بسم الله الرحمن الرحيم

ENGINEERING MANAGEMENT

(GE 404)

1

LECTURE #7

Resource Leveling

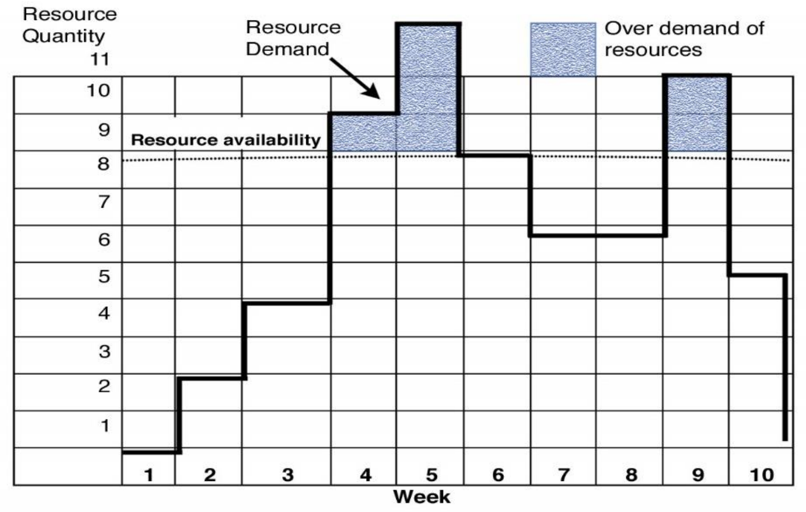
Contents

Objectives of the Present lecture

- *To discuss how to carry out resource leveling using time-scaled diagrams*

Management of Resources—Resource Leveling

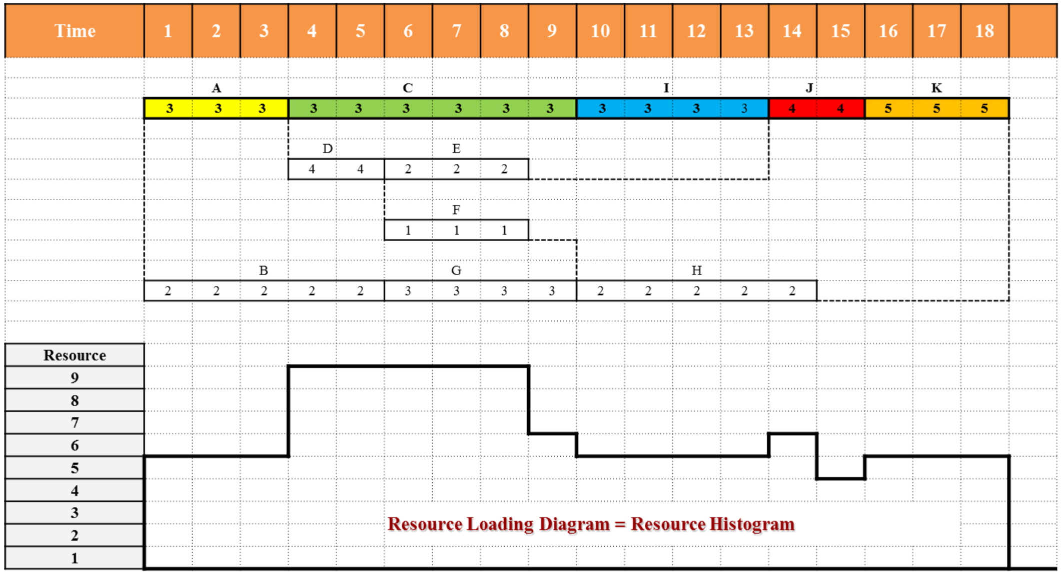
- Resource leveling is a technique to **reduce the amount of variability** (peak and valley) **in the pattern of resource usage** (manpower, equipment, or money) **over the project duration**.
- Resource leveling ensures that **resource demand does not exceed resource availability**.
- Main Aspects:
  - **Sufficient total resources** are **available**
  - Project must be completed by a specified due date, in other words, **project duration is not allowed to increase**



Contd.

Improvements can be made to the level of resource requirements by:

- **Delaying or bringing forward the start of certain activities**
- **Extending the duration of** certain **activities** and so reducing the demand for resources over the duration of the activity or by a combination of both of these adjustments
- Note: Time-scale network or bar chart is generally used for resource leveling. The reason for this is that resource leveling must be considered within a time framework and **Time-scale network or bar charts are drawn to a time scale** while other networks (e.g. AON etc.) are not.



Resource Leveling (Smoothing) Procedures

- Although the **sum of daily resource requirements** over the project duration is **constant**, but the **sum of the squares of the daily requirements decreases** as the peaks and valleys are leveled.
- Burgess method utilizes a simple measure of effectiveness given by the ***Sum of the squares of the resource requirements* for each "day"** (period). This value reaches a minimum for a schedule that is level and equals

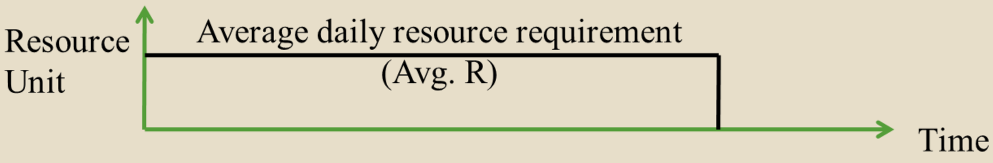
$$Eff = (DR)^2 \times D$$

where;

Eff = Effectiveness

DR = Average daily requirement

D = Project duration



Note: R in the figure is the same as DR in the equation

Burgess Leveling Procedure (Steps 1-4)

1. List the project activities in order of precedence. Add to this listing the duration, early start, and float (slack) values for each activity

2. **Starting with the last activity**, **schedule it period by period** to give the **lowest sum of squares** of resource requirements for each time unit. If more than one schedule gives the same total sum of squares, then **schedule the activity as late as possible to get as much slack as possible in all preceding activities**.

3. Holding the last activity fixed, **repeat Step 2 on the *next to the last activity*** in the network, taking advantage of any slack that may have been made available to it by the rescheduling in Step 2.

4. Continue Step 3 until the first activity in the list has been considered; this completes the first rescheduling cycle.

Burgess Leveling Procedure (Steps 5-8)

5. Carry out additional rescheduling cycles by repeating Steps 2 through 4 until no further reduction in the total sum of squares of resource requirements is possible, noting that **only movement of an activity to the right (schedule later)** is permissible under this scheme.

