CENG 6101 Project Management

Resource Allocation and Leveling

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Resource Allocation and Leveling: Problem

- In practice, basic PERT and CPM scheduling techniques have proven to be helpful only when the project deadline is not fixed and the resources are not constrained by either availability or time.

TABLE 1. Case Study Data

Activity (1)	Duration (days) (2)	Predecessors (3)	Resource Requirements per Day					
			R1 (4)	R2 (5)	R3 (6)	R4 (7)	R5 (8)	R6 (9)
A	6	—	5	2	2	2	7	4
B	3	—	3	5	2	3	9	6
C	4	A	2	4	4	2	3	1
D	6	—	5	4	3	5	5	4
E	7	A, B	3	5	2	3	8	0
F	5	C	4	1	4	9	2	5
G	2	D	4	1	4	3	9	8
H	2	A, B	5	5	4	0	9	1
I	2	G, H	3	2	4	3	4	2
J	6	F	1	5	4	6	7	3
K	1	C, E	3	3	2	4	5	1
L	2	E, G, H	3	2	2	8	3	4
M	4	I, K	2	2	2	2	4	8
N	2	F, L	1	4	4	3	4	1
O	3	L	5	5	4	6	2	3
P	5	J, M, N	3	2	3	4	7	8
Q	8	O	4	5	4	2	3	4
R	2	D, O	5	3	3	3	7	8
S	6	P, R	2	4	6	2	3	4
T	2	Q	1	6	2	7	5	2
Daily Resource Limits			7	10	10	16	18	13

Case study:
20 activities and
6 resources

Source: Hegazy (1999)

Resource Allocation and Leveling: Problem

Case study: 20 activities and 6 resources

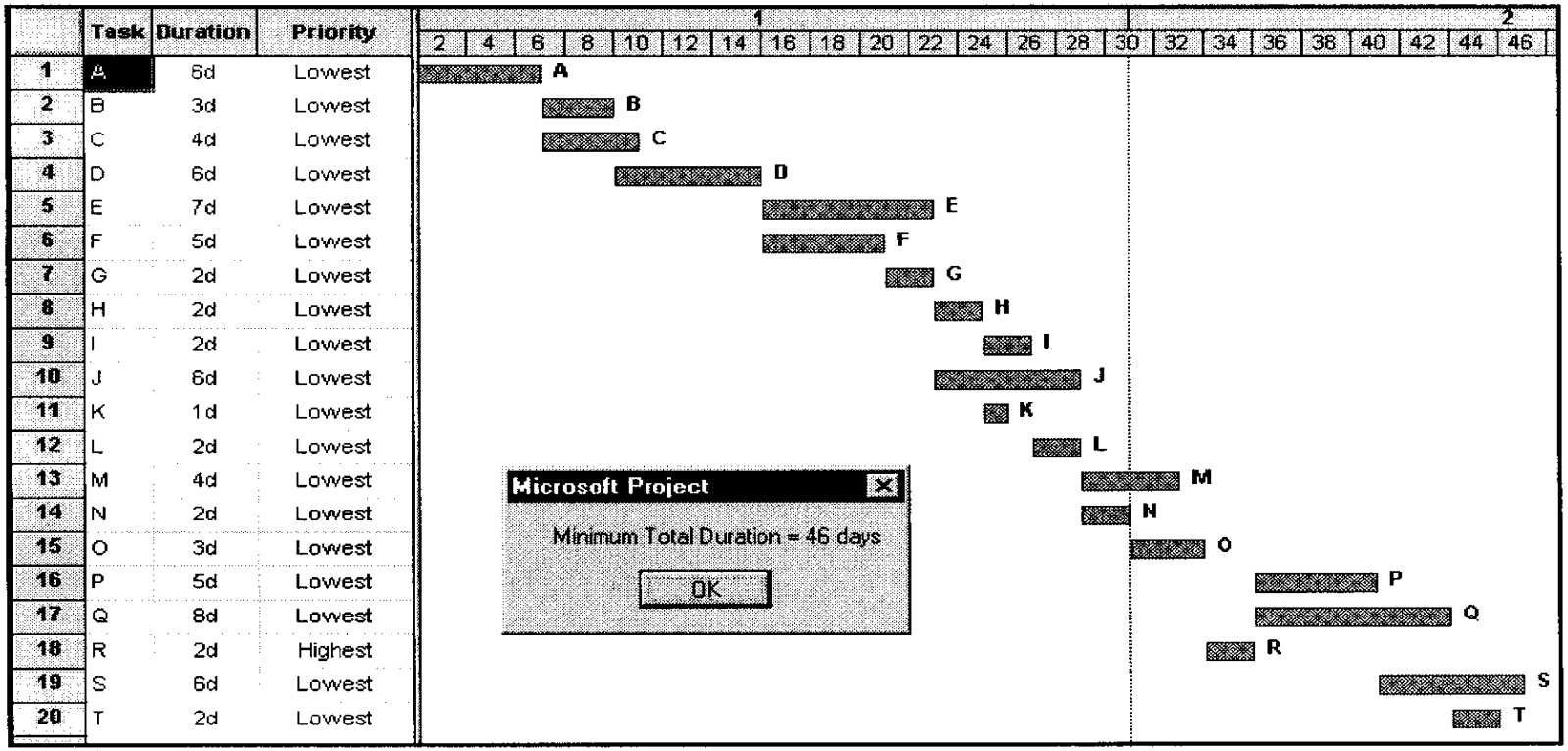
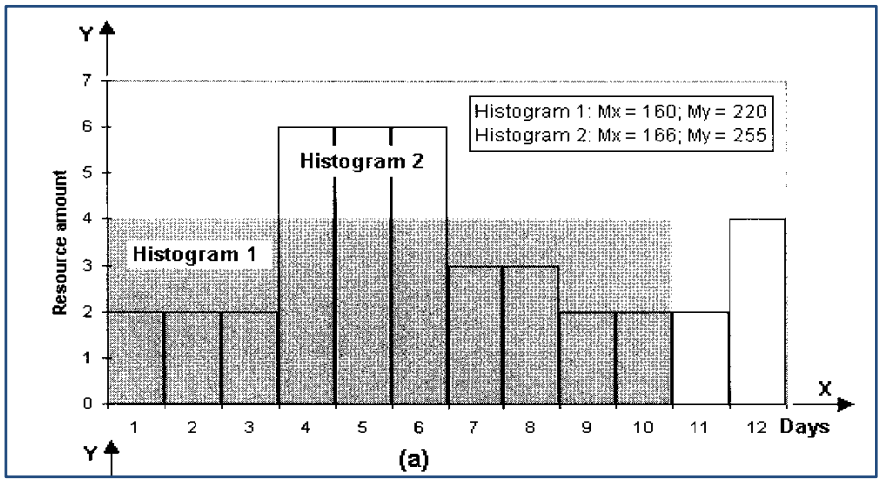


