Approaches to Line Balancing COMSOAL & RPW

Active Learning

Module 2

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Background Material

- **Modeling and Analysis of Manufacturing Systems** by Ronald G. Askin , Charles R. Standridge, John Wiley & Sons, 1993, Chapter 2.
- **Manufacturing Systems Engineering** by Stanley B. Gershwin, Prentice – Hall,1994, Chapter 2.
- Any good manufacturing systems textbook which has detailed explanation on reliable serial systems.

Lecture Objectives

- At the end of this module, the students should be able to
  - Explain the approaches to line balancing
    - COMSOAL Random Sequence Generation
    - Ranked Positional Weight Heuristics
  - Solve and find the optimal solutions to line balancing problems using the above techniques

Time Management

Introduction	5
Readiness Assessment Test (RAT)	5
COMSOAL Procedure	12
Spot Exercise	5
RPW Procedure	15
Team Exercise	5
Assignment	3
Total Time	**50 Mins**

Readiness Assessment Test (RAT)

1. In a ______layout, work stations are arranged according to the general function they perform without regard to any particular product.

   a) product,   b) process,   c) fixed position,   d) storage

2. A product layout is more suited to situations where product demand is stable than when it is fluctuating.

   a) True,   b) False

3. Fixed position layouts are used in projects where the product cannot be moved, and therefore equipment, workers, and materials are brought to it.

   a) True,   b) False

4. In general, work-in-process inventory is large for a product layout and small for a process layout.

   a) True,   b) False

5. Which of the following characteristics is associated with process layout?

   a) stable demand   b) less skilled workers
   c) specialized machinery   d) low volume
   e) product for general market

RAT – Solution

1. In a Process layout, work stations are arranged according to the general function they perform without regard to any particular product.
2. True. A product layout is more suited to situations where product demand is stable than when it is fluctuating.
3. True. Fixed position layouts are used in projects where the product cannot be moved, and therefore equipment, workers, and materials are brought to it.
4. False. In general, work-in-process inventory is large for a process layout and small for a product layout.
5. Low Volume is associated with process layout.

Approaches to Line Balancing

Three Basic Approaches for finding a solution

- COMSOAL – Basic random solution generation method
- Ranked Positional Weight Heuristic – Good solutions found quickly
- Implicit Enumeration Scheme

Assumptions

Required cycle time, sequencing restrictions and task times are known

COMSOAL Random Sequence Generation

- A simple record-keeping approach that allows a large number of possible sequences to be examined quickly
- Only tasks that satisfy all the constraints are considered at each step.
- Sequence discarded as soon as it exceeds the upper bound.
- Sequence saved if it is better than the previous upper bound and the bound is updated.
- Efficiency depends on the data storage and processing structure

COMSOAL – Cont…

- COMSOAL uses several list for speed computation.
  - *NIP(i)* ➔ Number of immediate predecessors for each task *i*.
  - *WIP(i)* ➔ Indicates for which other tasks *i* is an immediate predecessor.
  - *TK* ➔ Consists of *N* tasks.
- During each sequence generation,
  - List of unassigned tasks (*A*)
  - Tasks from A with all immediate predecessors (*B*)
  - Tasks from B with task times not exceeding remaining cycle time in the workstation (*F – Fit List*)

are updated.

COMSOAL Procedure

1. Set $x = 0$, $UB = \propto$, C = Cycle Time, $c = C$.
2. Start the new sequence : Set $x = x+1$, $A = TK$, $NIPW(i) = NIP(i)$.
3. Precedence Feasibility : For all, if $NIPW(i) = 0$, add i to B.
4. Time Feasibility : For all $i \in B$, if $t_i \leq c$, add i to F. If F empty, Step 5; otherwise Step 6.
5. Open new station : $IDLE = IDLE + c$. $c = C$. If $IDLE > UB$ go to Step 2; Otherwise Step 3.

