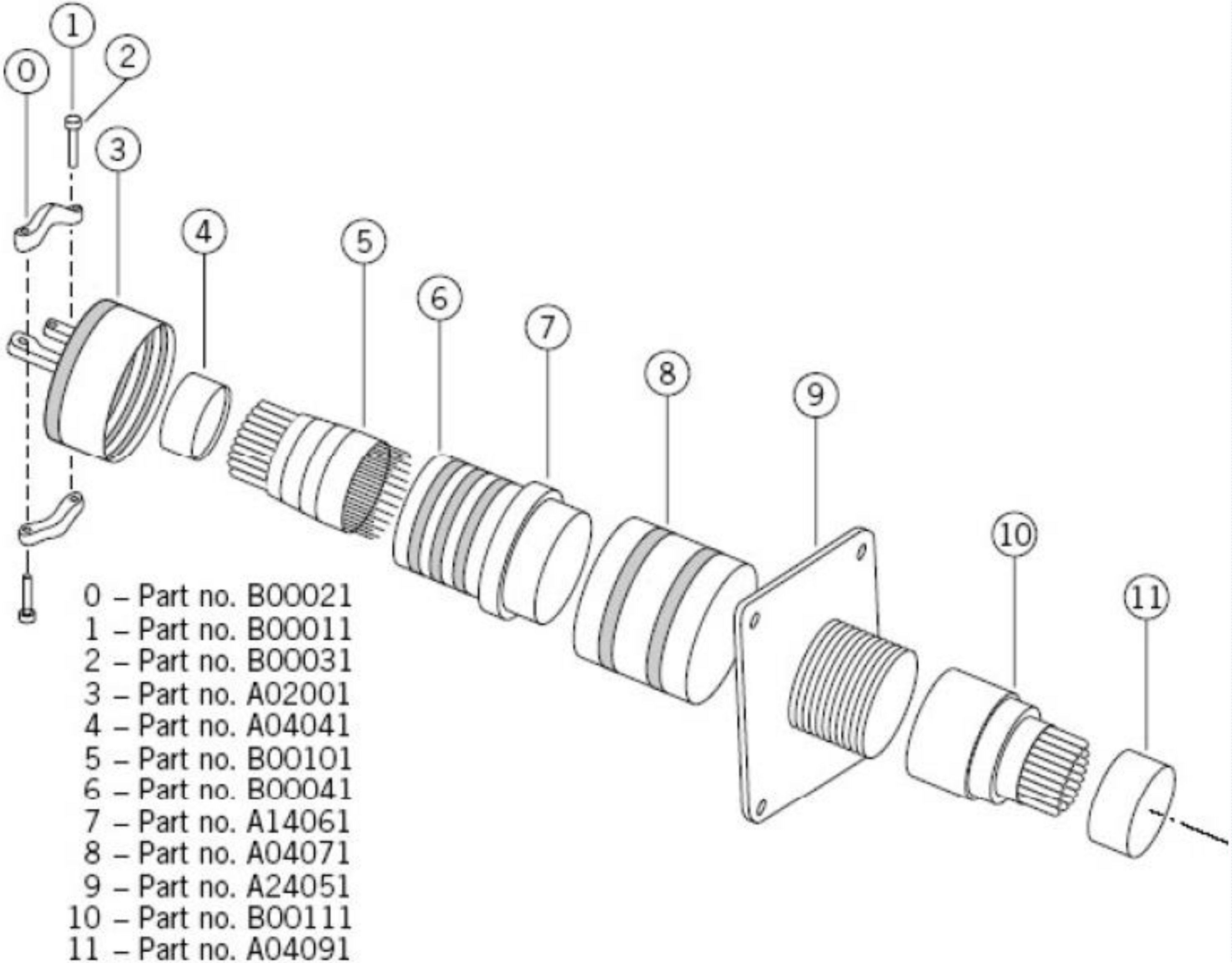
- Finally, detailed designs take place:
  - CAD designs
  - Prototypes
  - Assembly designs
  - 2D drawings and dimension determinations

- All these can be observed easily in most of the commercial CAD programs (AutoCAD, ProE, CATIA etc)

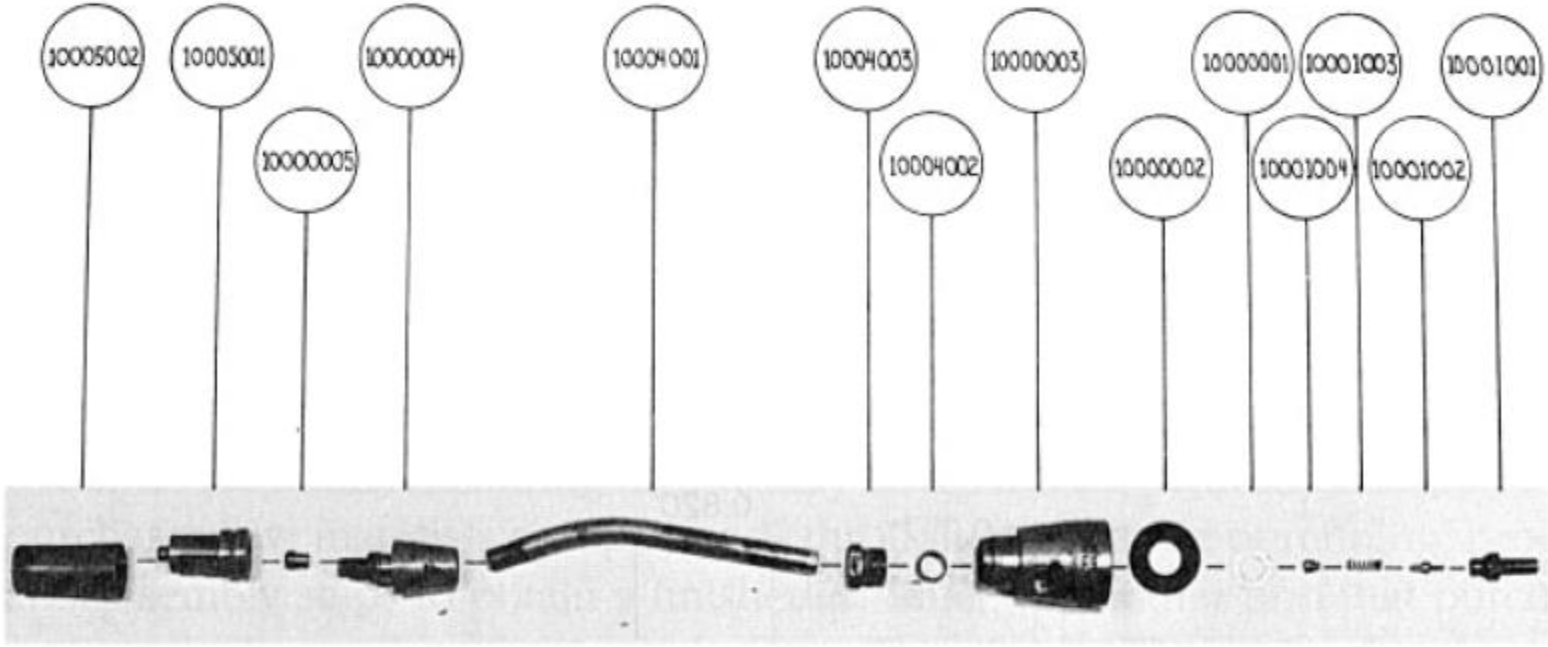
- **Product design**
- **Process design**
- **Schedule design**

2. Detailed Design– Documentation

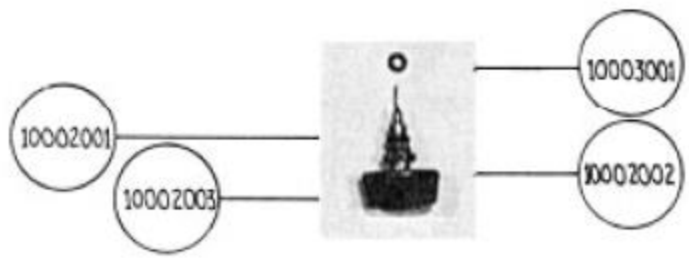
- Once the product design is completed, usually following documents are provided for the facilities planning process as inputs:
  - ***Exploded assembly drawing*** – omits specifications and dimensions, useful in designing the layout and handling system
  - ***Exploded parts photographs*** – allow the planner to visualize how the product is assembled, provide a reference for part numbers, and promote cleaner communication during oral presentation
  - ***Component part drawing*** – provide part specification and dimensions in sufficient details to allow part fabrication