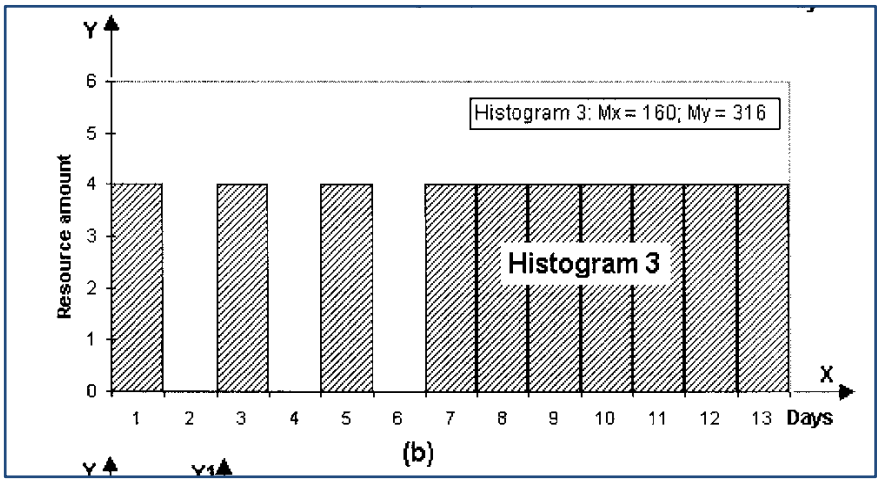
FIG. 1. Case Study Project with High Priority Assigned to Task (R)

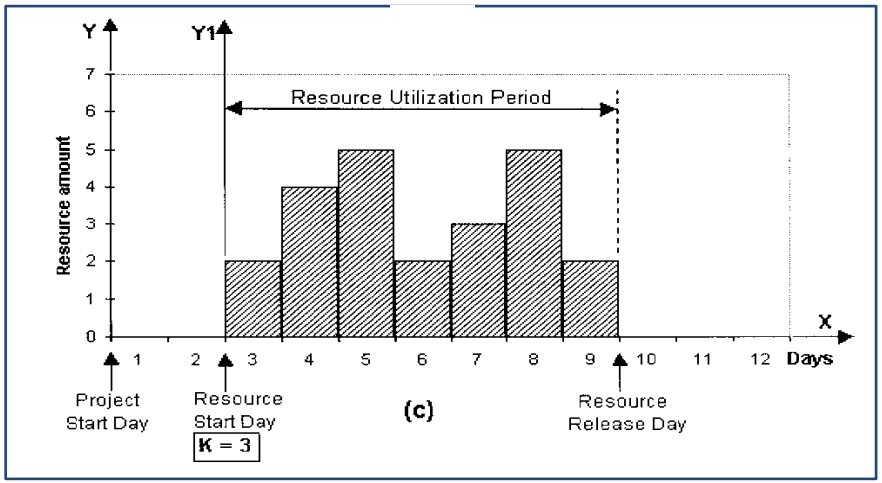
Source: Hegazy (1999)

Resource Allocation and Leveling: Problem

Case study: 20 activities and 6 resources







Source: Hegazy (1999)

Resource Allocation and Leveling

Resource Allocation vs. Leveling

Availability of resources superimposed on CPM project duration under two conditions:

1. Limited resources (and variable project duration)
   - Evaluate impact on project duration of limited resources and keep the impact to the minimum

   → Resource Allocation or Constrained resource scheduling.
2. Unlimited resource (and fixed project duration)
   - no constraints on availability
   - What is optimal level of resources, while maintaining the original project completion duration?

   → Resource leveling or Resource smoothing.

Resource Allocation

Two methods of allocating limited resources: constrained resource scheduling

1. Heuristic Rules
   - priority rules and a procedure for allocating resources.

2. Optimal Procedures
   - Designed to produce best (optimal, shortest) schedules (with limited resources).

Resource Allocation

1. Heuristic Rules

e.g. Allocate resources to activity that:

- has earliest start time
- least float
- largest duration
- shortest duration
- most successors

Resource Allocation

→no way to tell what is best combination of rules (differs for different schedules).

→several planners have concluded that minimum float heuristic gives shorter duration than rest of rules.

→need to use trial and error of different heuristics for same network and compare ~6 gets nearly optimal solution (shortest schedule).

– Heuristic approach produces good resource feasible schedules.

Resource Allocation

Priority rules for heuristic method of allocating limited resources:

1. Allocate resources to the activity having the least float.
2. Allocate to activity requiring the largest number of resource days.
3. Allocate to activity using largest number of resources (people or machines).
4. Allocate to an activity that precedes the largest remaining resource days requirement.
5. If a tie, allocate to the activity with the lowest sequence (*i* – *j* value).

Resource Allocation

2. Optimal procedures

→designed to produce best (i.e., optimal, shortest) schedules (with limited resources). Options include:

   1. Procedures based on Linear Programming (LP).

   2. Procedures based on enumerative (heuristic) and other mathematical and artificial intelligence based techniques.

→need to go through all possible solutions.

→used only for large networks or projects where large number of resources are required.

Resource Allocation and Leveling: Problem

- Case study: Results
- No resource constraints CPM: 32 days.
- MS Project:
  - Using resource-leveling feature (leveling is used in the software's terminology for both allocation and leveling) with "Automatic" setting, total project duration was extended to 49 days, avoiding resource over-allocations.
  - This solution was obtained using the software's "standard" set of heuristic rules, which maintains logical relationships and applies the "minimum total slack" rule to resolve conflicts.

Source: Hegazy (1999)

Resource Allocation and Leveling: Problem

- Case study: Results
- Primavera:
  - The same results were also obtained using the "minimum total slack" rule.
  - Several other heuristic rules were also tried on Primavera software, without improving the schedule.
  - A project duration of 49 days is, therefore, the best result that can be obtained from widely used commercial software.
  - It is noted that this result is obtained when all project activities have the same priority level.

Source: Hegazy (1999)

Resource Allocation and Leveling: Problem

- Hegazy (1999): Using Genetic Algorithm

TABLE 2. Results of Genetic Algorithm Experiments

(1)	Initial Schedule (2)	Experiment 1 (3)	Experiment 2 (4)	Experiment 3 (5)	Experiment 4 (6)
GA Optimization Objective(s)	None	Min. Project Duration	Min. Duration + Min. Daily Fluctuation of R4	Min. Duration + Min. Utilization Period of R4	Min. Duration + Min Fluctuation of R4 + Min. Utilization Period of R4
Gene Evaluation Criteria & Weights	None	---------- Proj. Dur. 100%	Proj. Dur. 50% Mx of R4 50%	Proj. Dur. 50% My of R4 50%	Proj. Dur. 50% Mx+My of R4 50%
Activity		**Activity Priority**		**Results**	
A	Lowest	Highest	Very High	Higher	Higher
B	Lowest	Medium	Very Low	Low	Medium
C	Lowest	Very High	Medium	Higher	High
D	Lowest	Very High	Very High	Medium	Higher
E	Lowest	Very High	Lowest	Higher	Highest
F	Lowest	Very High	High	Medium	Low
G	Lowest	Medium	Lowest	Low	Low
H	Lowest	Lowest	High	Lowest	Very Low
I	Lowest	Very High	High	Very Low	Very Low
J	Lowest	Medium	High	Very Low	Lower
K	Lowest	Medium	Higher	Medium	Higher
L	Lowest	Medium	High	Lower	Very Low
M	Lowest	Very High	Very High	Medium	High
N	Lowest	Very Low	Medium	Low	Very High
O	Lowest	High	Very High	High	High
P	Lowest	Very High	Medium	Low	Lower
Q	Lowest	Lowest	Lowest	Lower	Low
R	Lowest	Higher	Very High	Low	High
S	Lowest	Medium	Low	Highest	Very High
T	Lowest	Lowest	Higher	Very High	Low
Project Duration	49	44	45	44	45
Calculated Moments of R4 Mx	2409	2381	2265	2375	2345
My	7231	6752	6952	6746	6832
Mx+My	9640	9133	9217	9121	9177
Range of R4	12	10	10	10	10
Utilization Period of R4	Day 1 to Day 49	Day 1 to Day 44	Day 1 to Day 45	Day 1 to Day 44	Day 1 to Day 45