COMSOAL Procedure – Cont…

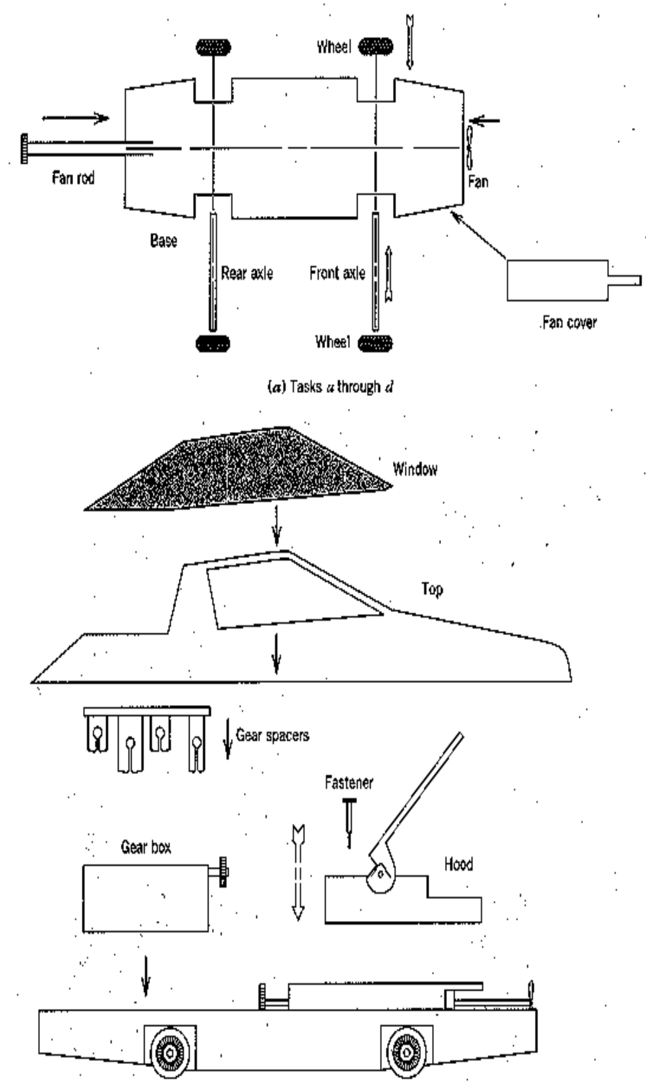
6. Select Task : Set $m = card\ \{F\}$. Randomly generate $RN \in U(0,1)$. Let $i^* = [m.RN]_{th}$ task from F. Remove i^* from A, B, F. $c = c - t_{i^*}$. For all $i \in WIP(i^*)$, $NIPW(i) = NIPW(i) - 1$. If A empty, go to Step 7; otherwise go to Step 3.
7. Schedule completion : $IDLE = IDLE + c$. If $IDLE \leq UB$, $UB = IDLE$ and store schedule. If $x = X$, stop; otherwise go to Step 2.

COMSOAL – Advantages

- The technique is relatively easy to program.
- Feasible solutions are found quickly.
- Greater the computational effort expended, the better the expected solution .
- Basic idea can be applied to many decision problems, the only requirement being that we can build solutions sequentially and a function evaluation can be performed to rank candidate solutions.

COMSOAL – Example

Task	Activity	Assembly Time	Immediate Predecessor
a	Insert Front Axle / Wheels	20	-
b	Insert Fan Rod	6	*a*
c	Insert Fan Rod Cover	5	*b*
d	Insert Rear Axle / Wheels	21	-
e	Insert Hood to Wheel Frame	8	-
f	Glue Windows to top	35	-
g	Insert Gear Assembly	15	*c, d*
h	Insert Gear Spacers	10	*g*
i	Secure Front Wheel Frame	15	*e, h*
j	Insert Engine	5	*c*
k	Attach Top	46	*f, i, j*
l	Add Decals	16	*k*