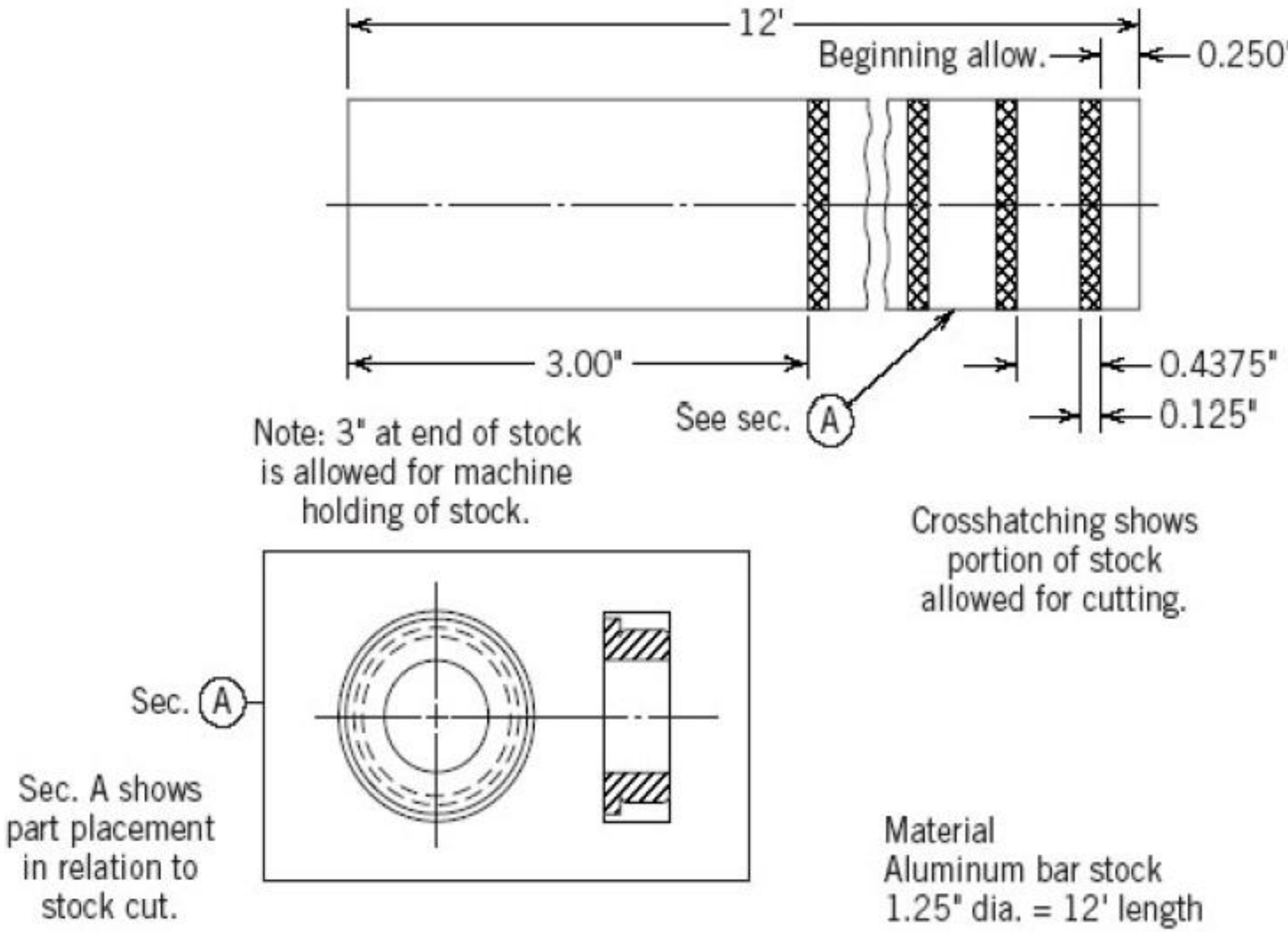
Exploded assembly drawing



DRAWING No.	4482
DRAWING TYPE	EXPLODED ASSEMBLY
PREPARED BY	FRAZELLE
CHECKED BY	DEW
DATE	3-14-91
COMPANY	UNCAN-ARNELL, INC.



Exploded parts photograph



Component part drawing

Process Design

- **Product design**
- **Process design**
- **Schedule design**

- Determination of ***how*** the product is to be produced:
  - Which part of the products should be made in-house?
  - Which equipment will be used? (for the parts which will be made in-house)
  - Who should do the processing?
  - How long will it take to perform the operation?

- Production methods are the most fundamental factor affecting the physical layout

Process Design (contd.)

- Product design
- **Process design**
- Schedule design

- Within the process design process, we need to consider following issues:

1. Process identification
2. Process selection
3. Process sequencing

1. ***Process identification***
   - Make-or-buy analysis
   - Parts identification
2. ***Process selection***
   - How the product will be made (operations, equipment, raw material, etc.)
3. ***Process sequencing***
   - How components are put together

Process Design:
1. Process identification

1. Process identification
2. Process selection
3. Process sequencing

- ***Make-or-buy decisions:***
  - Determining the scope of the facility (determining the processes that are to be included within the facility)
  - How are the make-or-buy decisions made?
    - Can the item be purchased? If NO: MAKE
    - Can we make the item? If NO: BUY
    - Is it cheaper for us to make than to buy? If NO: BUY
    - Is the capital available so that we can make it? If NO: BUY, IF Yes: MAKE
- Make-or-buy decisions are managerial decisions requiring input from finance, industrial engineering, marketing, process engineering, purchasing, human resources, etc.

Process Design:
1. Process identification (contd.)

1. Process identification
2. Process selection
3. Process sequencing

- Advantages of outsourcing:
  - Minimize your capital investment
  - Free machines or equipments
  - Hazards/ problems
  - Concentrate on Core competence
- Advantages of in-sourcing:
  - To retain control over the design, quality, reliability and delivery schedules.
  - To avoid increase in supplier price

Process Design:
1. Process identification (contd.)

1. Process identification
2. Process selection
3. Process sequencing

- After the make or buy decisions have been made, the list of items to be made and the items to be purchased.
- The listing often takes the form of a parts list or a bill of materials (BOM). A parts list includes at least the following
  1. Part number
  2. Part name
  3. Number of parts per product
  4. Drawing
  5. Material
  6. Size (Dimensions)
  7. Make or buy

make or buy

Bill of Material (BOM) for an **Air flow regulator**

BILL OF MATERIALS

Company T. W., Inc. Prepared by J. A.

Product Air Flow Regulator Date

Level	Part No.	Part Name	Drwg. No.	Quant./ Unit	Make or Buy	Comments
0	0021	Air flow regulator	0999	1	Make	
1	1050	Pipe plug	4006	1	Buy	
1	6023	Main assembly	—	1	Make	
2	4250	Lock nut	4007	1	Buy	
2	6022	Body assembly	—	1	Make	
3	2200	Body	1003	1	Make	
3	6021	Plunger assembly	—	1	Make	
4	3250	Seat ring	1005	1	Make	
4	3251	O-ring	—	1	Buy	
4	3252	Plunger	1007	1	Make	
4	3253	Spring	—	1	Buy	
4	3254	Plunger housing	1009	1	Make	
4	3255	O-ring	—	1	Buy	
4	4150	Plunger retainer	1011	1	Make	

Figure 2.8 Bill of materials for an air flow regulator.