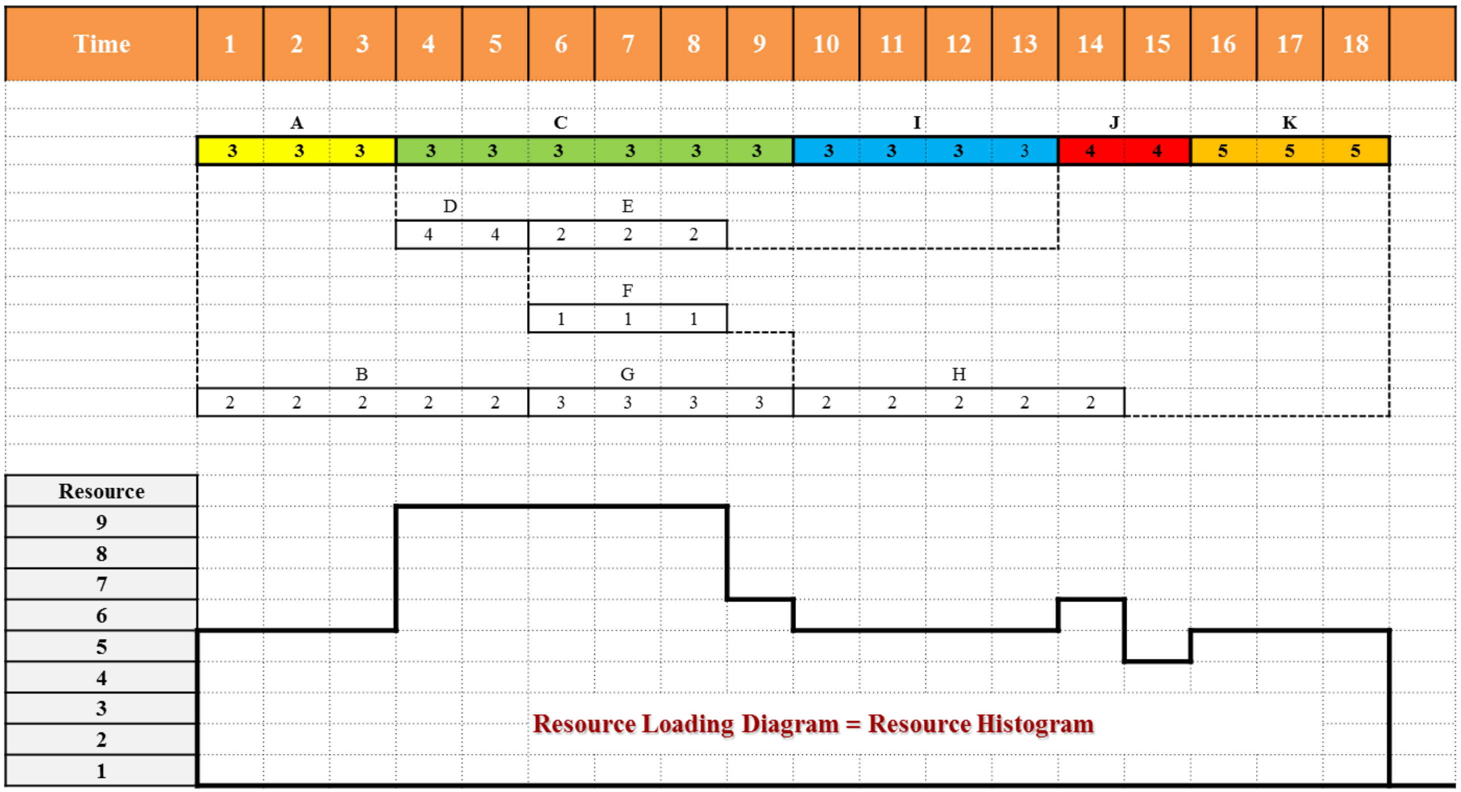
6. If this resource is particularly critical, repeat Steps 1 through 5 on a different ordering of the activities. which, of course, must still list the activities in order of precedence.

7. Choose the best schedule of those obtained in Steps 5 and 6.

8. Make final adjustments to the schedule chosen in Step 7, taking into account factors not considered in the basic scheduling procedure.

Problem-2

Time-scaled network is given below with the resource demands of each activity on each day. Using **Burgess leveling procedure**, level the resources.



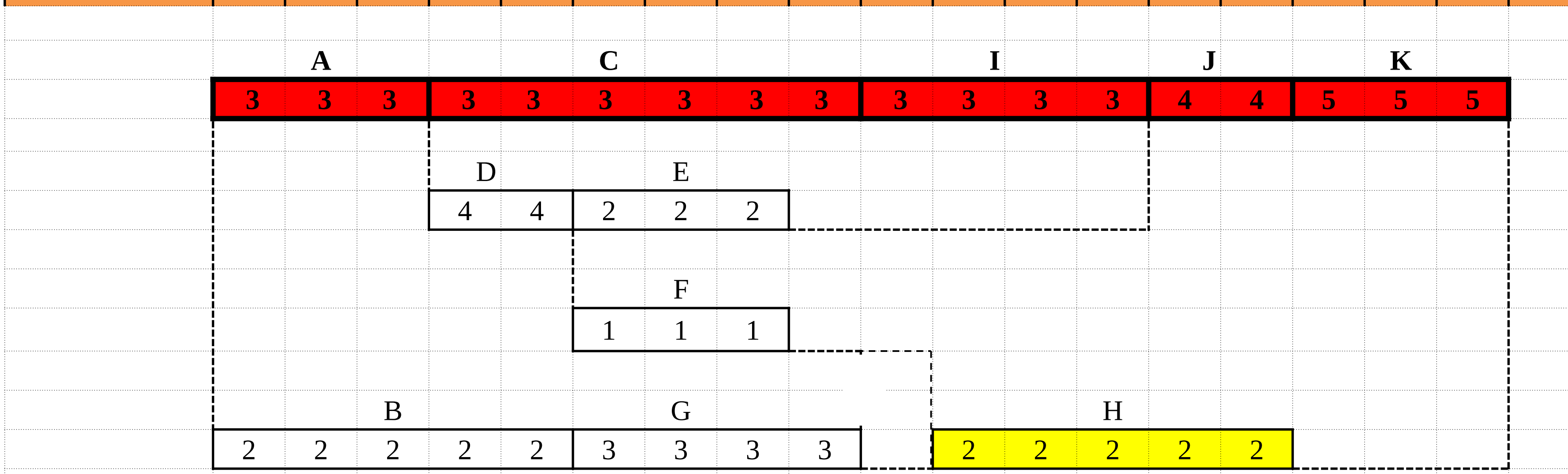
Solution

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	3	3	3															
C				3	3	3	3	3	3									
I										3	3	3	3					
J														4	4			
K																5	5	5
D				4	4													
E						2	2	2										
F						1	1	1										
B	2	2	2	2	2													
G						3	3	3	3									
H										2	2	2	2	2				
R	**5**	**5**	**5**	**9**	**9**	**9**	**9**	**9**	**6**	**5**	**5**	**5**	**5**	**6**	**4**	**5**	**5**	**5**
ΣR	**5**	**10**	**15**	**24**	**33**	**42**	**51**	**60**	**66**	**71**	**76**	**81**	**86**	**92**	**96**	**101**	**106**	**111**