Notations:
- Proj. Dur. = Project Duration.
- Mx = Moment around the x-axis (Time) of resource histogram
- My = Moment around the y-axis (Number of Resources) of resource histogram
- Range = (Maximum – Minimum) amount of the resource needed per day

Resource Allocation

- Basic allocation procedure is method of scheduling work by balancing need with availability of resources at a given time.

- An approach to allocating resources (limited or unlimited resources):

Series Method:

→ allocate resources to activities in series – one activity at a time from start to finish.

Series Method of Allocating Limited Resources

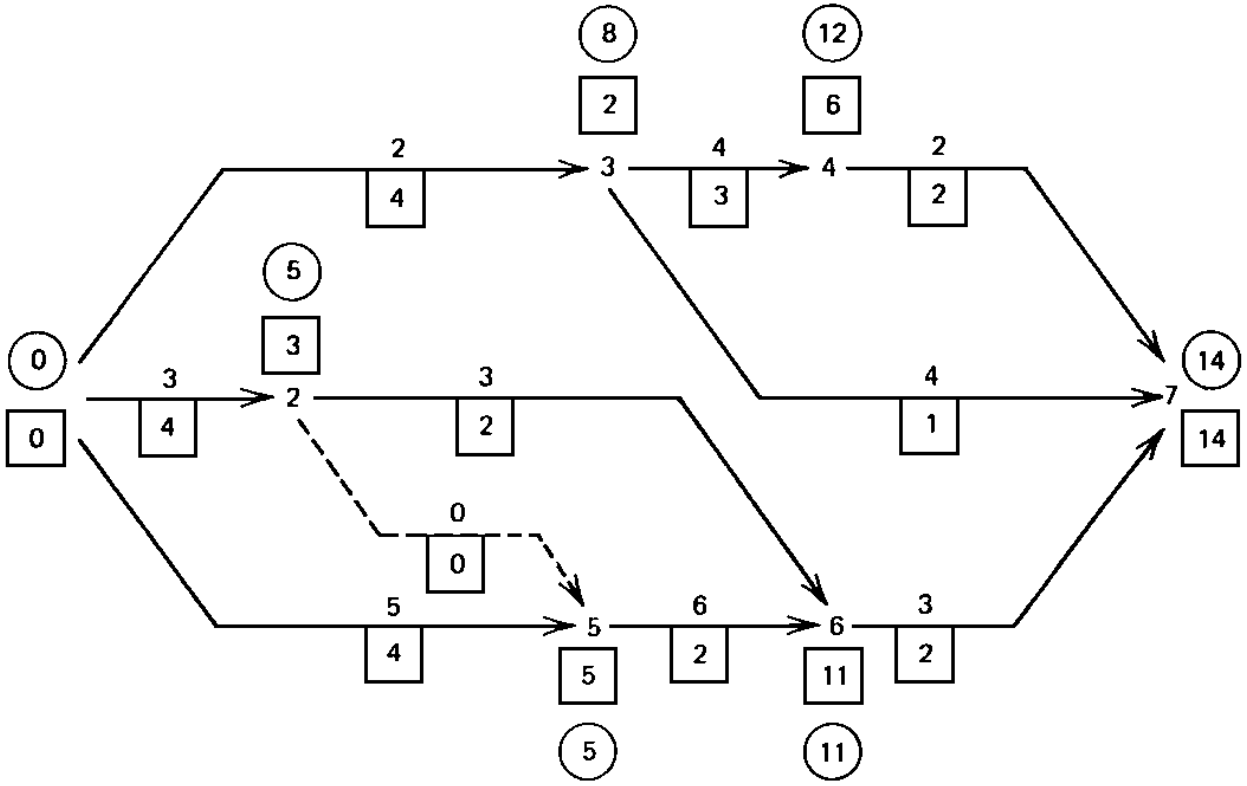


FIGURE 9.3 Example Network No. 2

Series Method of Allocating Limited Resources

TABLE 9.1 Single Resource Allocation Table: Limit of Six Resources per Day: Series Method

ACTIVITY	DURATION	RESOURCES	RESOURCE DAYS	EARLIEST START	TOTAL FLOAT	PRIORITY	PROJECT CLOCK → 0 2 4 6 8 10 12 14 16 18 20
1-2	3	4	12	0 5	2 -3	2 1	4 4 4
1-3	2	4	8	0 5 8	6 1 -2	3 2 2	4 4
1-5	5	4	20	0	0	1	4 4 4 4 4
2-5	0	0	0	3 8	2 -3	T	
2-6	3	2	6	3 8 10 14	5 0 -2 -6	3 2 1	2 2 2
3-4	4	3	12	2 10	6 -2	1	3 3 3 3
3-7	4	1	4	2 10	8 0	3	1 1 1 1
4-7	2	2	4	6 14	6 -2	2	2 2
5-6	6	2	12	5 8	0 -3	1	2 2 2 2 2 2
6-7	3	2	6	11	0	1	2 2 2

Resource Allocation

Series Method of Allocating Limited Resources

Resource days = resources required x duration of activity

Step 1: Calculate number of resources in resource pool

Sum total number of resource days for project (e.g. for a resource such as workers).

→ Total number of worker-days necessary to complete project.

Resource Allocation

Series Method of Allocating Limited Resources

Divide total by project duration

→ average number of workers required per day.

* May not meet requirements of all activities but provides good starting point.

* Average number should not be less than number of resources required by single activity on a given day (otherwise activity can not be done) and should always be an integer (round up).

Resource Allocation

Series Method of Allocating Limited Resources

Step 2: Two things to keep track of

A. When resources are allocated

→ determines start time of an activity.

∴ Maintain a project clock – Denoted by ↓ placed over day.

Clock initially set to time zero and reset to time where it stops.

Resource Allocation

Series Method of Allocating Limited Resources

Clock moves forward when either:

1. No Resources left to be allocated.
2. No activities to which resources can be allocated.

Clock stops when:

1. Resources available for allocation.
2. Activities available to which resources can be allocated.

- When clock stops, start times and floats of all eligible activities that have not been scheduled are updated (start ≥ clock setting).
- [Update all activities in network].

Resource Allocation

Series Method of Allocating Limited Resources

B. Number and availability of resources

- resource pool established with available (or given) level of resources.
- number of resources is decreased by quantity allocated to activities.
- resource pool is replenished by resources returned from completed activities.

