Assembly System Design Techniques

- Goals of this class
  - Introduce system design methods
  - Understand the things that must be considered
  - Look at two ways to approach it
  - Learn about SelectEquip

Assembly System Design Techniques

- Assembly system design algorithms exist
- They solve the “Equipment Selection and Task Assignment” problem
- Methods include dynamic programming, travelling salesman, mixed integer-linear programming, and a heuristic called ASDP
- These algorithms will design an assembly or other process line to meet average production requirements, adjusted for a fixed % uptime
- Detailed simulation is needed to verify production rate and study queues and other issues

What to Model

- The tasks that need to be done
- The number of units needed per year
- What resources are available or applicable to a given task
  - What each resource costs to buy
  - What tool it needs for each task
  - How long it will take to do the task, change tools, etc
  - What is its uptime and other operating characteristics
- Time for transport from station to station
- Reuse of a resource for several tasks
- Reuse of tools at one station

History

- Heuristics by R E Gustavson at Draper and N H Cook at MIT in 1970s
- Solutions based on OR techniques by Prof Graves and OR Center students
  - Terry Huttner, 1977 - mixed linear-integer programming
  - Bruce Lamar, 1979 - bus routing algorithm
  - Carol Holmes, 1987 - multiple products, dynamic programming
  - Curt Cooprider, 1989 - uncertain demand, dynamic programming
- Holmes-Cooprider method reprogrammed by Mike Hoag, 2001.

System Selection Criteria

- Minimize annualized cost
  - = unit labor cost + annualized cost of capital
- Systems can be forced to be all manual, all robot, or all fixed automation just by removing unwanted resource classes
- A wide variety of preferences can be accommodated this way

Summary of Required Input

- Info about assembly resources with cost, operation time, and "rho" or installed cost factor
  - rho relates total cost to equipment cost
- Info about assembly tasks with operation time and tool number for each resource
- Annual production volume, labor cost, min acceptable rate of return, number of shifts available
  - Rate of return expressed in annualized cost factor

Data Input (Applicable Technology Chart)

Title				Date	
Working days/year			Annualized cost factor		
Shifts available			Avg loaded labor rate ($/hr)		
		Station-station move time (s)			
Resource data set name:				Task data set name:	
	For each resource:			When a resource can be used:	
C	hardware Cost ($)				
rho	installed cost/hardware cost			Operation	Tool
e	% uptime expected			time (s)	number
v	operating/maintenance rate ($/hr)				
Tc	Tool change time (s)			Hardware cost	
Ms	Max # stations/worker				
NOTE: SEE FIG 14.8 OF CONCURRENT DESIGN AND PP 434-435					
Resource: .... Task:	__________ C_______ rho_____ e_______ v_______ Tc______ Ms______	__________ C_______ rho_____ e_______ v_______ Tc______ Ms______	__________ C_______ rho_____ e_______ v_______ Tc______ Ms______	__________ C_______ rho_____ e_______ v_______ Tc______ Ms______	__________ C_______ rho_____ e_______ v_______ Tc______ Ms______
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Assembly Planning Chart

	NAME								
	DATE								
	PREPARED BY								
NOTE: SEE FIG 14.7 OF CONCURRENT DESIGN	SHEET		OF						
PAGE 433									
TASK	SEQUENCEE	TYPE OF TASK	BASIC ORIENTATION	MOTIONS REQUIRED	JIGGING/TOOLING REQUIRED	TASK DIFFICULTY	INSPECTION REQUIRED	CYCLE TIME	COMMENTS
TASK TYPE	INSPECTION								
P = PLACE/ORIENT	B=BOLT TORQUE								
T=TIGHTEN BOLT, SCREW, ETC	G=GAUGE DIMENSION								
I=INSERT PART(S)	C=COMPARISON								
M=MEASURE									
S=MODIFY SHAPE									
A=ALIGN									