1st Trial with activity H

Start with Delay activity "H" one period

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	

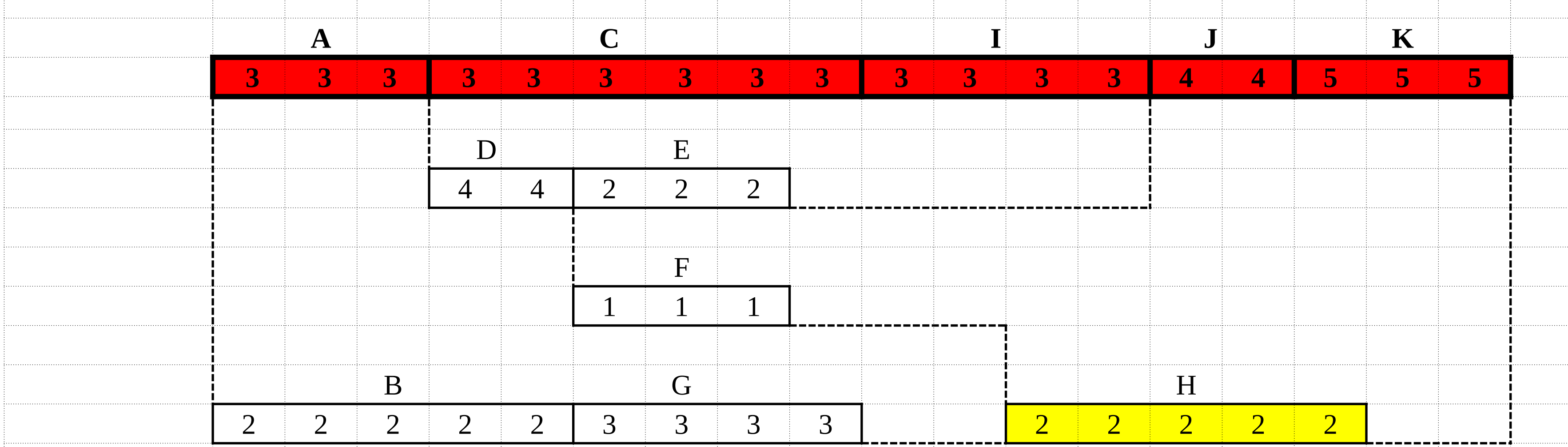


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	5	5	5	9	9	9	9	9	6	3	5	5	5	6	6	5	5	5
R^2	25	25	25	81	81	81	81	81	36	9	25	25	25	36	36	25	25	25

Delay activity "H" one period $\therefore \sum R^2 = 747$

2^{nd} Trial with activity H

Start with Delay activity "H" <u>two</u> periods



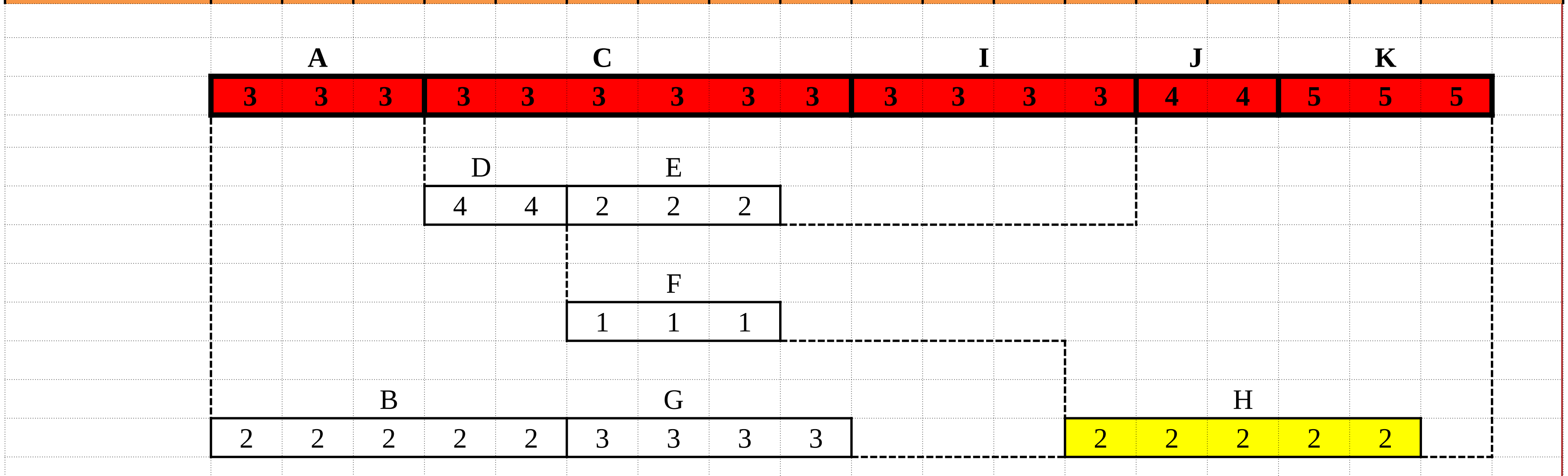
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	5	5	5	9	9	9	9	9	6	3	3	5	5	6	6	7	5	5
R^2	25	25	25	81	81	81	81	81	36	9	9	25	25	36	36	49	25	25