(a) Tasks a through d

(b) Tasks e through k

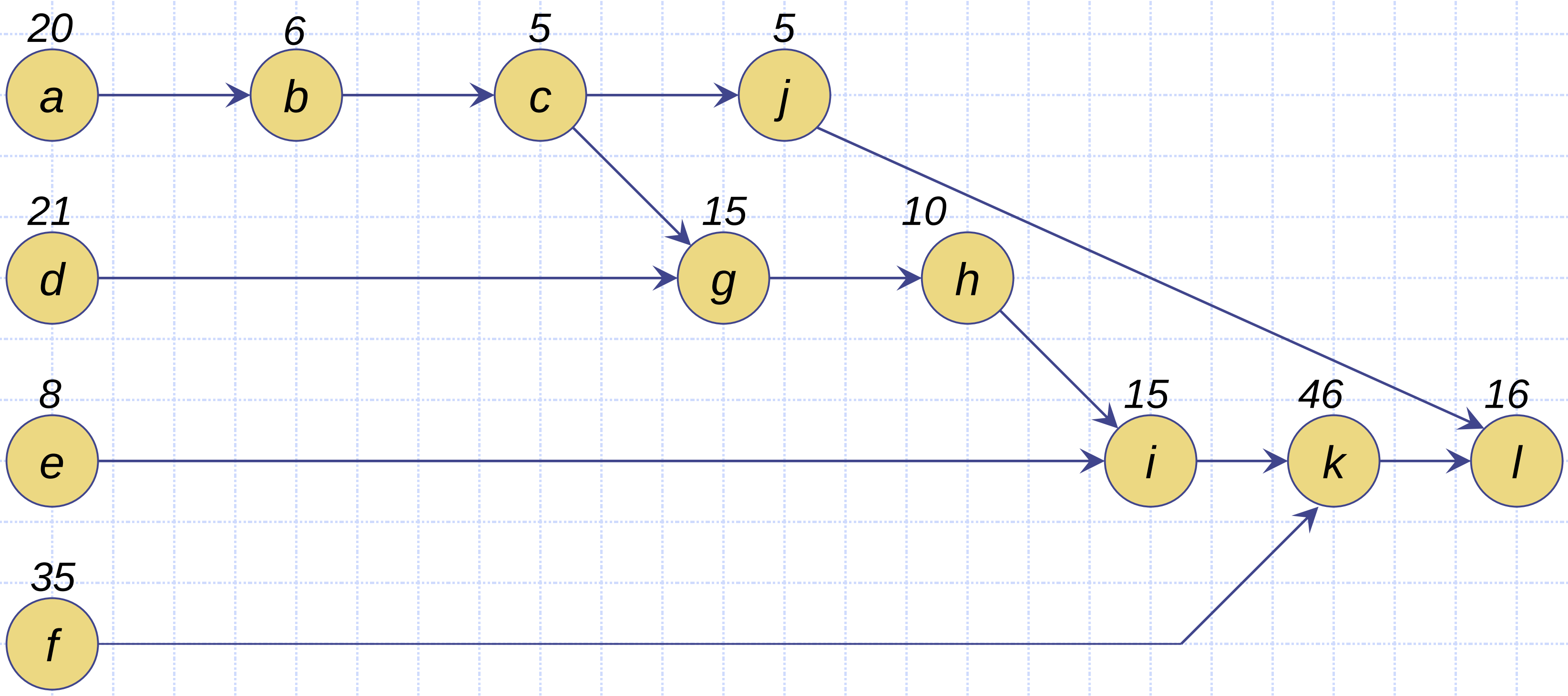
COMSOAL – Example

Data Known :

- Two 4 hour-shifts, 4 days a week will be used for assembly.
- Each shift receives two 10 minute breaks.
- Planned production rate of 1500 units/week.
- No Zoning constraints exist.

Example Solution

Model Car Precedence Structure



Example Solution – Cont…

$$C = \frac{1\text{ Week}}{1500\text{ Units}} \times 4\frac{\text{days}}{\text{week}} \times 2\frac{\text{shifts}}{\text{day}} \times 220\frac{\text{minutes}}{\text{shift}} = 1.17\frac{\text{minutes}}{\text{unit}}$$

- To meet demand *C* = 70 Seconds.
- Initially four potential tasks *a, d, e, or f*
- Generate random number between 0 and 1. Say outcome in our case is 0.34
- *R* is in second quadrant so keep *d* as first task.
- Continue the random generation.
- Quick check of lower bound

$$K^0 = \left\lfloor \sum_{r=a}^{l} t_r / C \right\rfloor = \left[202/70\right] = 3$$