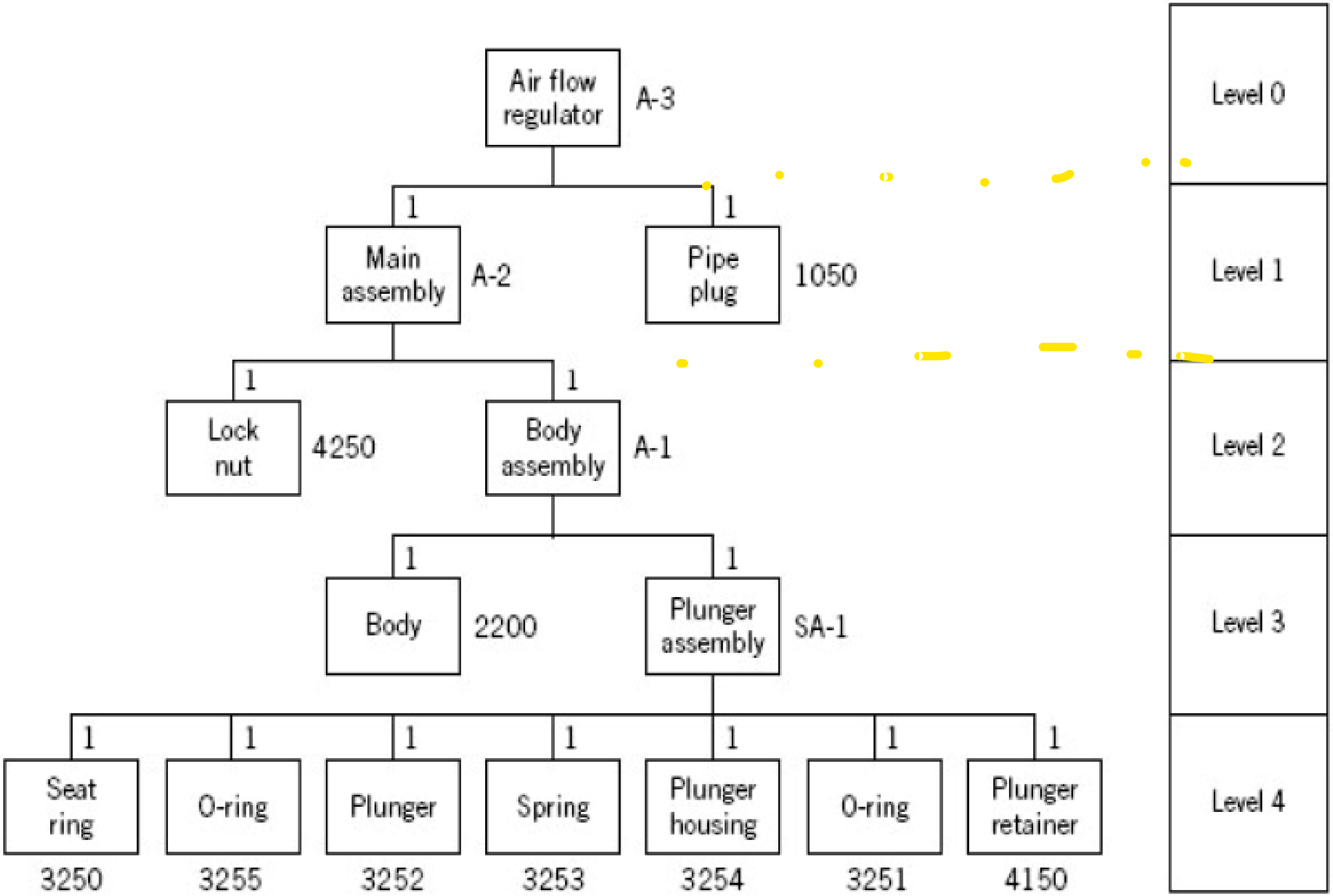


Figure 2.9 Bill of materials for an air flow regulator.

Process Design:
2. Process selection

1. Process identification
2. Process selection
3. Process sequencing

- After determining “in house” parts decisions are needed as to: ***how the products will be made***

- Such decisions are based on:
  - previous experiences
  - related requirements
  - available equipment
  - production rates
  - future expectations.

Process Design:
2. Process selection (contd.)

Process selection steps:

1. Define the elemental operations
2. Identify alternative processes for each operation
   - Manual vs. automated
3. Analyze the alternative processes
   - Consider equipment utilization
4. Evaluate the processes
   - Economics
   - Flexibility
   - Reliability
   - Maintainability
   - Safety
5. Select the process

Process Design:
2. Process selection (contd.)

1. Process identification
2. Process selection
3. Process sequencing

- Process identification can be done manually or with a computer.
- With a computer it is referred to as *Computer Aided Process Planning* (CAPP).
- Two general CAPP:
  - **Variant**: call up standard plans and modify
  - **Generative**: create a new plan from scratch (do not use existing plans).
- **Outputs** are processes, equipment, and raw materials required for the in-house production of products, also called a **route sheet**.

Route sheet

Company A.R.C., Inc. Part Name Plunger Housing Prepared by J. A.
Produce Air Flow Regulator Part No. 3254 Date

Oper. No.	Operation Description	Machine Type	Tooling	Dept.	Set-up Time (hr.)	Operation Time (hr.)	Materials or Parts Description
0104	Shape, drill, cut off	Automatic screw machine	.50 in. dia. collet, feed fingers, cir. form tool, .45 in. dia. center drill, .129 in. twist drill, finish spiral drill, cut off blade		5	.0057	Aluminum 1.0 in. dia. × 12 ft.
0204	Machine slot and thread	Chucker	.045 in. slot saw, turret slot attach. 3/8-32 thread chaser		2.25	.0067	
0304	Drill 8 holes	Auto. dr. unit (chucker)	.078 in. dia. twist drill		1.25	.0038	
0404	Deburr and blow out	Drill press	Deburring tool with pilot		.5	.0031	
SA1	Enclose subassembly	Dennison hyd. press	None		.25	.0100	

Figure 3.11 Route sheet for one component of the air flow regulator.

Rout sheet Data Requirements

Data	Production Example
Component name and number	Plunger housing – **3254**
Operation description and number	Shape, drill, and cut off – **0104**
Equipment requirements	Automatic screw machine and appropriate tooling
Unit times (Per components)	Set-up time: 5 hrs. Operating time: 0.0057 hrs
Raw material requirement	1 in. diameter X 12 ft aluminum bar per 80 components

Process Design:
2. Process sequencing

- The method of assembling the product.

- ***Assembly chart***
  - shows how the components are combined
- ***Operation process chart***
  - Gives an overview of the flow within the facility
  - A combination of route sheets and assembly charts
- ***Precedence diagram***
  - establishes precedence relationships

Process Design:
2. Process sequencing

- *Assembly chart:*

- *Assembly chart* shows the sequence of operations in putting the product together.

- The easiest method of constructing an assembly chart is to begin with the completed product and trace the product disassembly back to its basic components.