Delay activity "H" <u>2</u> periods $\therefore \sum R^2 = 755$

3rd Trial with activity H

Start with Delay activity “H” <u>three</u> periods

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

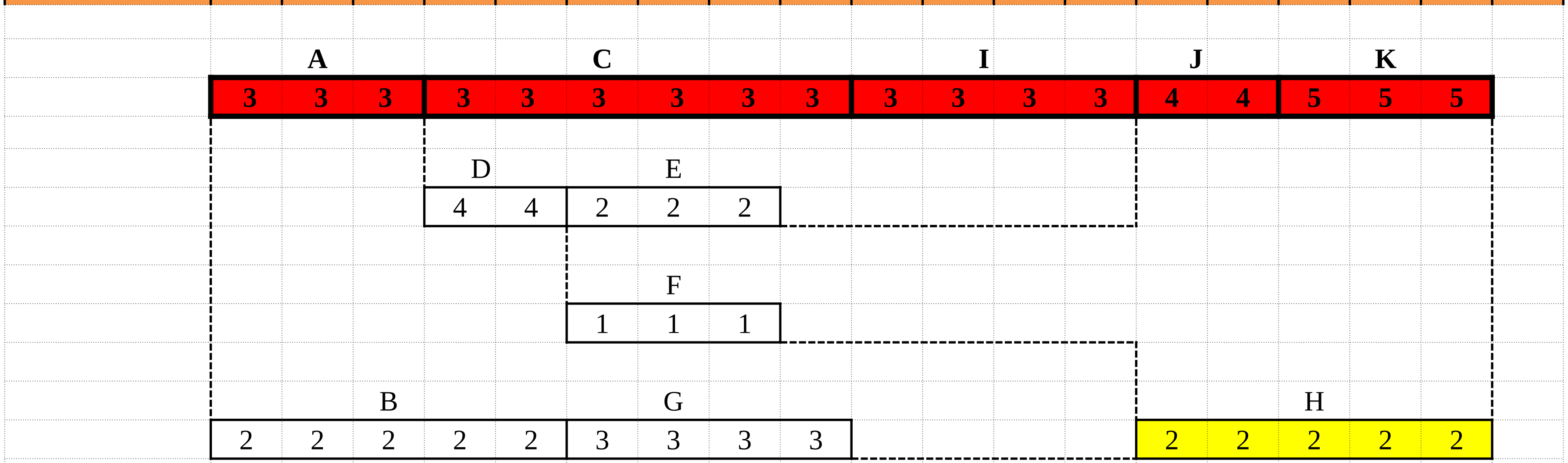


R	5	5	5	9	9	9	9	9	6	3	3	3	5	6	6	7	7	5
R^2	25	25	25	81	81	81	81	81	36	9	9	9	25	36	36	49	49	25

Delay activity “H” <u>3</u> periods $\therefore \sum R^2 = 763$

4th Trial with activity H

Start with Delay activity “H” <u>four</u> periods

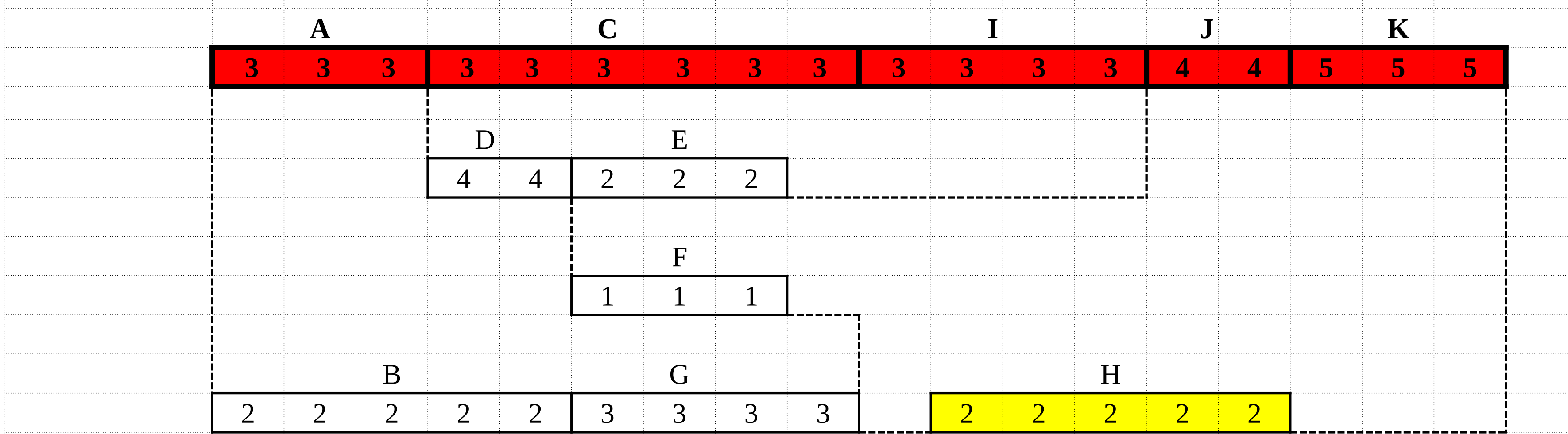


Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	5	5	5	9	9	9	9	9	6	3	3	3	3	6	6	7	7	7
R^2	25	25	25	81	81	81	81	81	36	9	9	9	9	36	36	49	49	49

Delay activity “H” <u>4</u> periods $\therefore \sum R^2 = 771$

Hence, $\therefore$ Lowest $\sum$ **R^2** = 747 with Delay activity “H” <u>**1**</u> period

Conclusion at the end of trials with activity H



Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	5	5	5	9	9	9	9	9	6	3	5	5	5	6	6	5	5	5
R^2	25	25	25	81	81	81	81	81	36	9	25	25	25	36	36	25	25	25

The result = Delay activity "H" one period $\therefore \sum R^2 = 747$

Trial with activity G

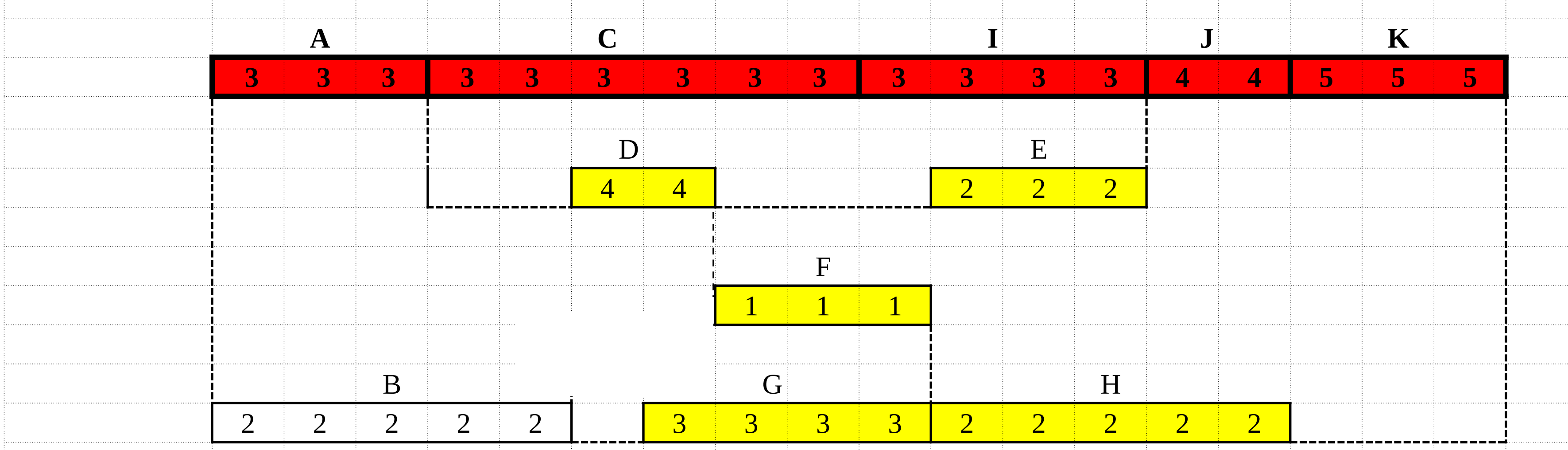
Start Delay activity "G" 1 period

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	3	3	3															
C				3	3	3	3	3	3									
I										3	3	3	3					
J														4	4			
K																5	5	5
D				4	4													
E						2	2	2										
F						1	1	1										
B	2	2	2	2	2													
G							3	3	3	3								
H											2	2	2	2	2			
R	**5**	**5**	**5**	**9**	**9**	**6**	**9**	**9**	**6**	**6**	**5**	**5**	**5**	**6**	**6**	**5**	**5**	**5**
R^2	**25**	**25**	**25**	**81**	**81**	**36**	**81**	**81**	**36**	**36**	**25**	**25**	**25**	**36**	**36**	**25**	**25**	**25**

Delay activity "H" one period & Delay activity "G" one period $\therefore \sum R^2 = 729$

Contd.

Continue Delay activities of non critical



Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	5	5	5	5	5	7	10	7	7	7	7	7	7	6	6	5	5	5
R^2	25	25	25	25	25	49	100	49	49	49	49	49	49	36	36	25	25	25

Delay activity "H" <u>1</u> period, Delay activity "G" <u>1</u> period, Delay activity "F" <u>2</u> periods, Delay activity "E" <u>5</u> periods, and Delay activity "D" <u>2</u> periods $\therefore \sum R^2 = 715$

Summary

<u>Sequence of major moves of the first rescheduling cycle</u>:

Delay activity "H" one period	$\therefore \sum R^2 = 747$
Delay activity "G" one period	$\therefore \sum R^2 = 729$
Delay activity "F" two periods	$\therefore \sum R^2 = 727$
Delay activity "E" five periods	$\therefore \sum R^2 = 723$
Delay activity "D" two periods	$\therefore \sum R^2 = 715$

Thus by delaying activities as given above (simultaneously) leads to the most levelled resources.

Shortcomings of Burgess leveling procedure

- The disadvantage of this approach is that a resource buildup occurs at the end of the project.
- The procedure does not position activities in a way so as to obtain an optimum solution, although this happen by chance.
- To get the optimum solution, alternate schedules have to be obtained using a different order of activities for shifting.
- The **number of** these **alternate schedules will be large** even for small projects rendering the approach an impractical one.