Thus Better Solutions may exist

Single COMSOAL Sequence Results

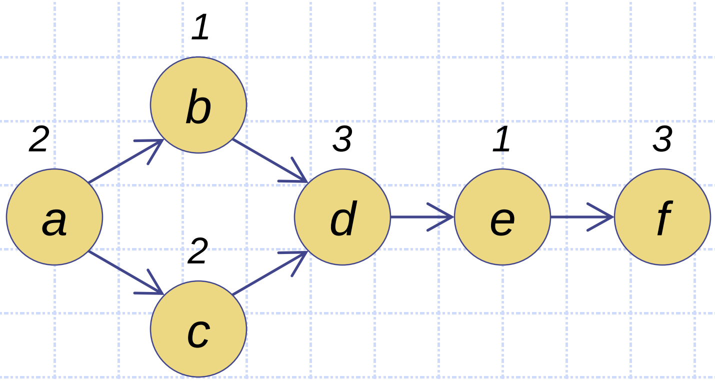
Step	List A	List B	List F	*U (0,1)*	Selected Tasks	Station (Idle Time)
1	*a through l*	*a, d, e, f*	*a, d, e, f*	0.34	*d*	1(49)
2	*a through l, -d*	*a, e, f*	*a, e, f*	0.83	*f*	1(14)
3	*a, b, c, e, g, h, i, j, k, l*	*a, e*	*e*	-	*e*	1(6)
4	*a, b, c, g, h, i, j, k, l*	*a*	-	Open Station		
4	*a, b, c, g, h, i, j, k, l*	*a*	*a*	-	*a*	2(50)
5	*b, c, g, h, i, j, k, l*	*b*	*b*	-	*b*	2(44)
6	*c, g, h, i, j, k, l*	*c*	*c*	-	*c*	2(39)
7	*g, h, i, j, k, l*	*g, j*	*g, j*	0.21	*g*	2(24)
8	*h, i, j, k, l*	*j, h*	*h, j*	0.42	*h*	2(14)
9	*i, j, k, l*	*i, j*	*j*	-	*j*	2(9)
10	*i, k, l*	*i*	-	Open Station		
10	*i, k, l*	*i*	*i*	-	*i*	3(55)
11	*k, l*	*k*	*k*	-	*k*	3(9)
12	*l*	*l*	-	Open Station		
12	*l*	*l*	*l*	-	*l*	4(54)

Spot Exercise

Solve the following line balancing problem using COMSOAL procedure. Assume demand is 100/day.

Task	Time	Immediate Predecessor
a	2	-
b	1	a
c	2	a
d	3	b, c
e	1	d
f	3	e

Exercise Solution



$$C = \frac{\text{Production time available}}{\text{Desired units of output}}$$

$$= \frac{8 \text{ Hours} \times 60 \text{ Minutes/hour}}{100}$$

$$= 4.8 \text{ Minutes}$$

$$K^0 = \left\lceil \sum_{r=a}^{l} t_r \Big/ C \right\rceil = [12/4.8] = 2.5 \approx 3$$

Exercise Solution – Cont…

Step	List A	List B	List F	U(0,1)	Selected Task	Station (Idle Time)
1	a to f	a	a	-	a	1(2.8)
2	b to f	b, c	b, c	0.68	c	1(0.8)
3	b to f, -c	b	b	-	b	2(3.8)
4	d to f	d	d	-	d	2(0.8)
5	e, f	e	e	-	e	3(3.8)
6	f	f	f	-	f	3(0.8)

Ranked Positional Weight Heuristic

- A task is prioritized based on the cumulative assembly time associated with itself and its successors.
- Tasks are assigned in this order to the lowest numbered feasible workstation.
- Cumulative remaining assembly time constrains the number of workstations required.
- Illustrates the greedy, single pass heuristics.
- Procedure requires computation of *positional weight PW(i)* of each task.

RPW Procedure

- Let $S(i)$ ➔ Set of successors of tasks *i*.
- Example, $j \in S(i)$ means *j* cannot begin until *i* is complete.
- Compute $PW_i = t_i + \sum_{r \in S(i)} t_r$
- Tasks ordered such that $i < r$ implies i *not* $\in S(r)$.
- Task r is then a member of $S(i)$ only if there exists an immediate successor relationship from *i* to *r*.
- Immediate successors $IS(i)$ are known from the inverse of the $IP(i)$ relationships.