- See figure 2.11

Assembly chart

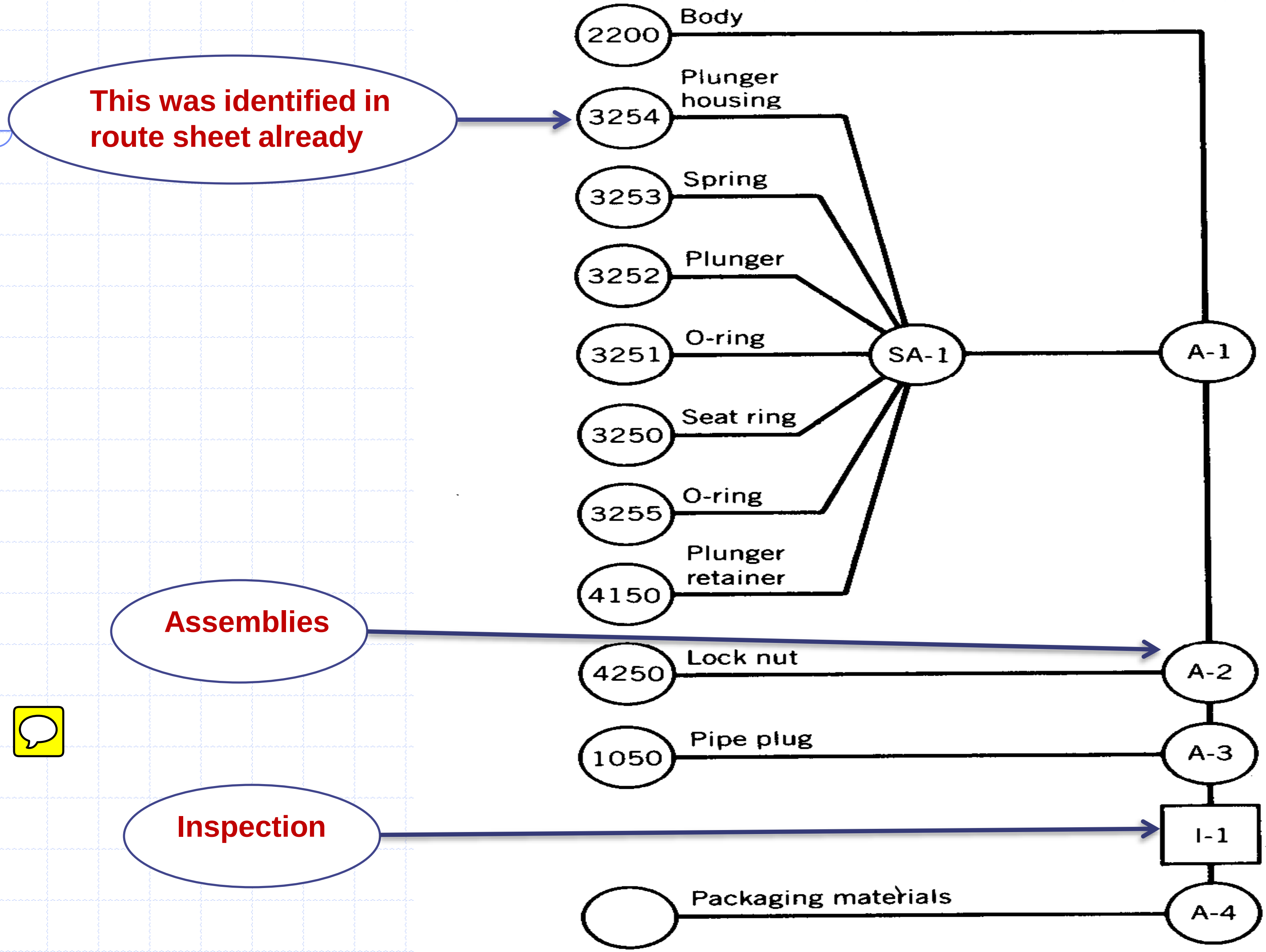


Figure 3.12 Assembly chart for an air flow regulator.

Process Design:
2. Process sequencing

1. Process identification
2. Process selection
3. **Process sequencing**

- *Operation process chart:*

- Although route sheets provide information on production methods and assembly charts indicate how components are combined, neither provides an overall understanding of the flow within the facility.

- This is accomplished with the **operation process chart**.

- See figure 2.12

Operation process chart

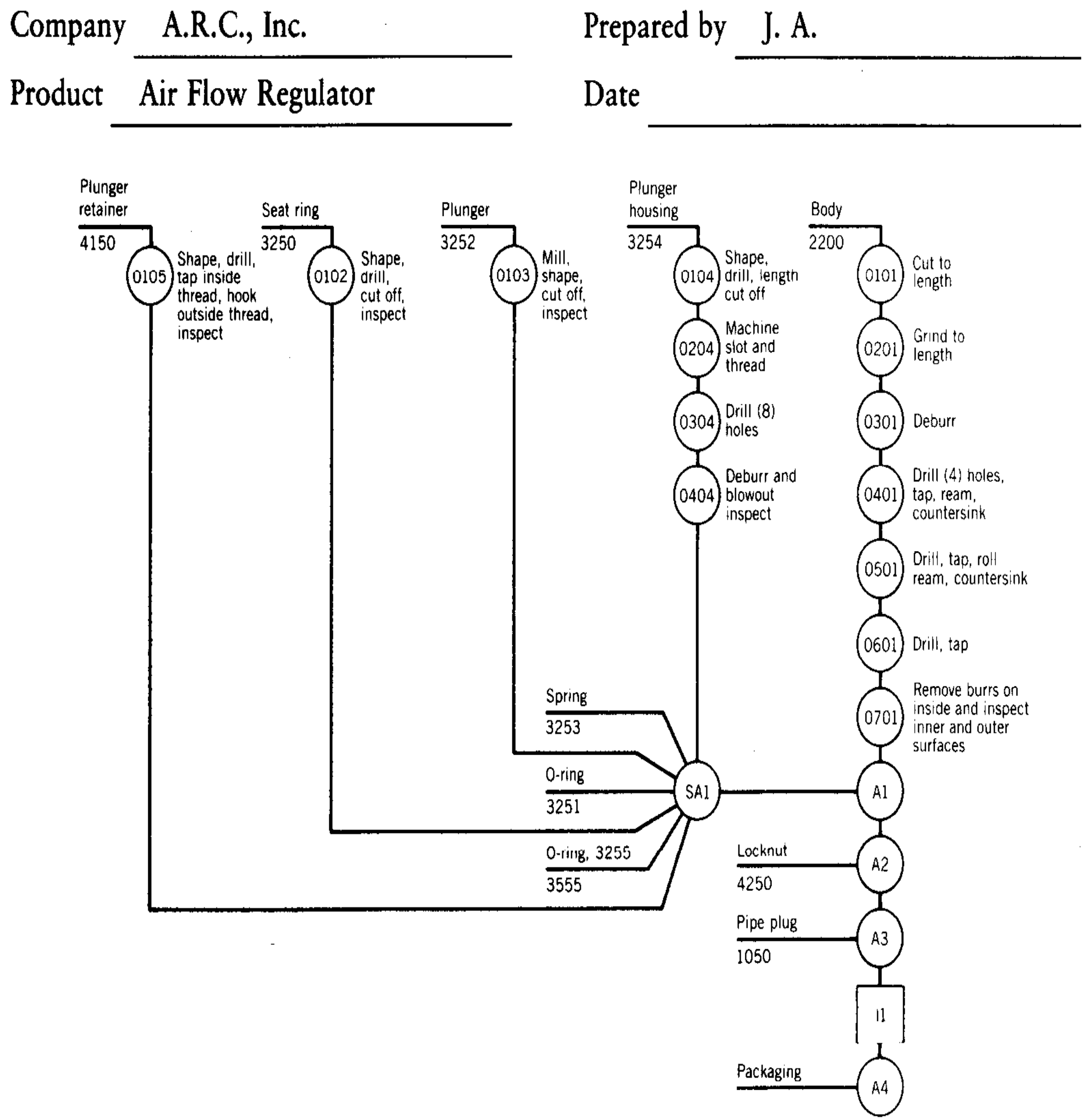


Figure 3.13 Operation process chart for the air flow regulator.

Process Design:
2. Process sequencing

1. Process identification
2. Process selection
3. Process sequencing

- *Precedence diagram:*

- A second viewpoint (from graph and network theory) is to interpret the charts as network representations, or more accurately, tree representations of a production process.

- A variation of the network viewpoint is to treat the assembly chart and the operations process chart as special cases of a more general graphical model, the **precedence diagram**.

Precedence Diagram

- In the operation process charts, it is not clear if two machining operations have any dependency

- Observe the part#3254 Operations 0204 and 0304 can be done **at the same time**
- Yet, the operation 0104 should be completed **before both 0204 and 0304**