Applicable Technology Chart

APPLICABLE TECHNOLOGY CHART

TITLE MECHANISM SUB-ASSEMBLY DATE 10 FEB. 1984

228 WORKING DAYS PER YEAR .3682 ANNUALIZED COST FACTOR

1 or 3 SHIFTS AVAILABLE 13 AVERAGE LOADED LABOR RATE ($/h)

2 s STATION-TO-STATION MOVE TIME

RESOURCE DATA SET NAME: RES14 TASK DATA SET NAME: RECB1

FOR EACH RESOURCE:

- C HARDWARE COST ($)
- ρ INSTALLED COST/HARDWARE COST
- ϵ UP-TIME EXPECTED (%)
- v OPERATING/MAINTENANCE RATE ($/h)
- t_c SECONDS TOOL CHANGE TIME
- m_s MAXIMUM STATIONS PER WORKER

WHEN A RESOURCE CAN BE USED ON A TASK: OPERATION TIME (s) | TOOL NUMBER; HARDWARE COST ($)

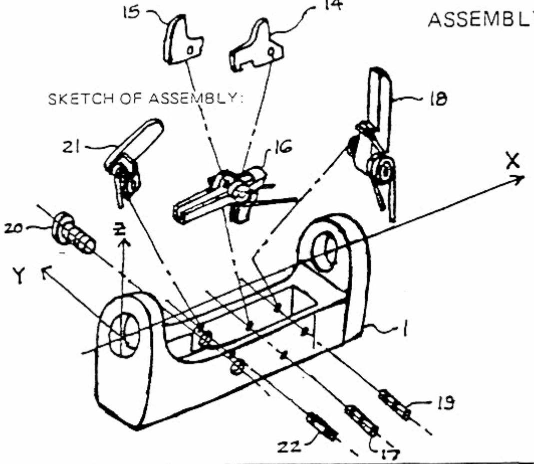
TASK NUMBER \ RESOURCE	M13	P29	F30	F60
	C: 200, ρ: 1.5, ε: 80, v: .88, t_c: 2, m_s: .833	C: 25000, ρ: 3.5, ε: 80, v: .75, t_c: 3, m_s: 6	C: 0, ρ: 1.5, ε: 80, v: .60, t_c: 0, m_s: 6	C: 0, ρ: 1.5, ε: 80, v: .60, t_c: 0, m_s: 4
1. Part 14	5 | 111 / 2000	4 | 211 / 7000	3 | 311 / 15000	2 | 411 / 60000
2. Part 15	5 | 111 / 2000	4 | 211 / 7000	3 | 311 / 15000	2 | 411 / 60000
3. Part 16	30 | 112 / 4000	20 | 212 / 10000	15 | 312 / 40000	10 | 411 / 60000
4. Part 17	10 | 113 / 1500	6 | 213 / 5000	4 | 312 / 40000	2 | 411 / 60000
5. Part 18	60 | 114 / 8000	X	X	20 | 412 / 60000
6. Part 19	10 | 113 / 1500	6 | 213 / 5000	4 | 313 / 15000	2 | 412 / 60000
7. Part 20	10 | 111 / 2000	6 | 211 / 7000	4 | 314 / 15000	2 | 413 / 60000
8. Part 21	25 | 112 / 4000	15 | 212 / 10000	12 | 315 / 30000	10 | 413 / 60000
9. Part 22	10 | 113 / 1500	6 | 213 / 5000	4 | 315 / 30000	2 | 413 / 60000

	UNITS	DAYS
PRODUCTION	60000	228
BATCH	180000	228
DATA	600000	228

Assembly Planning Chart

ASSEMBLY PLANNING CHART

SKETCH OF ASSEMBLY:



NAME: MECHANISM SUB-ASSEMBLY

DATE: 10 FEB. 1984

PREPARED BY: REG

SHEET 1 OF 1

TASK	SEQUENCE	TYPE OF TASK	BASIC ORIENTATION	MOTION(S) REQUIRED	JIGGING/TOOLING REQUIRED	DEGREE OF DIFFICULTY OF TASK	INSPECTION REQUIRED	CYCLE TIME (s)	COMMENTS
Pickup Part 14.	1		X-Z	X,Z		1			
Pickup Part 15.	2		X-Z	X,Z		1			
Assemble both into Part 16.		P	X-Z	-Z		2			
Install into Part 1.	3	A	X-Z	-Z	Y	3	C		Must be aligned
Push in Part 17.	4	I	Y-Z	Y		2	C		Check motion
Get Part 18.			X-Z			1			
Position inside part 1.	5	A	X-Z	X,Z	Y	4	C		Must be aligned
Push in Part 19.	6	I	Y-Z	Y		2	C		Check motion
Get Part 20.			Y-Z			1			
Install in part 1.	7	I	Y-Z	-Y		1			
Get Part 21			X-Z			1			
Position inside part 1.	8	A	X-Z	-Z	Y	3	C		Must be aligned
Push in Part 22	9	I	Y-Z	Y		2	C		Check motion

ABBREVIATIONS USED:

TASK TYPE
- P – PLACE, ORIENT
- T – TIGHTEN BOLTS, NUT, etc.
- I – INSERT PARTS
- M – MEASURE
- S – SHAPE MODIFY
- A – ALIGN

INSPECTION
- B – BOLT TORQUE
- G – GAUGE DIMENSION
- C – COMPARISON

Basic Nominal Capacity Equations

operations/unit * # units/year = # ops/yr

ops/sec = # ops/yr * (1 shift/28800 sec)*(1 day/n shifts)*(1 yr/280 days)

cycle time = 1/(ops/sec) = required sec/op

equipment capability = actual sec/op

actual sec/op < required sec/op -> happiness

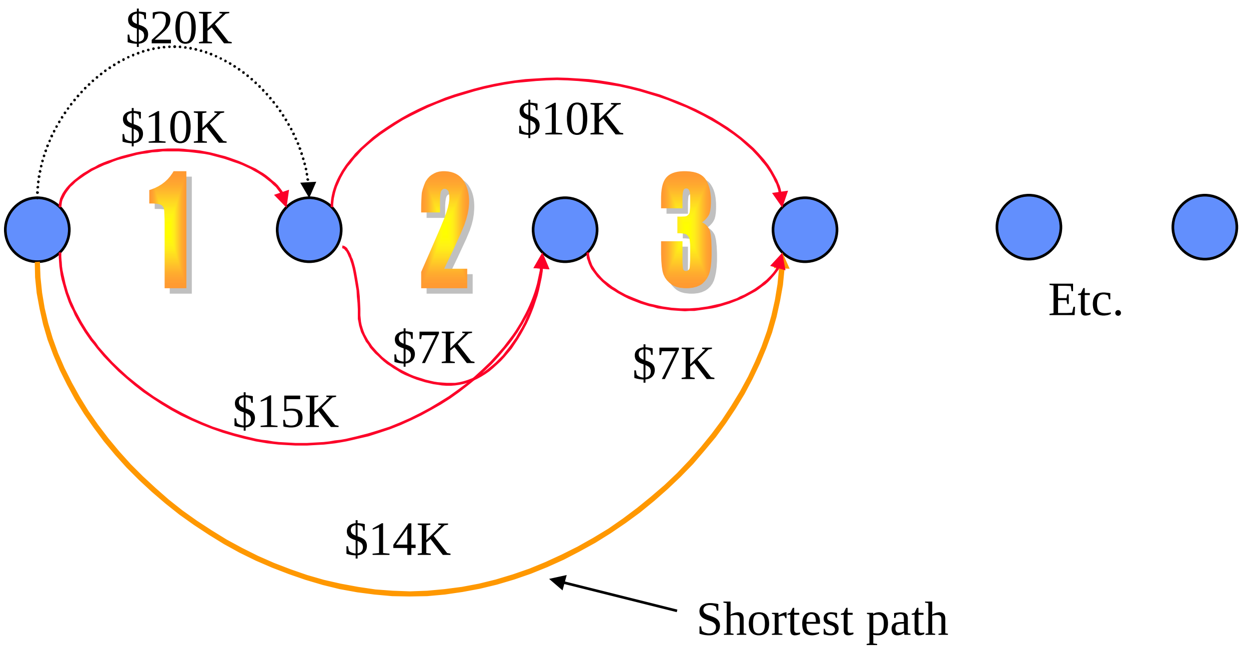
required sec/op < actual sec/op -> misery (or multiple resources)