RPW Procedure – Cont…

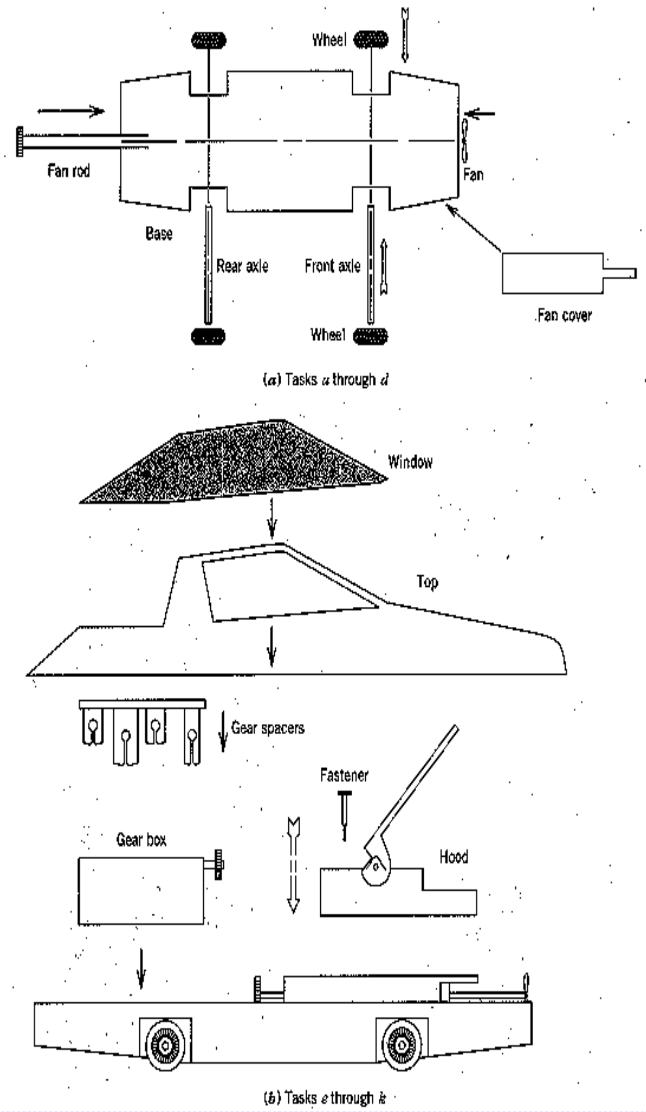
1. Task Ordering : For all tasks $i = 1,\ldots,N$ compute $PW(i)$. Order (rank) tasks by nonincreasing $PW(i)$
2. Task Assignment : For ranked tasks $i = ,\ldots,N$ assign task i to first feasible workstation.

Precedence Constraints : assignment to any workstation at least as large as that to which its predecessors are assigned

Zoning & Time Restrictions : Checked on placement.