- We cannot observe this information in operation process charts

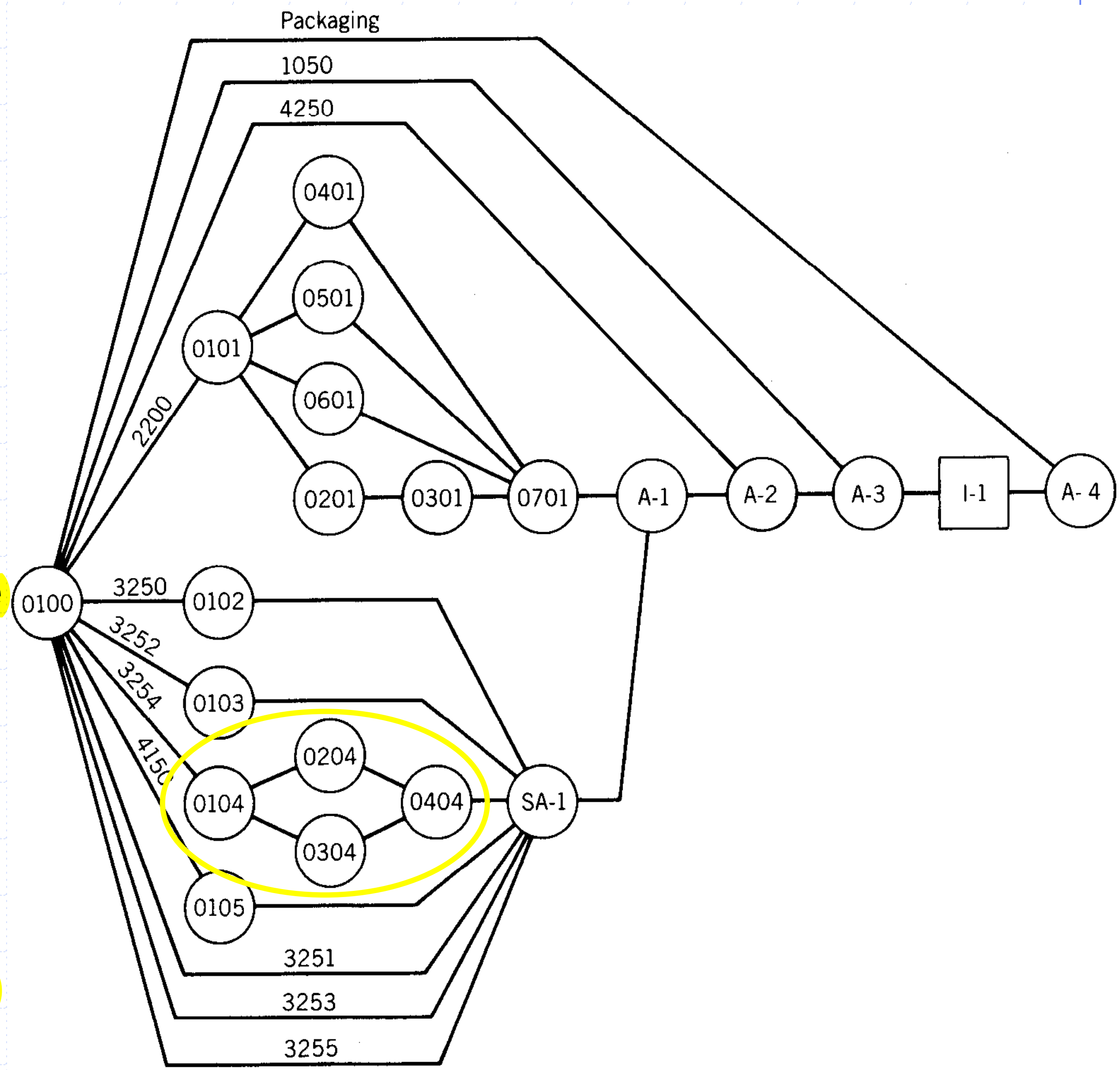


Figure 3.14 Precedence diagram for the air flow regulator.

Schedule Design

- **Product design**
- **Process design**
- **Schedule design**

- Schedule design decisions provide answers to questions involving:
  - how much to produce?
  - when to produce?
  - How long will the products be produced?
- *Production quantity* decisions are referred to as lot size decisions
- Determining *when* to produce is referred to as production scheduling.

Schedule Design (contd.)

- Product design
- Process design
- **Schedule design**

- We design facilities for major parts and operations

- What do we need to know to start designing our facilities:
  - Number of products to be produced
  - Number of machines required
  - Number of employees required
  - Sequence of operations
  - Relationships between departments

Impact of Schedule Design

- Product design
- Process design
- Schedule design

1. Machine selection
2. Number of machines
3. Number of shifts
4. Number of employees
5. Space requirements
6. Storage equipment
7. Material handling equipment
8. Personnel requirements
9. Storage policies
10. Unit load design
11. Building size, and so on.

Schedule Design *(Marketing)*

- Product design
- Process design
- Schedule design

- Marketing department provides a research function that analyzes what the world's consumer wants. Some of the information that marketing provides is:
  - Production volume, how many can we sell?
  - Seasonality, summer or winter product
  - Trends
- Note the Pareto effect that often 85% of the production volume comes from 15% of the product. So focus on the high volume products but don't completely ignore the low volume ones.

Schedule Design *(Marketing)*

- Product design
- Process design
- **Schedule design**

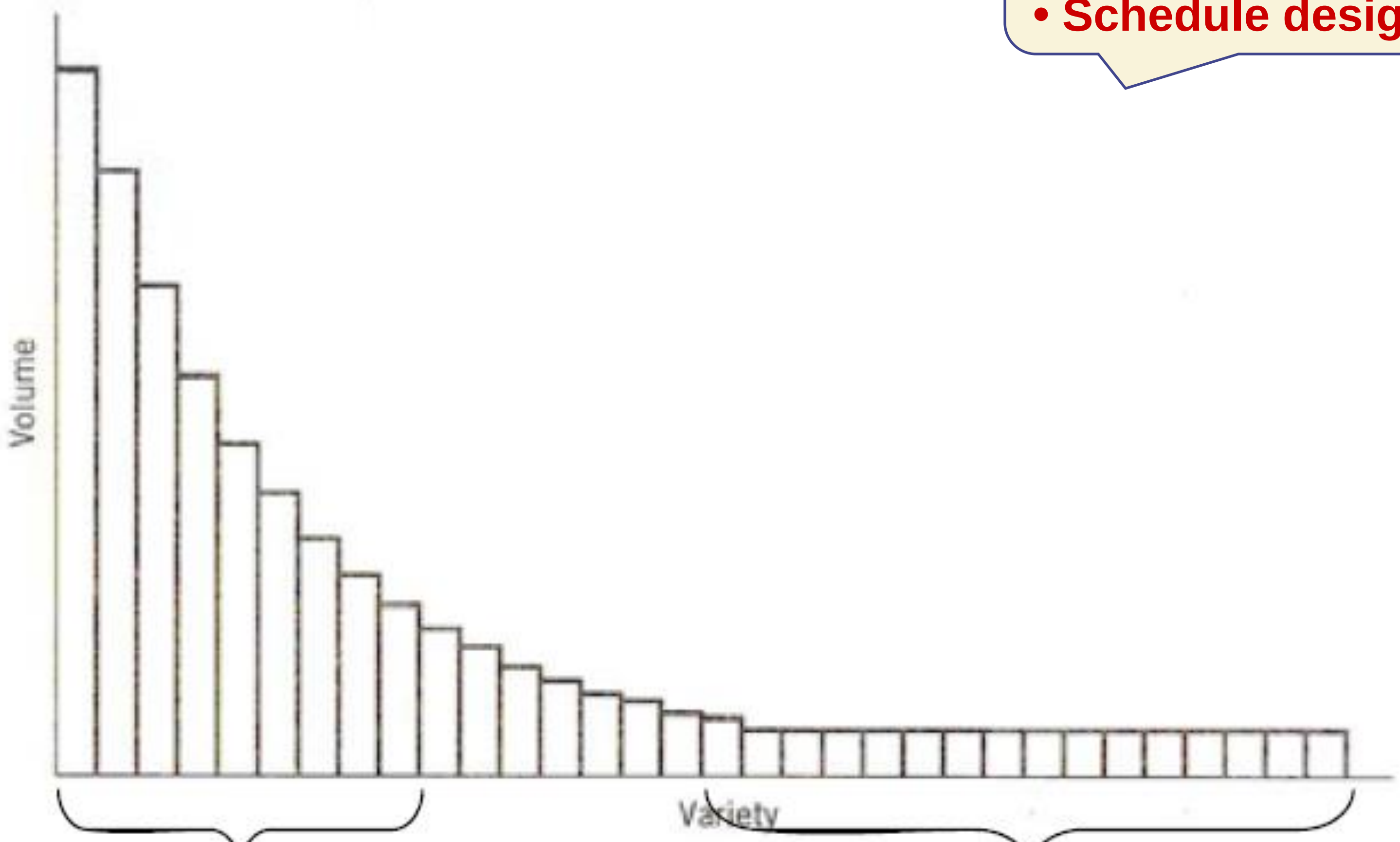


Figure 2.15 Volume-variety chart for a facility where Pareto's law is applicable.