Estimated Method

- Step 1: **Draw** the network in **a time scaled diagram** using the **early start** schedule method

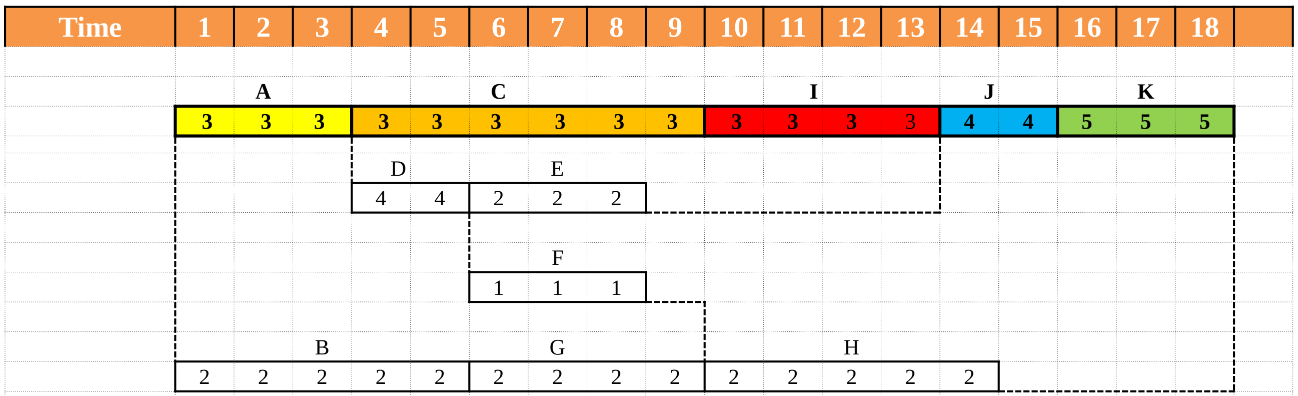
- Step 2: Perform resource loading for the activities and calculate the total number of resources at each period

- Step 3: **Reschedule non-critical activities** to reduce peaks and to smooth resource usage in the resource loading chart in order **to minimize $\sum R_i^2$**, where R_i is the number of resource usage in the resource loading chart

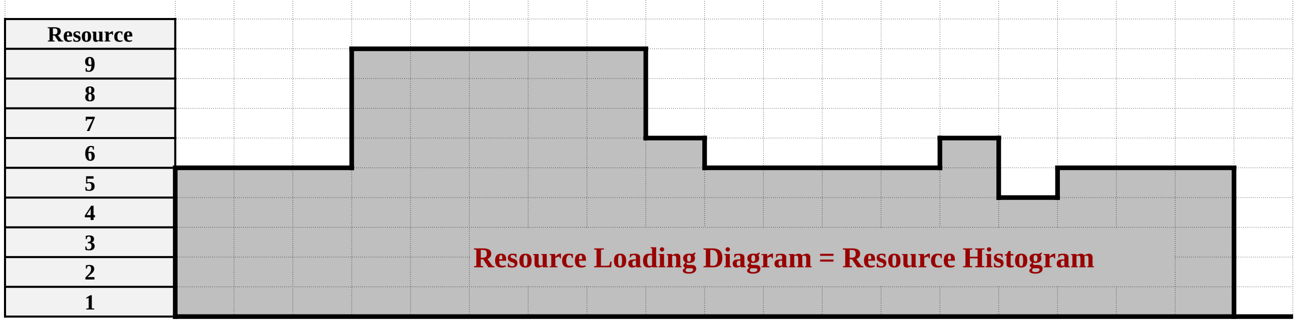
- Step 4: Continue Step 3 until you reach the schedule of having minimum value of $\sum R_i^2$

Problem-3

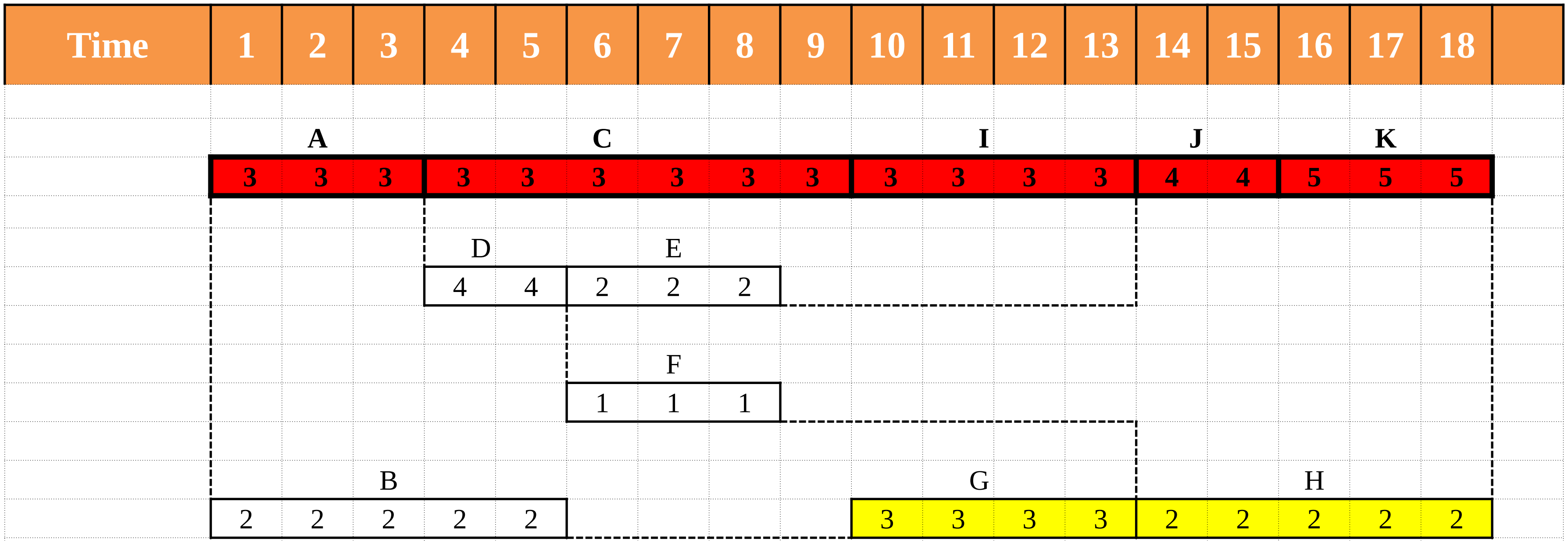
Time-scaled network is given below with the resource demands of each activity on each day. Using Estimated method of leveling procedure, level the resources.



Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	**5**	**5**	**5**	**9**	**9**	**9**	**9**	**9**	**6**	**5**	**5**	**5**	**5**	**6**	**4**	**5**	**5**	**5**
ΣR	**5**	**10**	**15**	**24**	**33**	**42**	**51**	**60**	**66**	**71**	**76**	**81**	**86**	**92**	**96**	**101**	**106**	**111**
R^2	**25**	**25**	**25**	**81**	**81**	**81**	**81**	**81**	**36**	**25**	**25**	**25**	**25**	**36**	**16**	**25**	**25**	**25**
ΣR^2	**25**	**50**	**75**	**156**	**237**	**318**	**399**	**480**	**516**	**541**	**566**	**591**	**616**	**652**	**668**	**693**	**718**	***743***



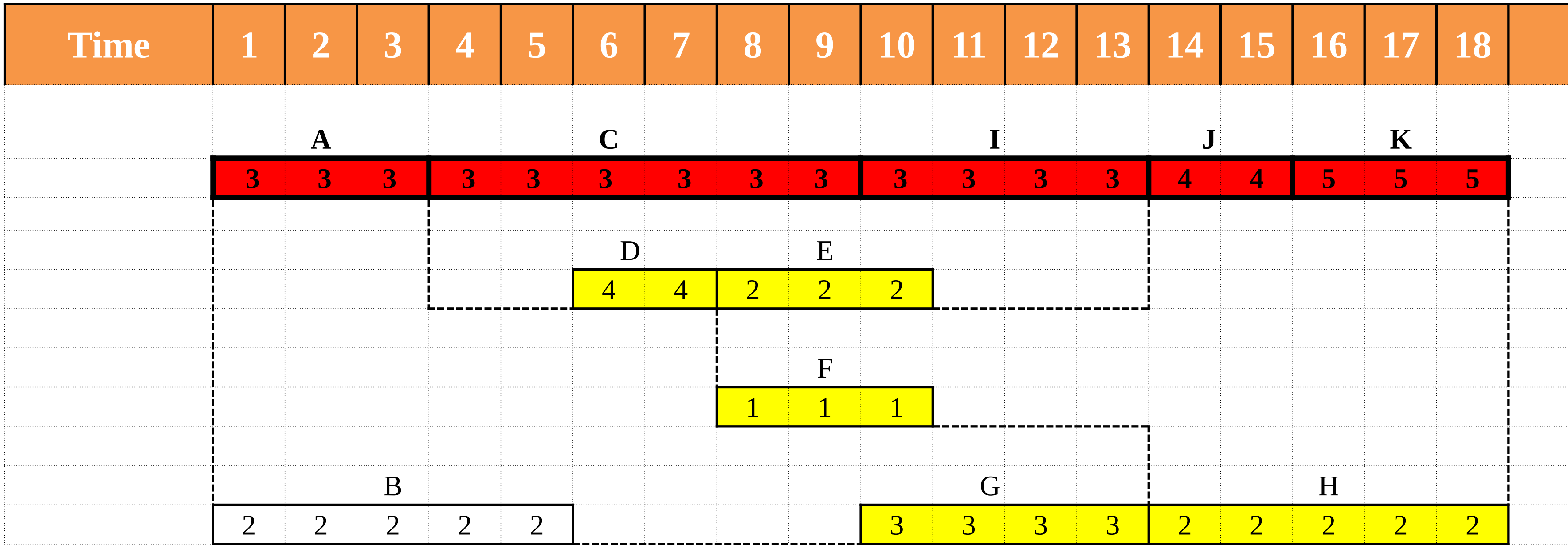
Trial-1



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	5	5	5	9	9	6	6	6	3	6	6	6	6	6	6	7	7	7
R^2	25	25	25	81	81	36	36	36	9	36	36	36	36	36	36	49	49	49

Delay activity "H" 4 periods & Delay activity "G" 4 period $\therefore \sum R^2 = 717$

Trial-2

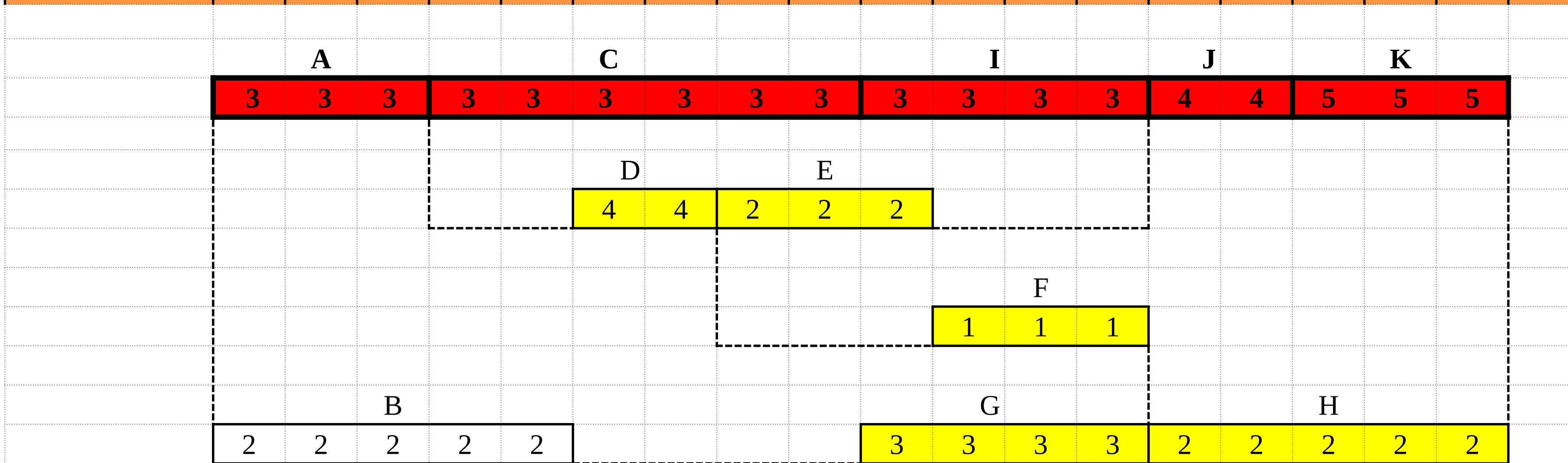


Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	5	5	5	5	5	7	7	6	6	9	6	6	6	6	6	7	7	7
R^2	25	25	25	25	25	49	49	36	36	81	36	36	36	36	36	49	49	49

Delay activity "H" 4 periods, Delay activity "G" 4 periods, Delay activity "E" 2 periods, Delay activity "F" 2 periods, and Delay activity "D" 2 periods

$\therefore \sum R^2 = 703$

Other Trials



Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	5	5	5	5	5	7	7	5	5	8	7	7	7	6	6	7	7	7
ΣR^2	25	50	75	100	125	174	223	248	273	337	386	435	484	520	556	605	654	703

Delay activity "H" 4 periods, Delay activity "G" 4 periods, Delay activity "F" 5 periods, Delay activity "E" 2 periods, and Delay activity "D" 2 periods

$\therefore \sum R^2 = 703$ Thus by delaying activities as given above (simultaneously) leads to the most levelled resources.

Problem-4

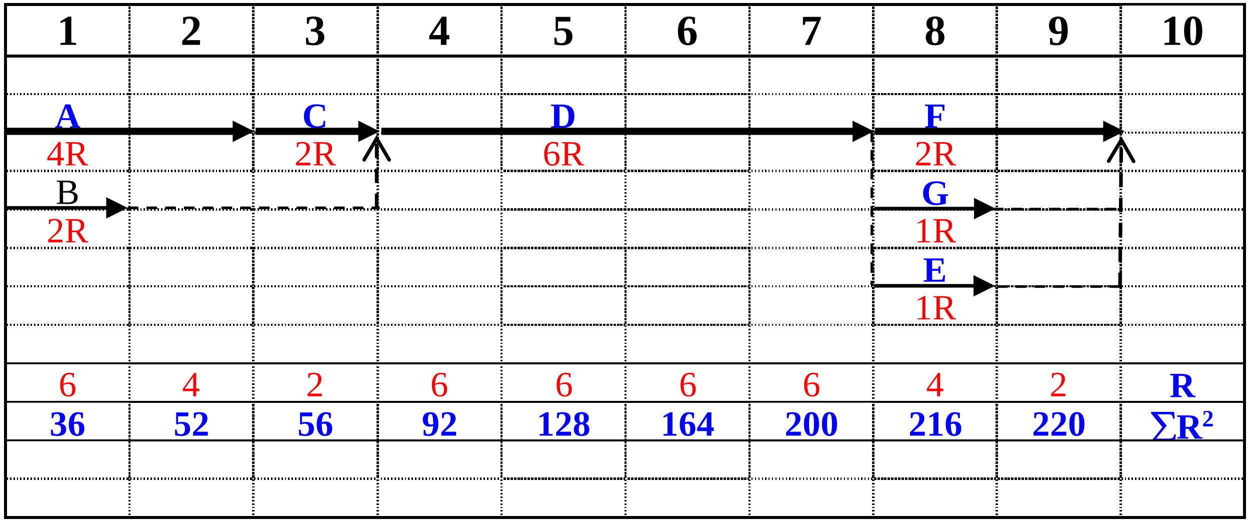
Data for small project is listed below:

Activity	Depends on	Duration	Resource Rate	Activity	Depends on	Duration	Resource Rate
A	—	2	4	F	D	2	2
B	—	1	2	G	D	1	1
C	A	1	2	E	D	1	1
D	B, C	4	6				

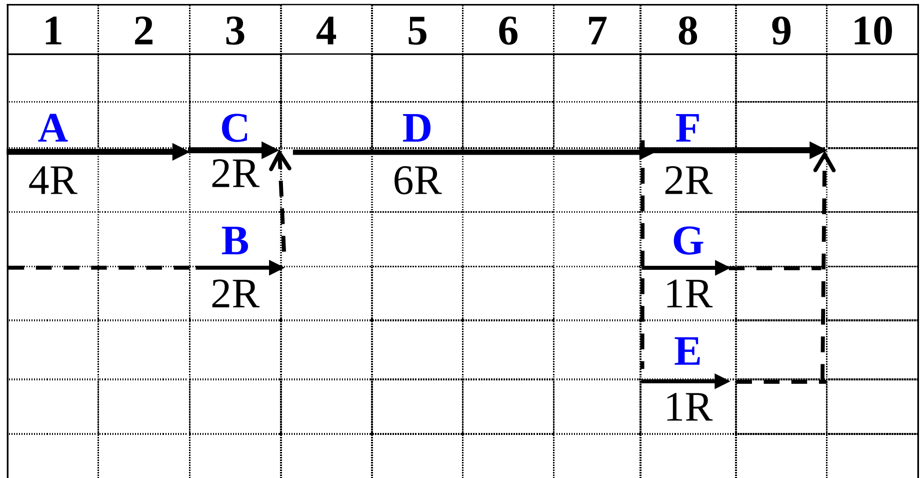
1. Draw Early Start Time-scaled schedule and calculate the corresponding used resource.

2. Perform 2 trials Resource Leveling. Also, specify which one of the two trials Time-scaled schedules is the final schedule and why.

Solution

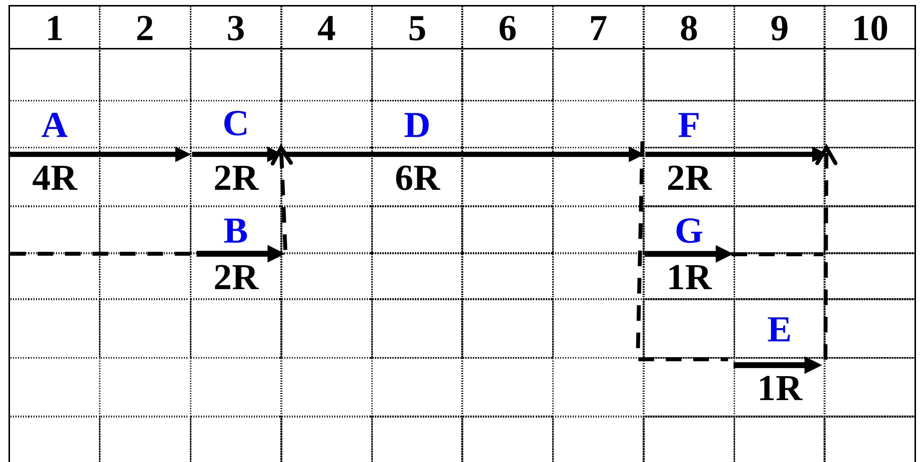

1 2 3 4 5 6 7 8 9 10
A
4R
C
2R
D
6R
F
2R
B
2R
G
1R
E
1R
6 4 2 6 6 6 6 4 2 R
36 52 56 92 128 164 200 216 220 ∑R²

Trial-1



4R	4R	4R	6R	6R	6R	6R	4R	2R	
16	32	48	84	120	156	192	208	212	$\sum R^2$

Trial-2



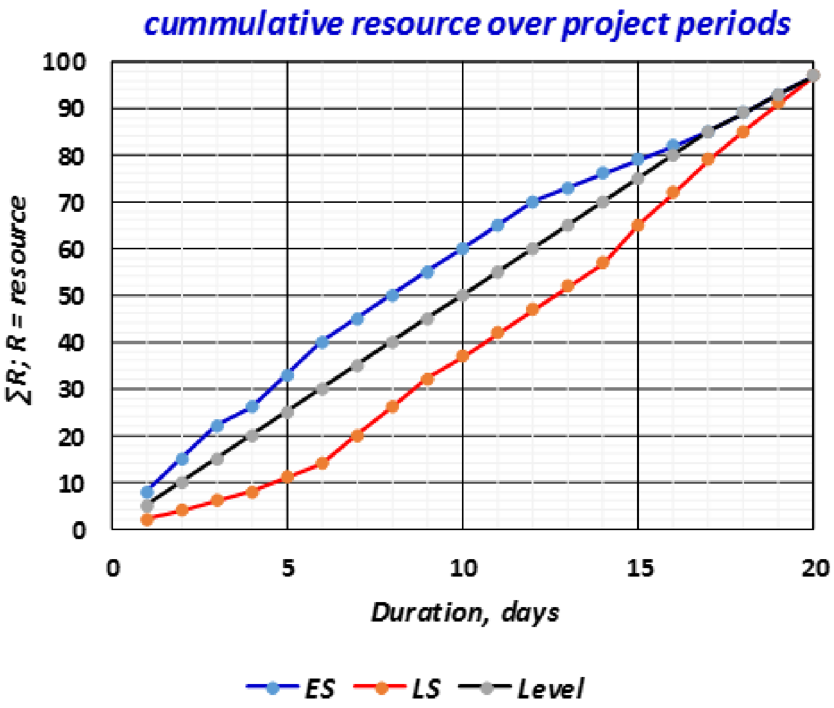
4	4	4	6	6	6	6	3	3	R
16	32	48	84	120	156	192	201	*210*	$\sum R^2$

The 2nd trial schedule is the best Resource Leveling result because it has ***lowest*** $\sum R^2$.