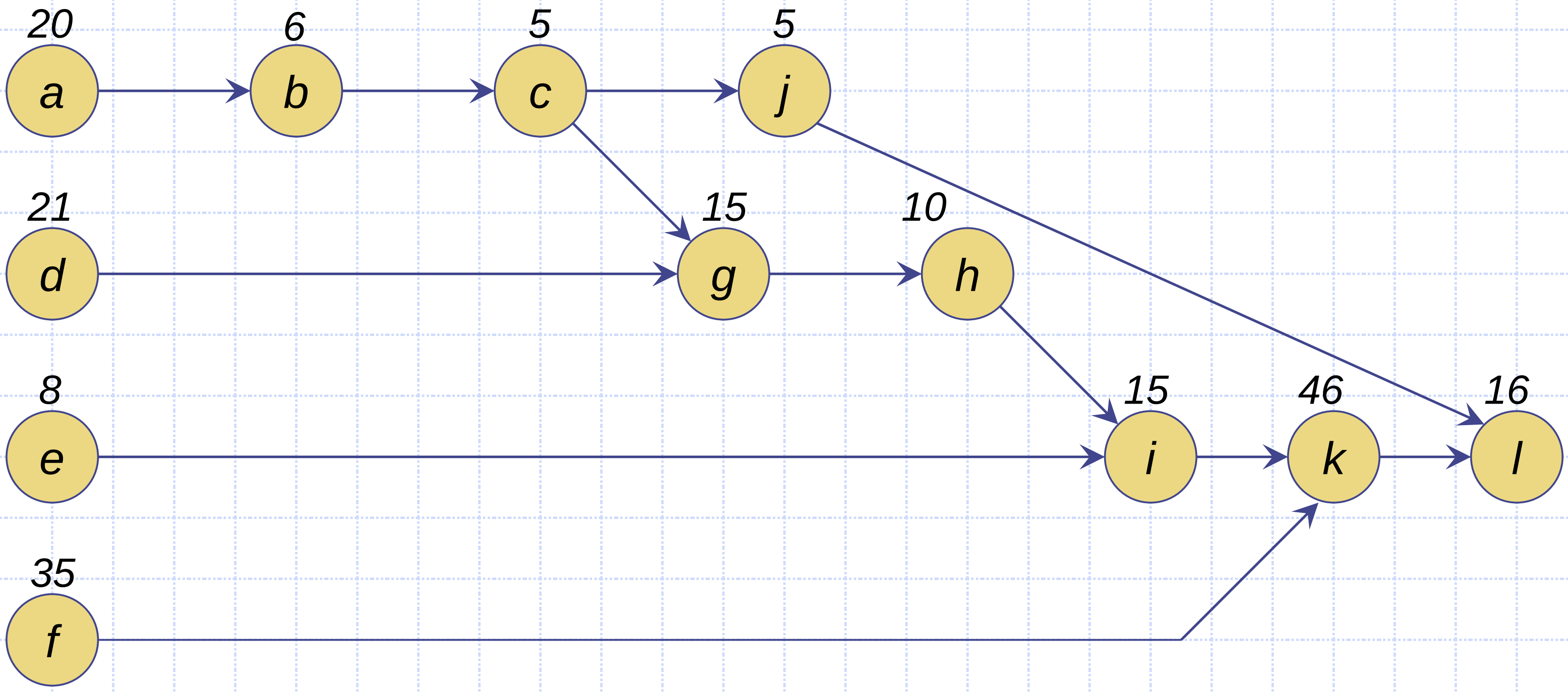
RPW Procedure - Example

Task	Activity	Assembly Time	Immediate Predecessor
a	Insert Front Axle / Wheels	20	-
b	Insert Fan Rod	6	*a*
c	Insert Fan Rod Cover	5	*b*
d	Insert Rear Axle / Wheels	21	-
e	Insert Hood to Wheel Frame	8	-
f	Glue Windows to top	35	-
g	Insert Gear Assembly	15	*c, d*
h	Insert Gear Spacers	10	*g*
i	Secure Front Wheel Frame	15	*e, h*
j	Insert Engine	5	*c*
k	Attach Top	46	*f, i, j*
l	Add Decals	16	*k*



Example Solution

Model Car Precedence Structure



RPW Procedure - Solution

Positional Weight calculated based on the precedence structure (previous slide).

PW_l = its task time = 16

$PW_k = t_k + PW_l = 46+16 = 62$

$PW_j = t_j + PW_k = 5+62 = 67$

Task	PW	Ranked PW
a	138	1
b	118	3
c	112	4
d	123	2
e	85	8
f	97	6
g	102	5
h	87	7
i	77	9
j	67	10
k	62	11
l	16	12

RPW Solution Cont...

- Assignment order is given by the rankings.
- Task *a* assigned to station 1.
  - $c - t_a$ = 70 – 20 = 50 seconds left in Station 1.
- Next Assign task *d*
  - 50 – 21 = 29 seconds left in Station 1.

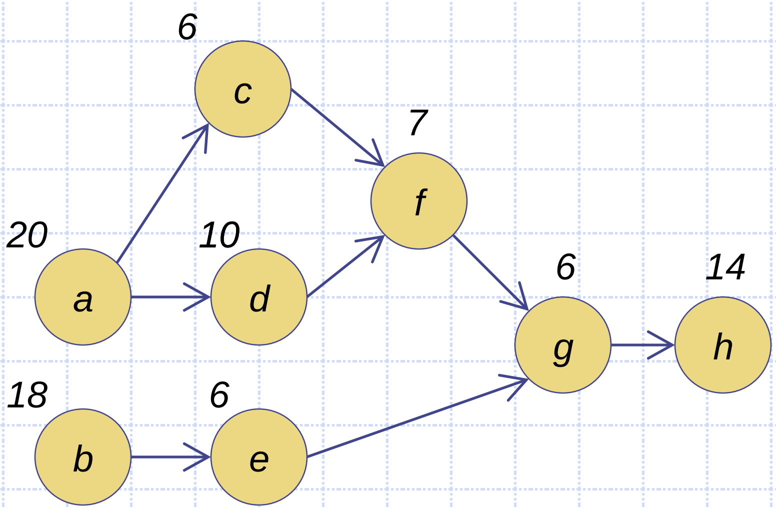
Station	Time Remaining	Tasks
1	70, 50, 29, 23, 18, 3	a, d, b, c, g
2	70, 35, 25, 17, 2	f, h, e, i
3	70, 65, 19, 3	j, k, l

Team Exercise

Assembly of a product has been divided into elemental tasks suitable for assignment to unskilled workers. Task times and constraints are given below. Solve by RPW Procedure

Task	Time	Immediate Predecessors
a	20	-
b	18	-
c	6	a
d	10	a
e	6	b
f	7	c, d
g	6	e, f
h	14	g

Exercise Solution



Task	PW_i	Rank
a	63	1
b	44	2
c	33	4
d	37	3
e	26	6
f	27	5
g	20	7
h	14	8

Workstation	Assigned Tasks	Remaining Time
1	a, d	30, 10, 0
2	b, c, e	30, 12, 6, 0
3	f, g, h	30, 23, 17, 3

Assignment

Write a flowchart for COMSOAL using the decision rule that feasible tasks are selected with probability proportional to their positional weight.