More general items produced everyday: *Mass production area*

Items that are produced (may be) by special orders etc.: *Job shop area*

Schedule Design *(Marketing)*

- **Product design**
- **Process design**
- **Schedule design**

- Valuable information that should be obtained from marketing and used by a facilities planner. See table 2.4 (on next slide)

  - Who are the consumers?
  - Where are the consumers?
  - Why will the consumer purchase the product?
  - Where will the consumer purchase the product?
  - What is the trend in product change?

Schedule Design
(*Process Requirements)*

- Product design
- Process design
- **Schedule design**

- Process design determines the specific equipment types required to produce the product. Schedule design determines the number of each equipment type.
- Specification of process requirements typically occurs in 3 phases.

1. Qty of components to be produced including scrap
2. Equipment requirements for each operation
3. Combine the operation requirements

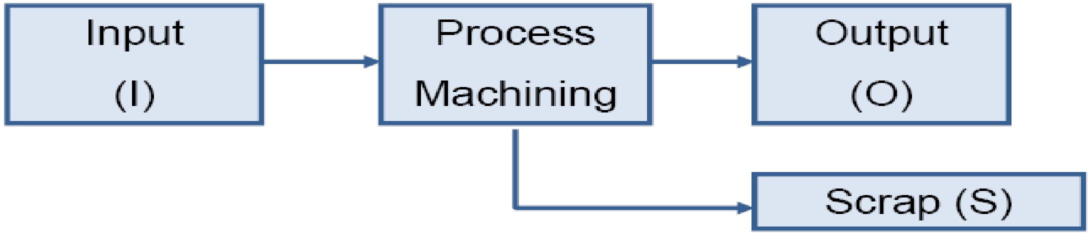
Schedule Design (*Process Requirements)*
Scrap estimate

- Scarp is the material waste generated in the manufacturing process due to geometric or quality considerations.

- The amount of scrap depends on how tight the tolerance is, automated process or not, quality, certified suppliers, and the grade of material.

- *Scrape estimates*: how many units of the product we need to make.

Schedule Design (*Process Requirements)*
Scrap estimate (contd.)

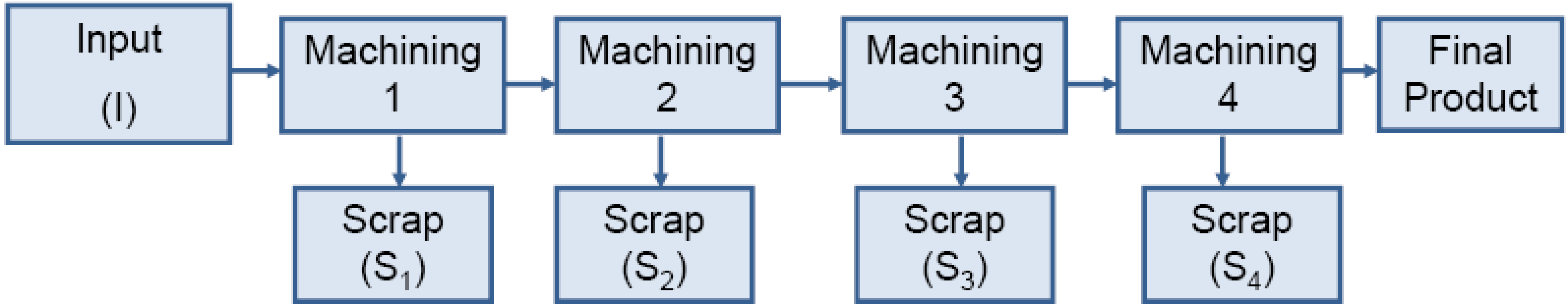


d_k =percentage of scrap made at operation *k*
O_k =desired output of non-defective items from operation *k*
I_k =the production input to operation *k*

$I_k = O_k + d_k I_k$
OR
$O_k = I_k (1-d_k)$

$I_k = O_k/1- d_k$

Schedule Design (*Process Requirements)*
Scrap estimate (contd.)



The expected number of units to start production for a part with n operations is:

$$I_1 = O_n / (1-d_1)(1-d_2)\ldots(1-d_n)$$

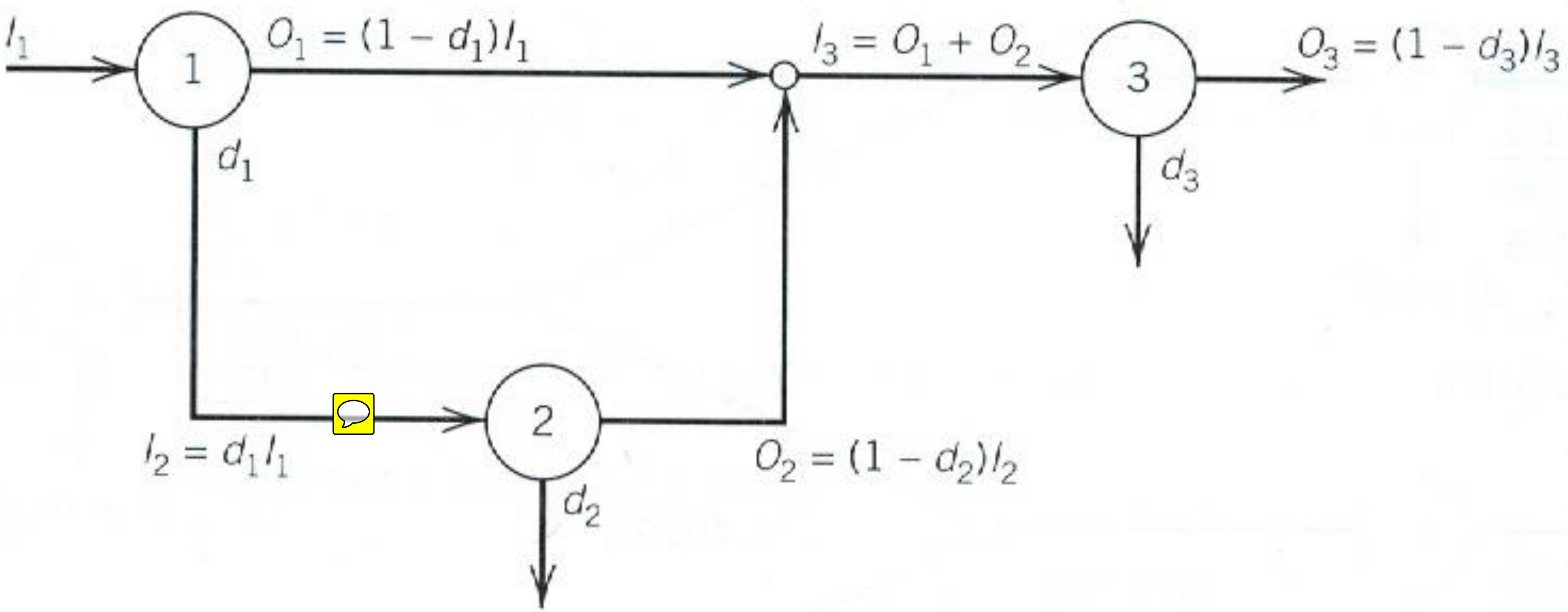
Schedule Design (*Process Requirements)*
Scrap estimate (contd.)

- Example:
  - Market estimate of 97,000 components
  - 3 operations: turning, milling and drilling
  - Scrap estimates: $d_1=0.04$, $d_2=0.01$ and $d_3=0.03$
  - Input to the production?
  - Production quantity scheduled for each operation?

$$Input = \frac{FinalOutput}{(1-d_1)(1-d_2)(1-d_3)}$$

$$Input = \frac{97{,}000}{(1-0.04)(1-0.01)(1-0.03)} = 105{,}219$$

Schedule Design (*Process Requirements)*
Scrap estimate with Rework



$$Input = \frac{FinalOutput}{(1-d_3)\left[(1-d_1)+d_1(1-d_2)\right]}$$

- We assume 100 % inspection at each operation, including the rework operation

Schedule Design (*Process Requirements)*
Equipment fraction

- Total required processing time for equipment divided by the time available per machine.
- Required processing time

  =Standard time per unit * Number of units
- Equation

$$F = \frac{SQ}{EHR}$$

F = number of machines required per shift

S = standard time per unit produced (obtained from route sheet)

Q = number of units to be produced per shift

E = actual performance, expressed as percent of standard time

H = amount of time available per machine

R = reliability of machine, expresses as percent of up time

Schedule Design (*Process Requirements)* *Equipment fraction (contd.)*

- A machined part has a standard machinery time of 2.8 min per part on a milling machine. During an 8-hr shift 200 unites are to be produced. Of the 8 hours available for the production, the milling machine will be operational 80% of the time. During the time the machine is operational, parts are produced at a rate equal to 95% of the standard rate.
- S=2.8 min, Q=200 units, H=480min, E=0.95 and R=0.8
- **How many milling machines are required**?

$$F = \frac{SQ}{EHR} = \frac{2.8(200)}{0.95(480)(0.80)} = 1.535$$

- We need 1.535 machines per shift.