Resource Allocation

Series Method of Allocating Limited Resources

* Assign resources according to priority rules applied to all activities that can start immediately.

* Dummy activities assigned top (T) priority, so they do not delay other activities (since dummy activities do not use any resources).

Resource Allocation

Example 1

TABLE 9.1 Single Resource Allocation Table: Limit of Six Resources per Day: Series Method

ACTIVITY	DURATION	RESOURCES	RESOURCE DAYS	EARLIEST START	TOTAL FLOAT	PRIORITY	PROJECT CLOCK → 0 2 4 6 8 10 12 14 16 18 20
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1-3	2	4	8	0 5 8	6 1 -2	3 2 2	4 4
1-5	5	4	20	0	0	1	4 4 4 4 4
2-5	0	0	0	3 8	2 -3	T	
2-6	3	2	6	3 8 10 14	5 0 -2 -6	3 2 1	2 2 2
3-4	4	3	12	2 10	6 -2	1	3 3 3 3
3-7	4	1	4	2 10	8 0	3	1 1 1 1
4-7	2	2	4	6 14	6 -2	2	2 2
5-6	6	2	12	5 8	0 -3	1	2 2 2 2 2 2
6-7	3	2	6	11	0	1	2 2 2

Resource Allocation

Example 1

Series method of allocating limited resources (Figure 9.3, Table 9.1)

1) $$\frac{\text{84 resource days}}{\text{14 days project duration}} = \text{6 resources in pool}$$

Consider project network as a subnetwork of all activities that use the resource in question.

Series Method of Allocating Limited Resources

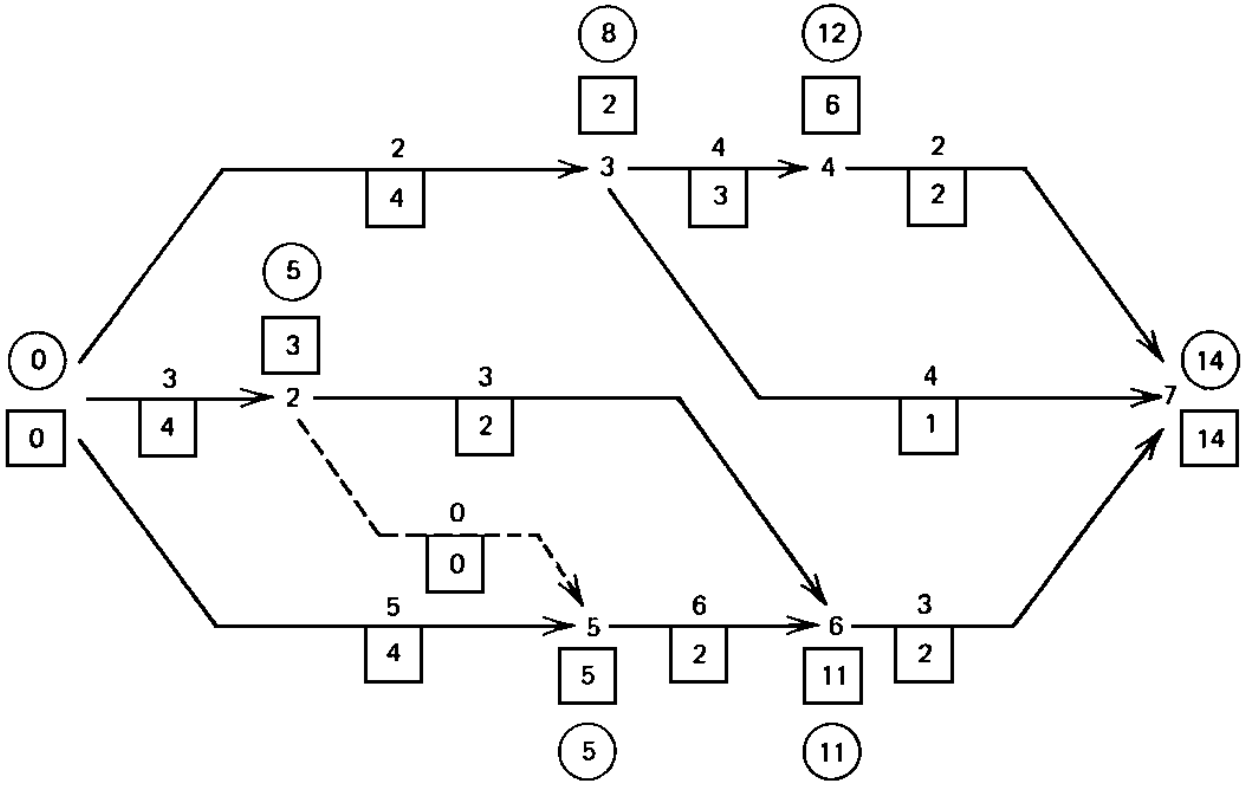

FIGURE 9.3 Example Network No. 2

Series Method of Allocating Limited Resources

TABLE 9.1 Single Resource Allocation Table: Limit of Six Resources per Day: Series Method

ACTIVITY	DURATION	RESOURCES	RESOURCE DAYS	EARLIEST START	TOTAL FLOAT	PRIORITY	PROJECT CLOCK 0 2 4 6 8 10 12 14 16 18 20
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1-3	2	4	8	0 5 8	6 1 -2	3 2 2	4 4
1-5	5	4	20	0	0	1	4 4 4 4 4
2-5	0	0	0	3 8	2 -3	T	
2-6	3	2	6	3 8 10 14	5 0 -2 -6	3 2 1	2 2 2
3-4	4	3	12	2 10	6 -2	1	3 3 3 3
3-7	4	1	4	2 10	8 0	3	1 1 1 1
4-7	2	2	4	6 14	6 -2	2	2 2
5-6	6	2	12	5 8	0 -3	1	2 2 2 2 2 2
6-7	3	2	6	11	0	1	2 2 2

Example

Series Method of allocating limited resources (Figure 9.3, Table 9.1)

2)

Activities Considered	ES	Total Float	Priority
1-2	0	2	2
1-3	0	6	3
1-5	0	0	1 (4 resources assigned)

If 2 resources are required together (e.g. formwork panels and a crew) then consider them as one resource

Resource Allocation

$\therefore$ Assign resources to activity 1-5 (4 resources for 5 days).

$\therefore$ Not enough resources to perform activity 1-2 or 1-3.

$\therefore$ Clock moves to end of activity 1-5 when resources return to pool.

Resource Allocation

3)

Activities	ES	Float	Priority
1-2	5	-3 (2-5)	1 (4 resources assigned)
1-3	5	1 (6-5)	2

Float [This step] =

Original Float [Original or previous step] – (Revised ES – Original ES) [Original or previous step]

Update all activities that did not receive resources and are eligible to begin.

Resource Allocation

Cannot consider Activity 5-6 yet since activity 1-2 is a predecessor also.

$\therefore$ Assign resources to activity 1-2 (4 resources, 3 days).

$\therefore$ Not enough for 1-3.

$\therefore$ Clock moves to end of 1-2.