Typical cycle times: 3-5 sec manual small parts
5-10 sec small robot
1-4 sec small fixed automation
10-60 sec large robot or manual large parts

How the Holmes-Cooprider Method Works

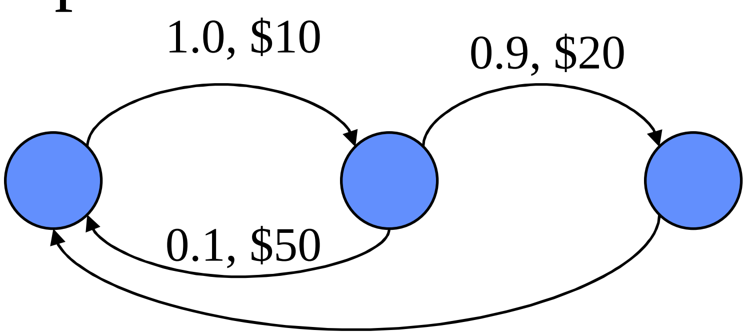
- The maximum takt or cycle time is calculated based on annual volume requirement and # shifts
- Each resource is tested to see if it can do one task without running out of time, two tasks, three tasks, etc.
- A network is built where pairs of nodes are tasks, and arcs are resources
- Each arc has a cost based on investment, tools, and labor (labor cost based on time used)
- The shortest path through the network is the string of selected resources and the tasks they will do

Network



Network Models of Assembly Systems

- Model of system as flows in a network
- Represents equilibrium state
- Based on probabilities and costs



- Outbound probabilities add to 1.0
- Equilibrium solution gives average cost to go through and average flow on each branch

Equations

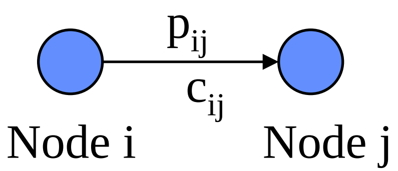
p_{ij}=pr of going from node i to node j
c_{ij}=cost of going from node i to node j

f_{ij}=flow from node i to node j
y_i = total flow out of node i

$$f_{ij} = y_i p_{ij}$$

where we must have

$$\sum_j p_{ij} = 1 \text{ for each } \; i$$



Conservation of flow at node j:

$$y_j = y_j p_{jj} + \sum_{k.\ j} y_k p_{kj} + x_j \longrightarrow Y = P^T Y + X$$