Schedule Design (*Process Requirements)*
Equipment fraction

F can also be affected by:

- Number of shifts
- Set-up times
- Degree of flexibility- small lots or large lots
- Layout type-process or product
- Total productive maintenance

Management Tools

Management Tools

- Once we have the product, process, and scheduling information we need to organize the information and generate and evaluate layout, material handling, and storage alternatives.
- In this process it may be helpful to apply the following seven management tools to facilities planning and design: (read in text book)

Management Tools

1. Affinity diagram
   - Brainstorm ideas
   - Gather the ideas into general headings or topics
2. Interrelationship diagraph
   - Show the relationships between headings
   - Directed arcs
   - Help to show the order of doing things
3. Tree diagram
   - Gives more detail about the various activites that need to be done

Management Tools

4. Matrix diagram
   - Can show who is responsible for doing what task
5. Contingency diagram
   - Plan for unfamiliar tasks
6. Activity network diagram
   - Basically a Gantt chart or PERT CPM type information
   - Who does what, when.
7. Prioritization matrix
   - Evaluate design alternatives

Affinity diagram

Issues in reducing manufacturing leadtime

Facilities design	Equipment issues	Quality	Set-up time	Scheduling
1. form product families	1. operator certification program	1. provide training on how to use process documentation	1. provide documentation on set-up procedures	1. provide visibility to daily product sequence
2. assign families to cells	2. sit technicians closer to production	2. implement successive inspection with feedback	2. locate fixtures and tooling close to machines	2. do not authorize products for which the needed parts are not available
3. assign raw mtl's to their point of use	3. monitor breakdowns to predict future occurrences	3. develop mistake-proof devices	3. provide training so operators can participate	3. negotiate frequent and smaller lots to customers
4. keep receiving and shipping close to production	4. recruit enough technicians per shift	4. develop capabilities for monitoring key machine parameters	4. provide information on daily sequence	

Figure 2.19 Affinity diagram example for reducing manufacturing leadtime.

Interrelationship diagraph

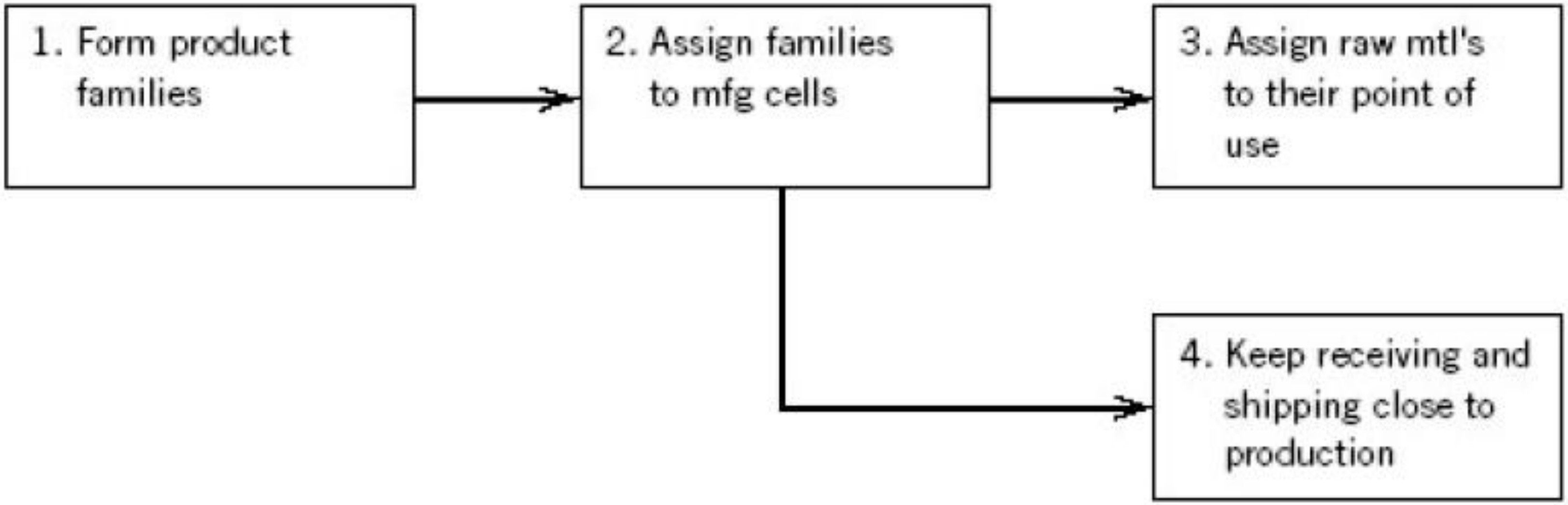


Figure 2.20 Interrelationship digraph for facilities design.