Resource Allocation

4)

Activities	ES	Float	Priority
1-3	8	-2 (1-(8-5))	2 (4 resources assigned
2-5	8	-3 (2-(8-3))	T (dummy)
2-6	8	0 (5-5)	3
5-6	8	-3 (0-3)	1 (2 resources assigned)

* Whenever dummy is encountered, assigned top priority "T" so does not delay other activities (since dummy does not need resources).

Resource Allocation

5) When activity 1-3 ends, 4 resources come back in pool – at time 10 (5-6 not done yet).

Activities	ES	Float	Priority
2-6	10	-2 (0-(10-8))	2 (needs 2 resources, can not assign 2)
3-4	10	-2 (6-8)	1 (3 resources assigned)
3-7	10	0 (8-8)	3 (1 resource assigned)

More resource days (rule 2)

Resource Allocation

6) At day 14, all 6 resources come back in pool. 5-6, 3-4 and 3-7 all end.

Activities	ES	Float	Priority
2-6	14	-6 (-2-(14-10))	1 (2 resources assigned)
4-7	14	-2 (6-(14-6))	2 (2 resources assigned)

Left over

Resource Allocation

7) Only remaining activity is 6-7.

→requires 2 resources for 3 days.

→can start on day 17 when activity 2-6 ends.

∴ Project ends on day 20 = project duration using 6 resources.

Resource Allocation

Series Method with a fixed project duration

→ increase resource level by one, allocate resources, assess resulting project duration.

→repeat successively until obtain acceptable project duration.

→8 resources gives duration of 14 days.

Resource Allocation

Other Criteria for Priority Rules

- Savings associated with early return of a resource (e.g. crane) ∴ higher priority to activities that use crane.
- Piece of equipment required by another project.
- Use of temporary personnel.
- High priority to activities presenting greatest (or least) potential difficulty.
- Priority to activities that will bring in large amount of progress payment.

Resource Allocation and Leveling

So far, resource allocation based on fixed activity duration derived from fixed resource need for each activity in network.

– Assumption made that work on activity can not start until required number of workers or machines available

→may not be true in reality.

Resource Leveling

Example:

- Project manager who does not have 8 carpenters for formwork may start activity with 2 carpenters.
- May have a limit of 16 carpenters on activity due to space constraints.

∴ Normal duration of activity may be based on level of resources normally employed by organization.

E.g., 2 and 16 may be secondary levels of resources

→ may be considered in scheduling when primary level not available.

Unlimited Resource Allocation: Resource Leveling

Unlimited Resource Allocation

- If ample resources available, allocate them in best way so as to not delay project and to obtain least costly profile (lowest project costs)

  →achieved by resource leveling.
- Resource profile varies depending on whether we schedule activities according to ES times, LS times, or any time in between two.

Unlimited Resource Allocation: Resource Leveling

Unlimited Resource Allocation

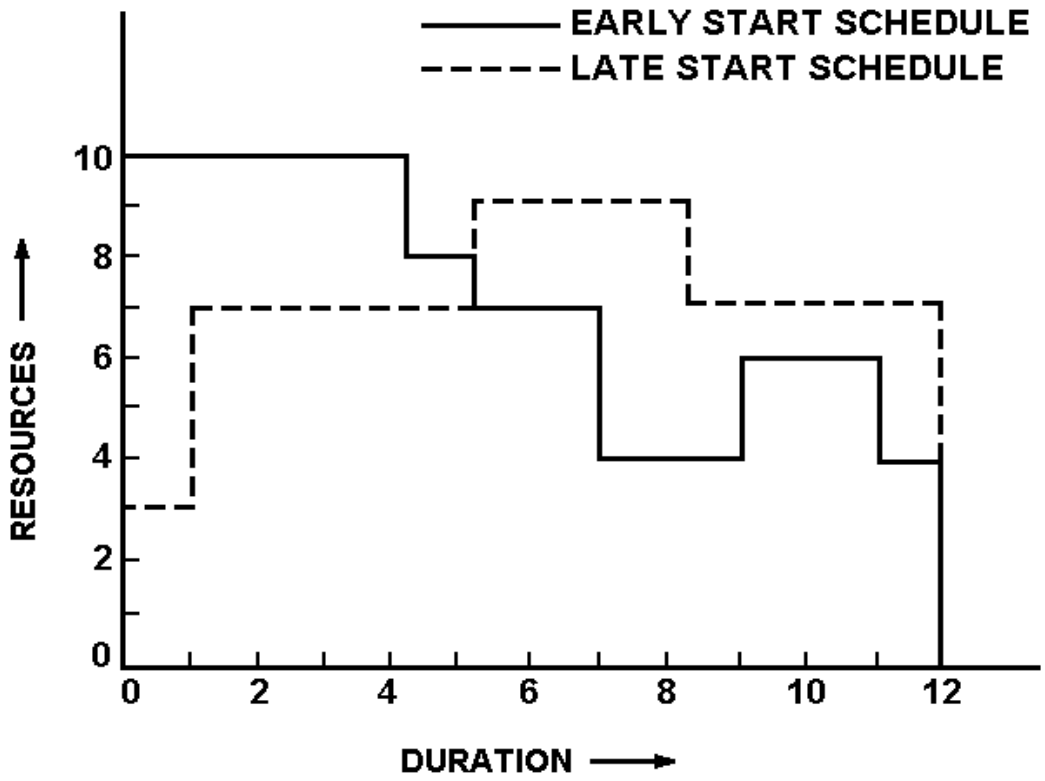


FIGURE 9.6 Resource Profile

Unlimited Resource Allocation: Resource Leveling

Unlimited Resource Allocation

- Resources allocated in such a way that resource profile gradually built up to peak and slowly brought down to end without another rise

  → applicable to manpower usage.

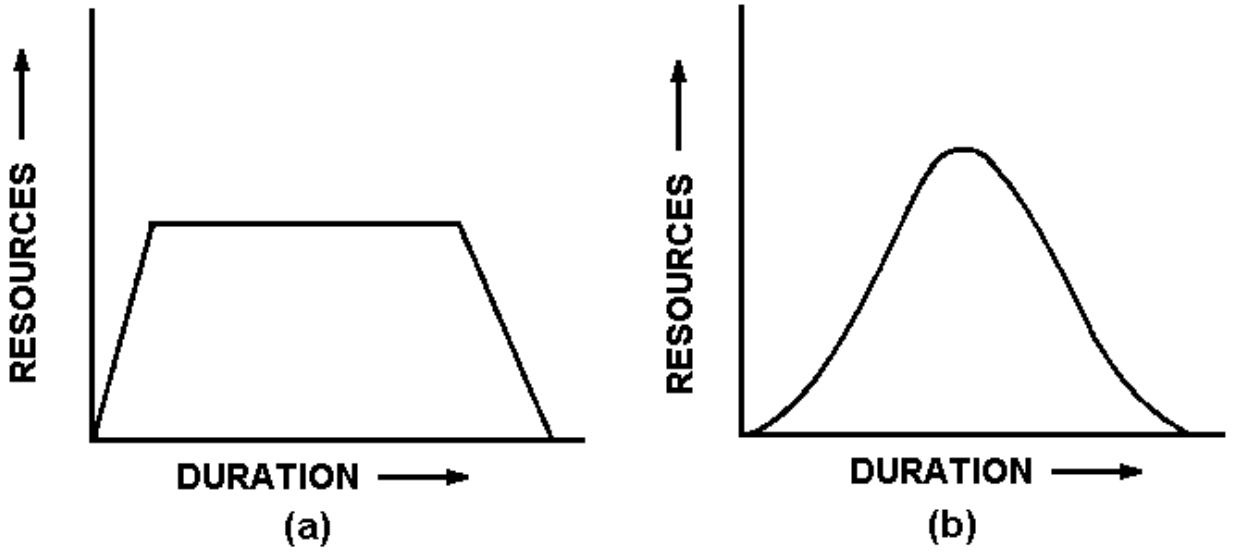


FIGURE 9.7 General Resource Profiles

Unlimited Resource Allocation: Resource Leveling

Unlimited Resource Allocation

e.g., carpenters – fewer at beginning of project when fewer activities are occurring – build up to peak activity level – wind down as activities are completed near end of project (not a level profile for entire duration of project).