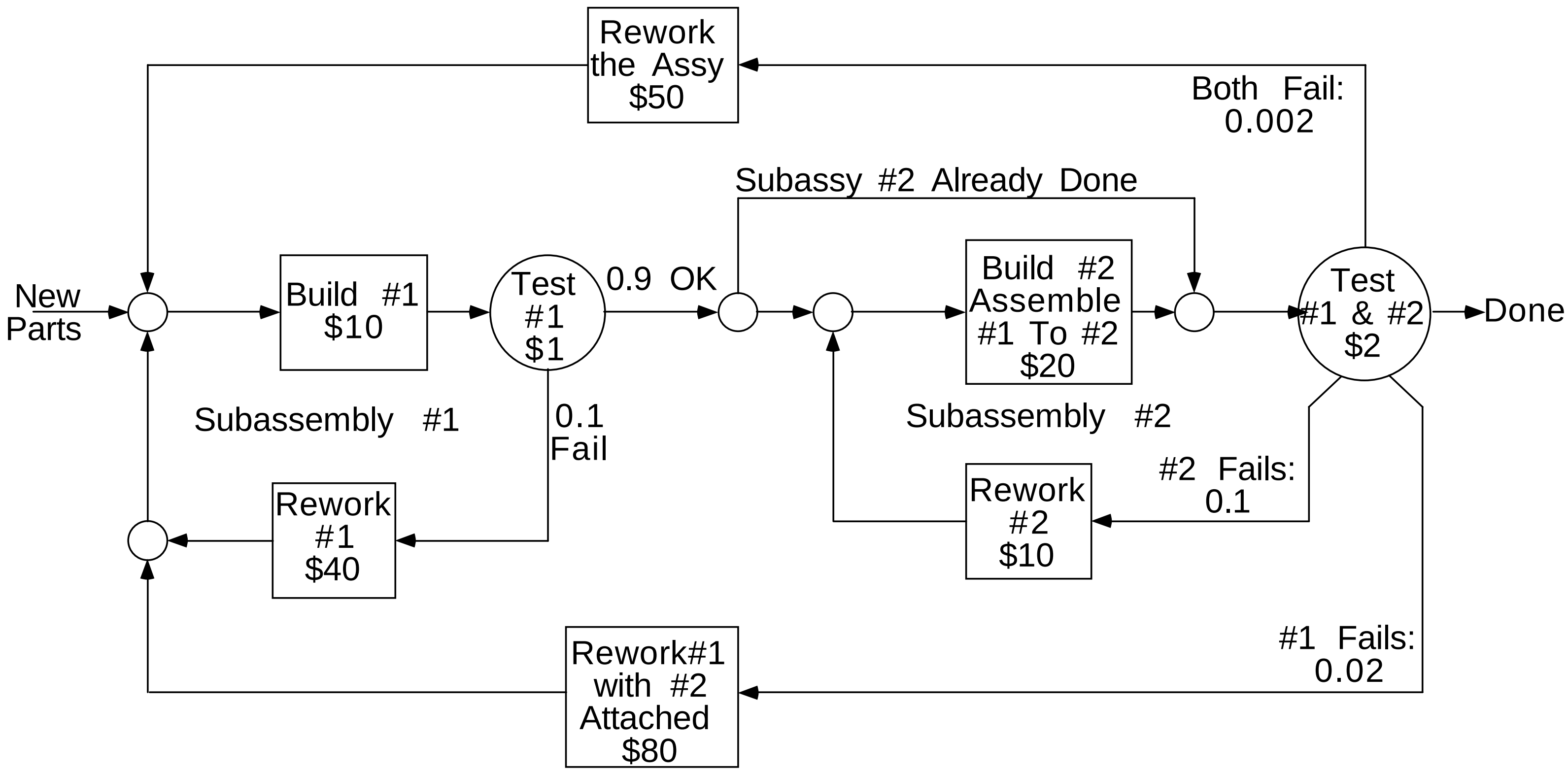
x_j=flow into node j from outside

Solution: $$Y = \left[I - P^T\right]^{-1} X$$

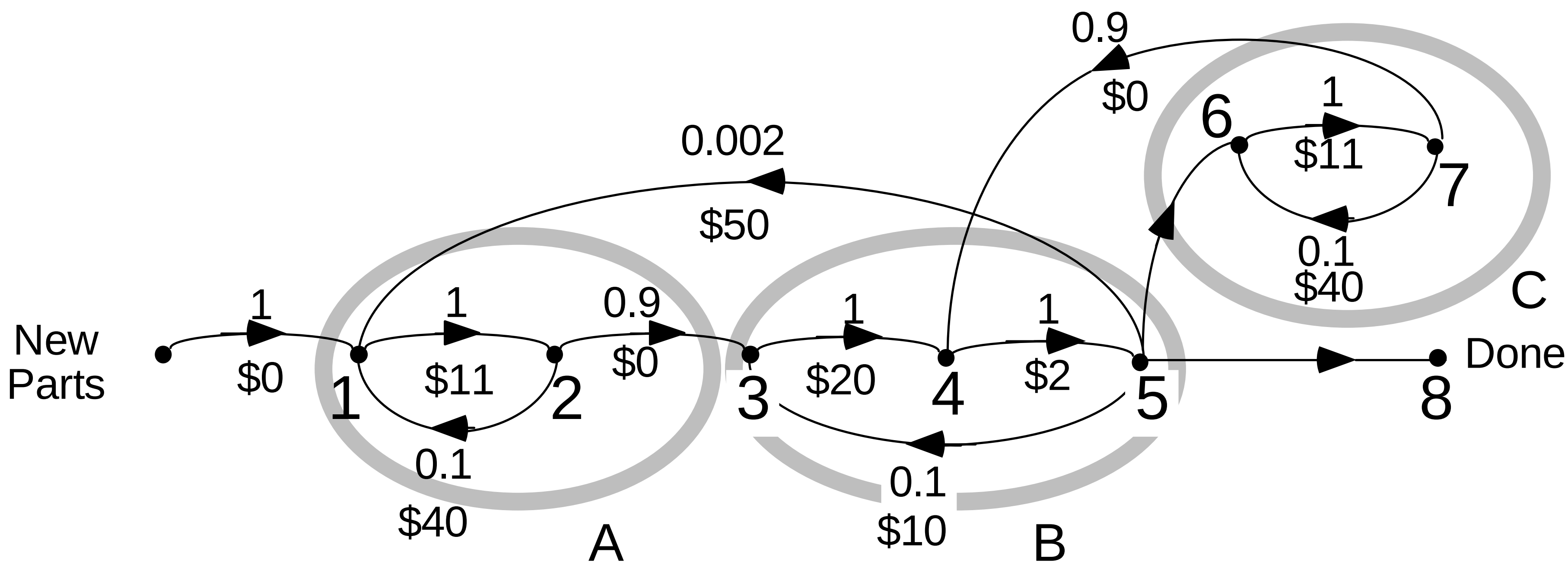
p_{jj}=0

$$cost = \sum_i \sum_j f_{ij} c_{ij}$$

Example System: an assembly with two subassemblies and several test and rework stations



Network Equivalent of Example



A Build/repair Subassembly #1 and Test it
B Build/repair Subassembly #2 and Test Both
C Repair/rebuild #1 While Attached to #2

Matlab Solution

```
»P=zeros(8)
»C=zeros(8)
%Arc probabilities:
»P(1,2)=1;
»P(2,1)=.1;
»p(2,3)=.9;
»P(2,3)=.9;
»P(3,4)=1;
»P(4,5)=1;
»P(5,3)=.1;
»P(5,1)=.002;
»P(5,6)=.02;
»P(5,8)=1-P(5,6)-P(5,3)-P(5,1);
»P(6,7)=1;
»P(7,4)=.9;
»P(7,6)=.1;
»X=[1 0 0 0 0 0 0 0];
»X=X'
```

```
»Y=inv(eye(8)-P')*X
Y =
1.1136
1.1136
1.1162
1.1390
1.1390
0.0253
0.0253
1.0000
»YY=[Y Y Y Y Y Y Y Y]
»F=box(YY,P)
```

Equilibrium Flows

F =

0.0000	1.1136	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.1114	0.0000	1.0023	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	1.1162	0.0000	0.0000	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	1.1390	0.0000	0.0000	0.0000
0.0023	0.0000	0.1139	0.0000	0.0000	0.0228	0.0000	1.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0253	0.0000
0.0000	0.0000	0.0000	0.0228	0.0000	0.0025	0.0000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Cost Solution

%Arc costs:

»C(1,2)=11;
»C(2,1)=40;
»C(3,4)=20;
»C(4,5)=2;
»C(5,1)=50;
»C(5,3)=10;
»C(5,3)=10;
»C(5,6)=80;
»C(6,7)=11;
»C(7,6)=40;
»cost=sum(sum(box(C,F)))
cost =
$44.7608

Cost without rework = $33

%FF = total flow in system
»FF=sum(sum(F))
» FF=5.6720
%EX=excess flow
»EX=FF/5
EX =
1.1344

Total flow without rework = 5

Capacity devoted to rework = 13.44%