Tree Diagram

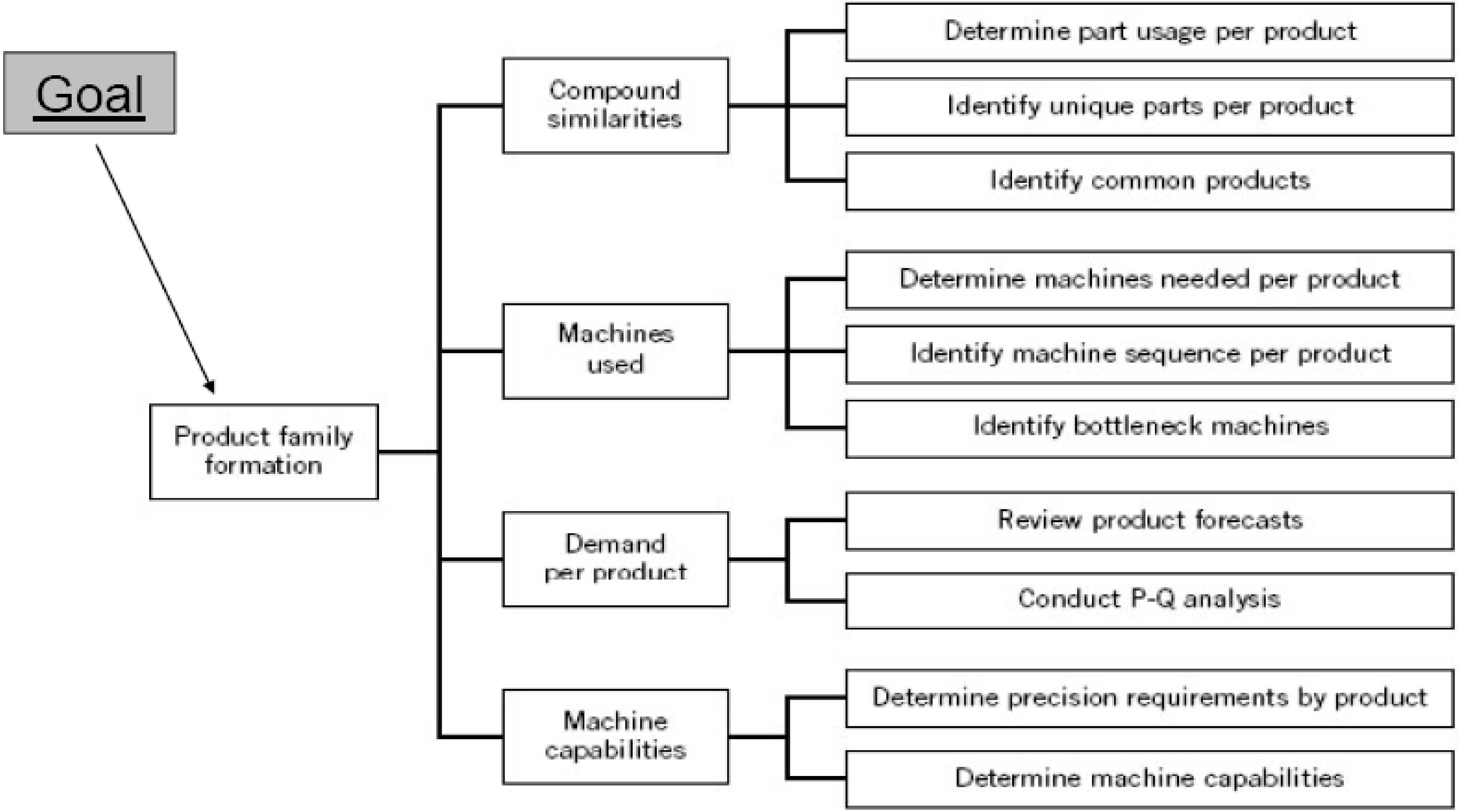


Figure 2.21 Tree diagram for the formation of product families.

Matrix diagram

Table 2.10 *Matrix Diagram for Team Participation*

Team\Participants	Joe	Mary	Jerry	Lou	Linda	Daisy	Jack
Part usage team	P	C	P	L			P
Machine use & cap team	L		C				P
Demand forecast team				P	C	L	

Note. L: Team Leader
C: Team Coordinator
P: Team Participant

Activity network diagram

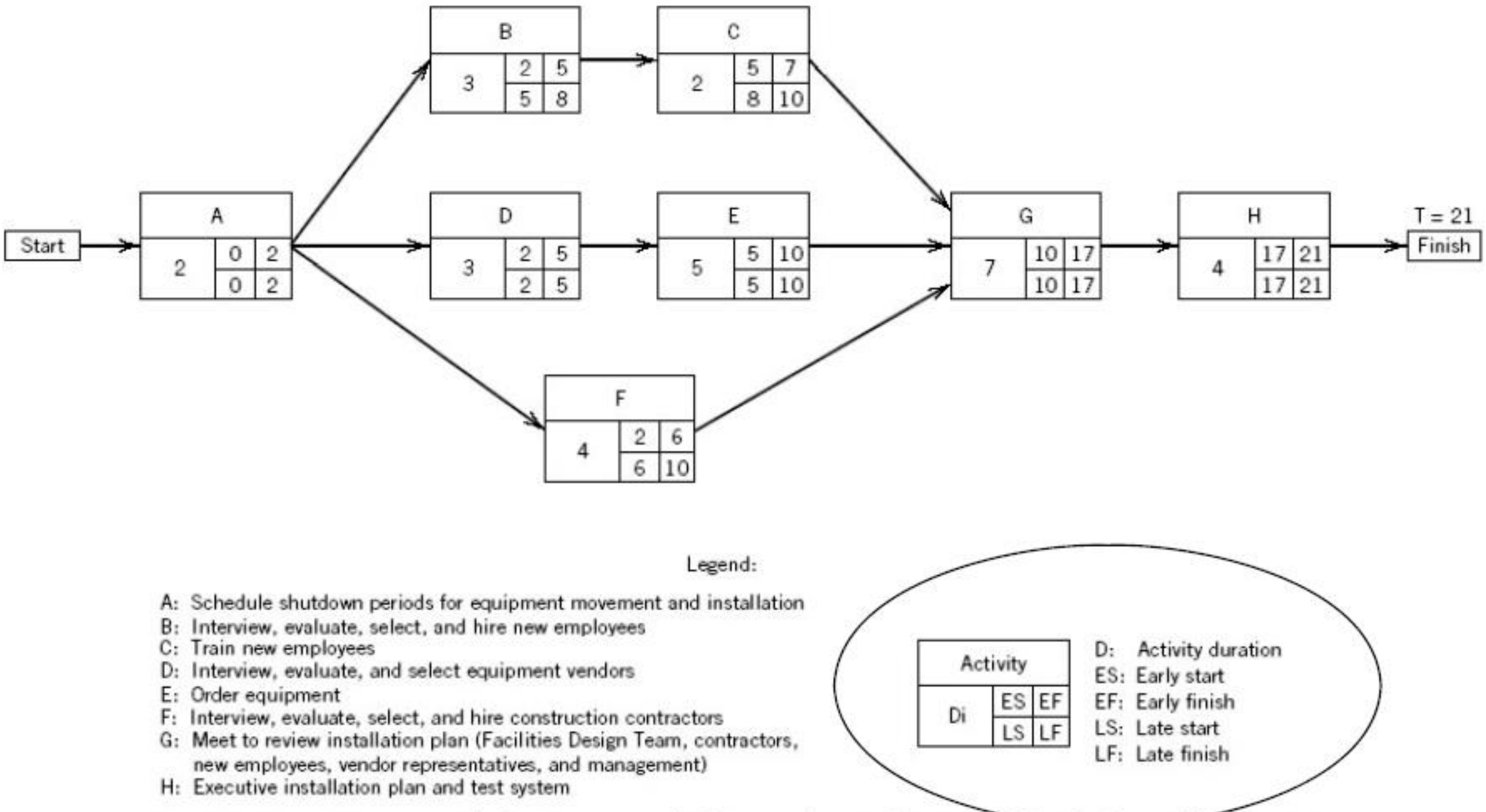


Figure 2.22 Activity network diagram example for a production line expansion facilities design project.

Prioritization matrix

Criteria used to evaluate facilities design alternatives	
A. Total distance traveled	B Manufacturing floor visibility
C. Overall aesthetics of the layout	D. Ease of adding future business
E. Use of current equipment	F. Investment in new equipment
G. Space requirements	H. People requirement
I. Impact on WIP levels	J. Human factor risk
K. Estimated cost of alternatives	

Weights used in comparison of criteria	
1= Equally important	
5 = Significantly more important	1/5 = significantly less important
10 = extremely important	1/10 = extremely less important

Prioritization matrix

Table 2.12 *Prioritization Matrix for the Evaluation of Facilities Design Alternatives*

	Criteria											
	A	B	C	D	E	F	G	H	I	J	K	Row totals (%)
A	1	5	10	5	1	1	1	1	1	5	1	32. (9.9)
B	1/5	1	5	1/5	1/5	1/10	1/5	1/5	1/10	1/5	1/5	7.6 (2.4)
C	1/10	1/5	1	1/10	1/10	1/10	1/5	1/5	1/10	1/10	1/10	2.3 (0.7)
D	1/5	5	10	1	1/5	1/5	1/5	1/5	1/10	1/5	1/10	17.4 (5.4)
E	1	5	10	5	1	1	5	5	1/5	1	1/5	34.4 (10.7)
F	1	10	10	5	1	1	5	5	1	1	1	41. (12.7)
G	1	5	5	5	1/5	1/5	1	5	1/5	1/5	1/5	23. (7.1)
H	1	5	5	5	1/5	1/5	5	1	1/10	1/5	1/5	22.9 (7.1)
I	1	10	10	10	5	1	5	10	1	1	5	59. (18.3)
J	1/5	5	10	5	1	1	5	5	1	1	5	39.2 (12.2)
K	1	5	10	10	5	1	5	5	1/5	1/5	1	43.4 (13.5)
Column total	7.7	56.2	86.	51.3	14.9	6.8	32.6	37.6	5.	10.1	14.	322.2 Grand total

Prioritization matrix

Layout alternatives

Table 2.13 *Prioritization of Layout Alternatives Based on WIP Levels*

WIP Levels	P	Q	R	S	T	Row totals (%)
			Layout			
P	1	5	1	1/10	1/5	7.3 (9.9)
Q	1/5	1	1/5	1/10	1/10	1.6 (2.2)
R	1	5	1	10	5	22. (30.0)
S	10	10	1/10	1	1/5	21.3 (29.0)
T	5	10	1/5	5	1	21.2 (28.9)
Column Total	17.2	31	2.5	16.2	6.5	73.4 Grand total