– Level profile applicable to equipment usage, e.g., crane.

Unlimited Resource Allocation: Resource Leveling

Unlimited Resource Allocation

Objective of unlimited resource scheduling is to obtain least costly profile.

→ special costs associated with hiring and dismissal of resources as well as resource idleness.

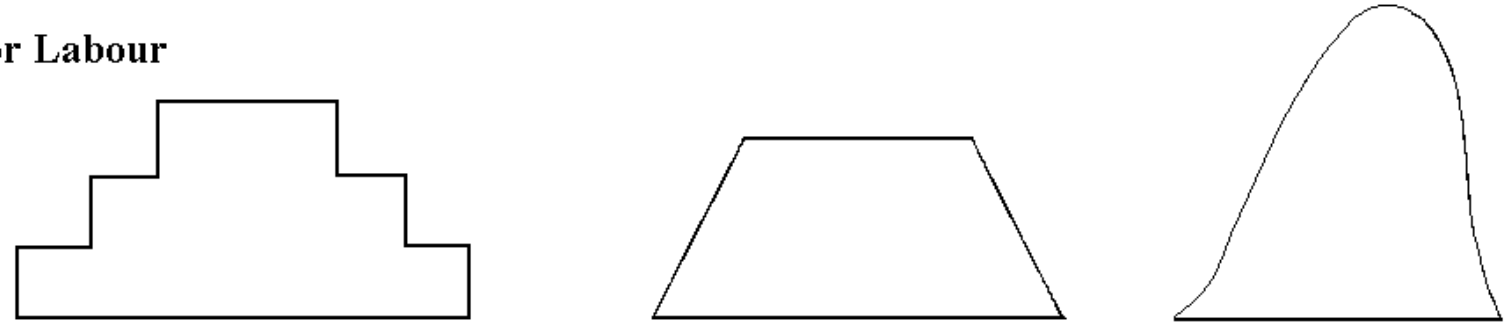
→ generally, the smoother the resource profile, the lower the overall cost.

Unlimited Resource Allocation: Resource Leveling

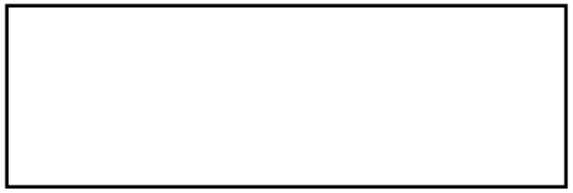
Unlimited Resource Allocation

Better Resource Profile → Leveled Profile

For Labour



For Equipment (e.g. cranes on site)



Unlimited Resource Allocation: Resource Leveling

Example of Unleveled Resource Profile

Construct Roads for Subdivision (No utilities)

1) Subgrade Preparation for Concrete Curbs

	Days	Labour (Number of people/day)
Grading	2	3
Cement Stabilizing	2	7
Trimming	1	3

Unlimited Resource Allocation: Resource Leveling

Example of Unleveled Resource Profile

2) Concrete Curbs

	Days	Labour (Number of people/day)
Stringline	2	4
Extrude Pour	1	10
Backfill	2	3

Unlimited Resource Allocation: Resource Leveling

Example of Unleveled Resource Profile

3) Prepare Road Surface

	Days	Labour (Number of people/day)
Grading	2	3
Cement Stabilising	2	7
Trimming	2	3
Gravel Base	1	5
Asphalt Paving	1	10

Unlimited Resource Allocation: Resource Leveling

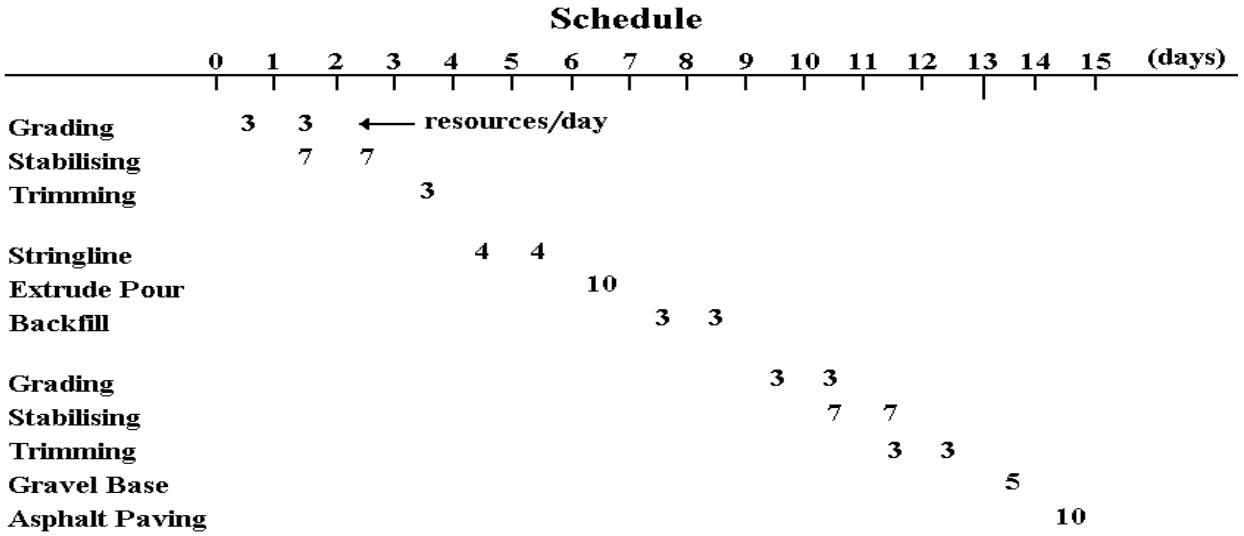
Example: Unleveled Resource Profile

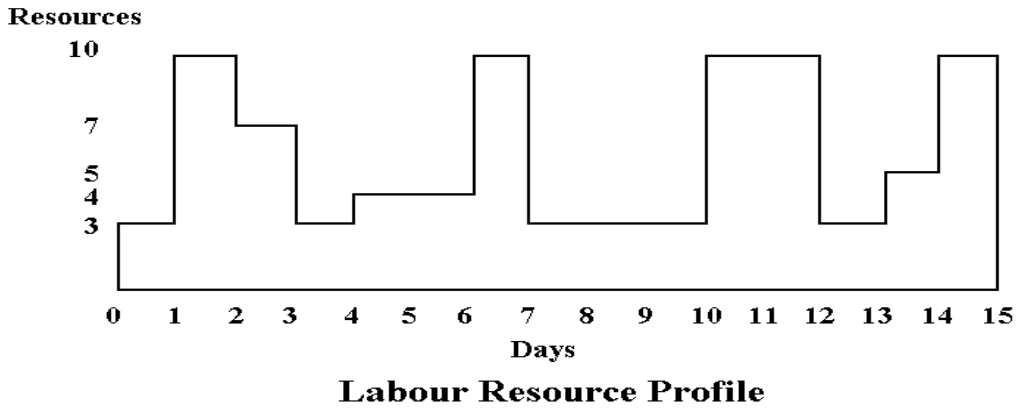
Construct Roads for Subdivision

Activity	Number of Days	Number of Labourers per Day
Subgrade preparation for concrete curbs		
Grading	2	3
Cement Stabilising	2	7
Trimming	1	3
Concrete Curbs		
Stringline	2	4
Extrude Pour	1	10
Backfill	2	3
Prepare Road Surface		
Grading	2	3
Cement Stabilising	2	7
Trimming	2	3
Gravel Base	1	5
Asphalt Paving	1	10

Unlimited Resource Allocation: Resource Leveling

Example of Unleveled Resource Profile





Labour Resource Profile

Resource Leveling

Heuristic Procedures for Resource Leveling

- Based on priority rules and a procedure for allocating resources.
- Difficult to tell what is best combination of rules – differs for different schedules.
- Use trial and error of different rules for same network and compare to get optimal solution.

Resource Leveling

Optimal Procedures

- Procedures based on linear programming and other mathematical techniques.
- Go through all possible solutions.
- Used for constrained resource scheduling for large project networks.
- Too expensive, time consuming, or infeasible for resource leveling.

$\therefore$ Normally use heuristic methods.

Resource Leveling

Heuristic and Optimal Procedures for Resource Leveling

→ optimal too expensive even for small networks, and medium and large problems difficult to solve using optimal procedures.

∴ Normally use heuristic methods.

Heuristic Approach

→ reschedule activities within limits of available float to achieve better distribution of resource usage.

→ schedule all critical activities first and selectively reschedule noncritical activities to obtain leveled profile.

Resource Leveling

A Heuristic Approach: Series Method

– Allocate resources to activities in series – one activity at a time from start to finish (i.e., do not interrupt an activity once it has started).

Heuristic Rules for Resource Leveling

1) Schedule all critical activities first.
2) Start noncritical activities whenever there is a drop in resource profile, so no ups and downs occur in resource profile.
3) Stop noncritical activities whenever there is a rise in profile up to point where peak is reached.

Resource Leveling

Heuristic Rules for Resource Leveling

→ peak determined by critical activities and their resource demands (∴ unlimited resources in terms of critical activities).

→ may exceed peak of critical activities by scheduling noncritical activities to avoid a drop (valley) in resource profile (∴ keep a smooth resource profile).

Resource Leveling using Series Method

(Figure 9.3, Table 9.5)

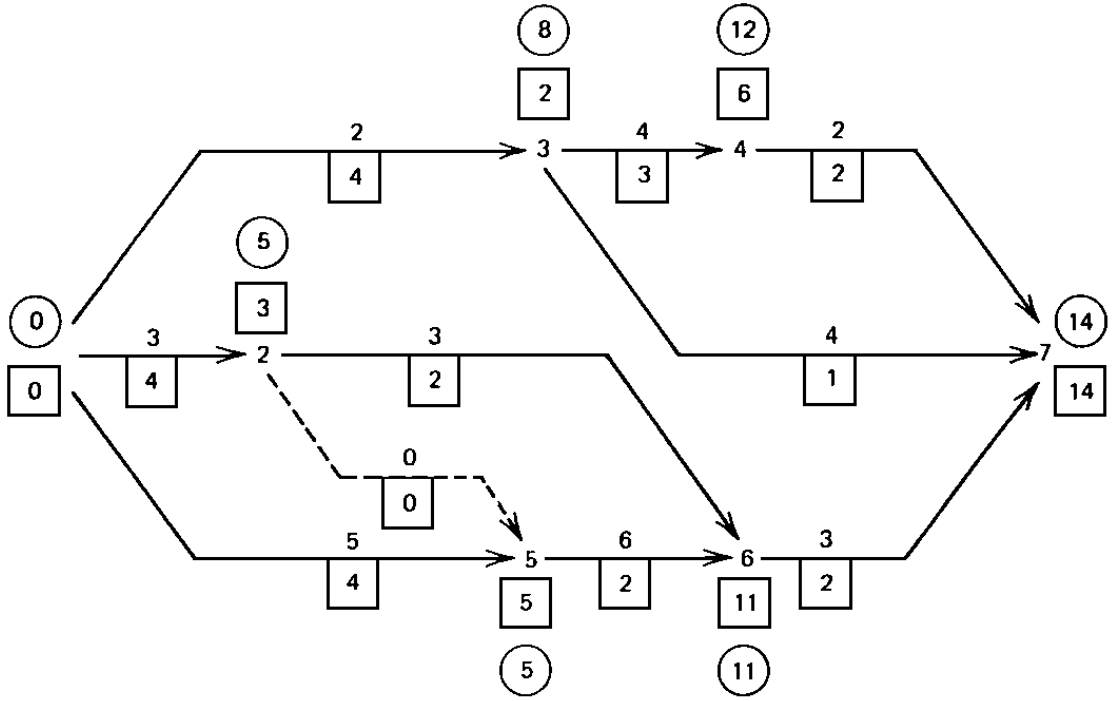


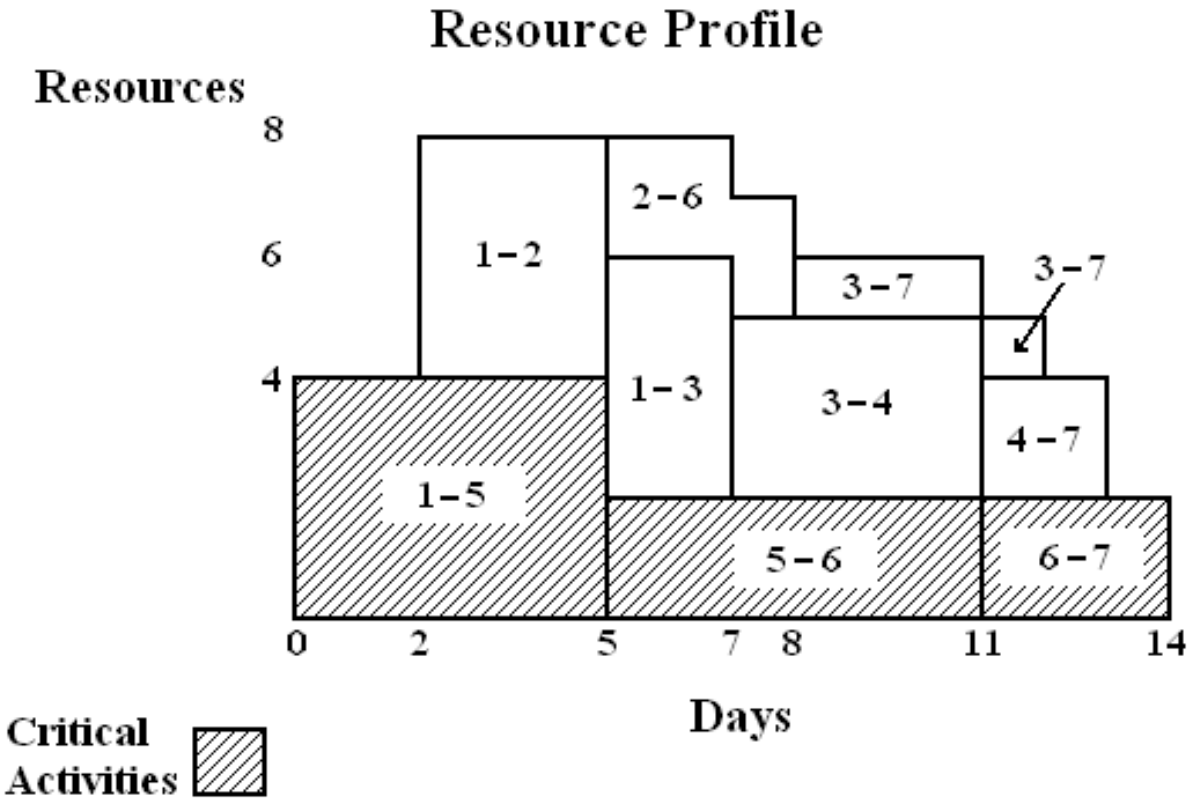
FIGURE 9.3 Example Network No. 2

Resource Leveling – Series Method

TABLE 9.6 Resource Levelling Series Method

ACTIVITY	DURATION	RESOURCES	RESOURCE DAYS	EARLIEST START	TOTAL FLOAT	PROJECT CLOCK DAYS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
1-2	3	4	12	0 2	2 0	4 4 4
1-3	2	4	8	0 5	6 1	4 4
1-5	5	4	20	0	0	4 4 4 4 4
2-5	0	0	0	3 5	2 0	
2-6	3	2	6	3 5	5 3	2 2 2
3-4	4	3	12	2 7	6 1	3 3 3 3
3-7	4	1	4	2 7	8 3	1 1 1 1
4-7	2	2	4	6 11	6 1	2 2
5-6	6	2	12	5	0	2 2 2 2 2 2
6-7	3	2	6	11	0	2 2 2

Resource Leveling – Series Method



Resource Leveling

Notes on Resource Leveling

1) If must choose to assign resources between 2 non-critical activities, assign resources first to most critical activity (i.e., with least TF).
2) Only starting times for non-critical activities are varied to produce a leveled profile.

   → project duration never extended.

3) Leveling can produce alternative solutions.

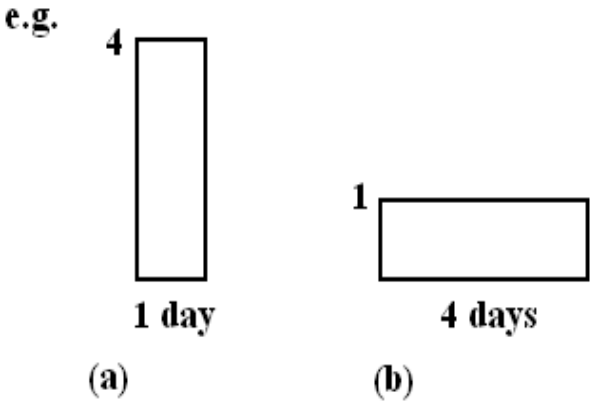
   → acceptable if one peak maintained and buildup and decline are gradual.

Resource Leveling

Notes on Resource Leveling

4) To compare solutions:

- Take sum of squares of resource usage within each time unit.
- Lowest value indicates most leveled solution.



- Both require 4 resource days.

- Shift activities one day at a time and calculate moment (minimum moment = optimum solution).

(a) $4^2 = 16$

(b) $1^2 + 1^2 + 1^2 + 1^2 = 4$ ← more level

Resource Allocation and Leveling

Computer-aided Resource Allocation

- For multi-resource leveling and complex networks.
- Can apply parallel or series method or combination of both.
- Can perform both fixed-resource and fixed-duration scheduling.
- Can select priority rules.
- Start by performing time analysis on network (CPM).
- Combine schedule with resource requirements and limitations to produce daily resource requirement schedule and modified project schedule.
- Important to understand priority rules and heuristic method employed by computer program (e.g., Primavera)

Resource Allocation and Leveling

Resource Leveling by Computer

- Need to establish an initial resource profile against which to create a leveled profile.
- Use leeway (i.e., float) between ES and LS schedules.
- Consider total manhour requirements for project and for each period and activity in project.
- Consider project management constraints (see following slides).
- Specify heuristic priority rules for leveling.

Management Factors to Consider in Establishing Resource Profile

→ Constraints to impose on profile.

1) Budgetary Constraints

– Corporation budgets amount per year for a large multi-year project

- dictates number of manhours per year to be expended on project
- affects annual project schedule.

Management Factors to Consider in Establishing Resource Profile

2) Personnel Constraints
   - Hiring of individuals.
     → applications, interviews, references, physicals, papers processed.
   - May be limited in number of applications that can be processed in on month.
     (on small projects, may just call on union for staffing).
   - Take limits into consideration when establishing initial profile.

Management Factors to Consider in Establishing Resource Profile

3) Craft Availability Constraints
   - Core number of in-house labour.
   - Limits in amounts of certain crafts available in some markets.
   - Other projects in area using similar personnel.

   → schedule manpower so that projects do not peak around same time.

Management Factors to Consider in Establishing Resource Profile

4) Availability of Manpower on Site

→ level of absenteeism on a given day due to illness, vacation, injury, personal business.

- May depend on season.
- e.g., 10% absenteeism rate and need 100 pipefitters ∴ hire 110 pipefitters.

Management Factors to Consider in Establishing Resource Profile

5) Supervisory Constraints
   - Maximum number of craft personnel a supervisor can effectively direct
   - Depends on crew size (i.e., typical crew size for a particular craft).
   - Larger crew mean more people can be supervised since each crew is doing a distinct job.
   - Also maximum amount of paperwork (for each person supervised) that a supervisor can handle at once.

Resource Allocation and Leveling

Management Factors to Consider in Establishing Resource Profile

6) Site Constraints
   - Depends on physical area of project and surrounding conditions (e.g. traffic).

7) Weather Constraints
   - Depending on location, some activities can only be performed at certain times of year.

   e.g., foundation work – not in frozen ground.

- Take all these constraints into consideration in developing initial resource profile, before even performing resource leveling.
- Saves time-consuming revisions in future.

References:

- *Project Management: Techniques in Planning and Controlling Construction Projects*, 2nd Edition, Ahuja, Dozzi, and AbouRizk, John Wiley and Sons, 1994, Chapter 9, pp. 127-162.
- Hegazy, T. (1999). Optimization of resource allocation and levelling using genetic algorithms. *Journal of Construction Engineering and Management*, 125 (3), 167-175.