Cumulative Resource Requirement Curve

Cumulative resource requirement curve (*S*-curve) may be used for:

- Planning and Control of progress
- Preliminary resource allocation



Resource leveling and allocation measures

1 – Average daily requirement, $DR_A = \frac{\text{Total unit of resources}}{\text{project duration}} = \frac{T}{D}$

2- Criticality index, $I_C = \frac{DR_A}{A_{\max}}$

3- Effectiveness, $Eff = (DR_A)^2 \times D$

4 - Total units of resources ; $T = \sum_{j=1}^{j=n} R_j$

5 - Sum of squares of rousources; $\text{SUM} = \sum_{j=1}^{j=n} R_j^2$

where,

D = Project duration

$A_{\max}$ = Maximum Avaliable Resourcs

n = Number of periods

Resource per period = R

Significance of Resource Criticality Index

$$I_C = \frac{DR_A}{A_{\max}}$$

- Higher values of resource criticality index are associated with the most critical (i.e., most tightly constrained) resources.
- Values of resource criticality index significantly below 1.0 typically are associated with non-constraining resources.
- Values around and above 1.0 indicate that project delays (beyond the original critical path duration) will be encountered.

Problem-5

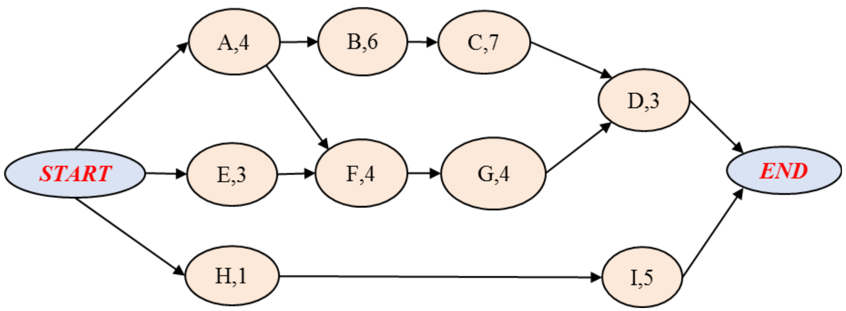
For a small Engineering project listed below:

a) Draw the Early Start and Late start project schedule using Time- scaled network.

b) Within only two trials, level the project Resource.

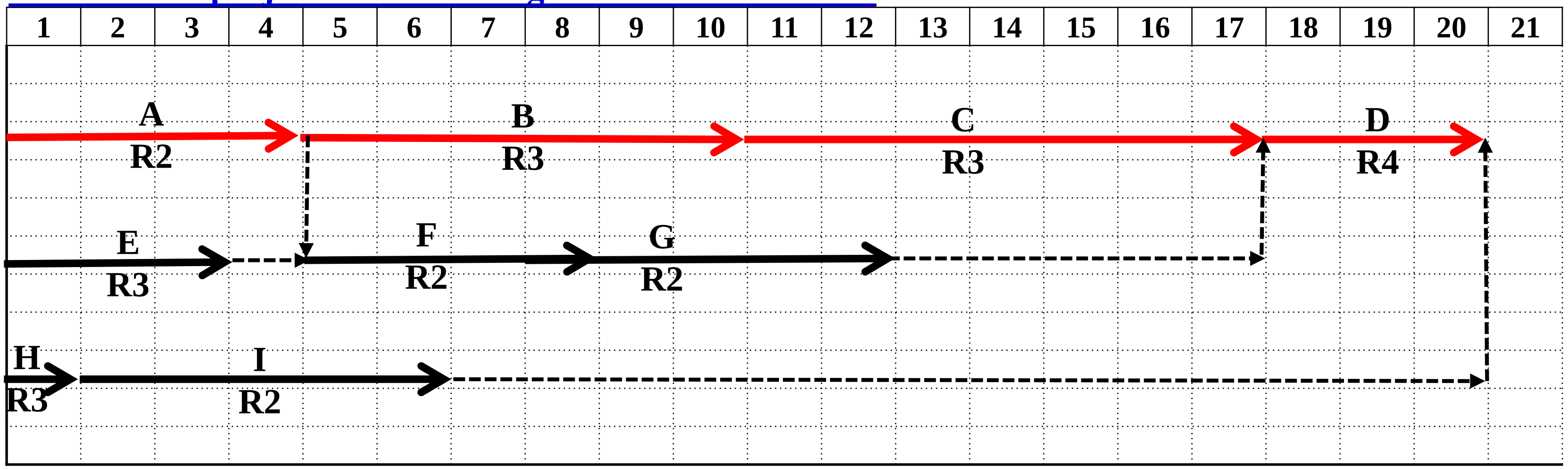
c) How many Worker(s)/day you should use in this project?

Activity	Depends on	Time, day	Resource, Worker/day
A	None	4	2
B	A	6	3
C	B	7	3
D	C, G	3	4
E	None	3	3
F	A, E	4	2
G	F	4	2
H	None	1	3
I	H	5	2



Solution (a)
ES Time Scaled Network

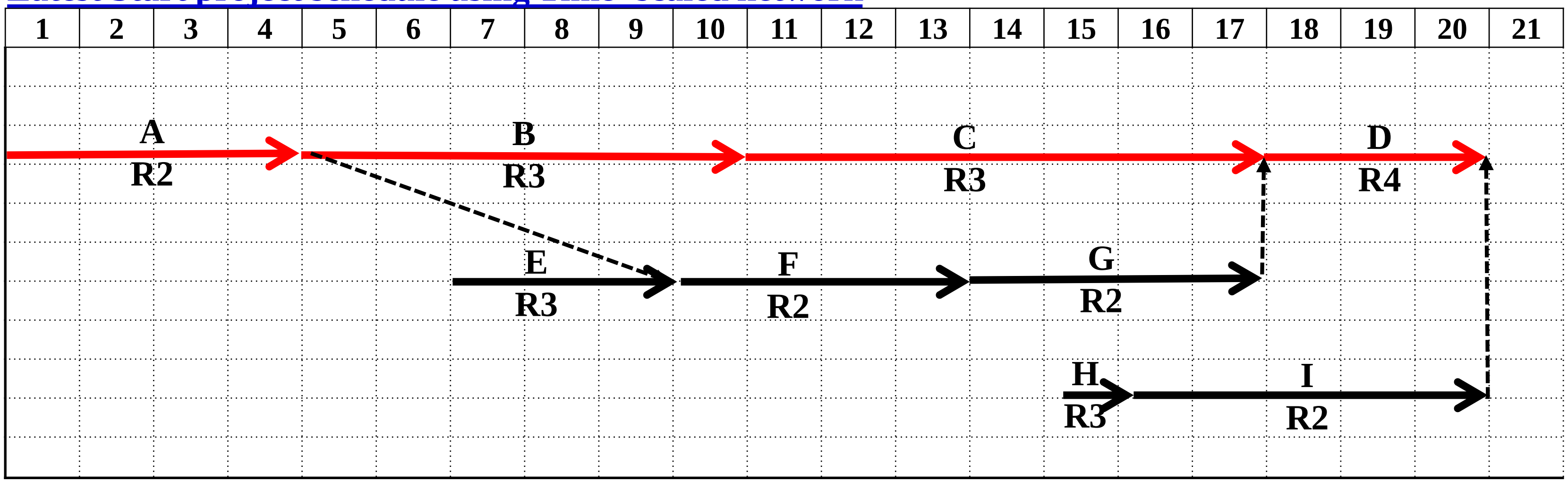
Earliest Start project schedule using Time- scaled network



R	8	7	7	4	7	7	5	5	5	5	5	5	3	3	3	3	3	4	4	4	
∑R	8	15	22	26	33	40	45	50	55	60	65	70	73	76	79	82	85	89	93	*97*	
R^2	64	49	49	16	49	49	25	25	25	25	25	25	9	9	9	9	9	16	16	16	
$\sum R^2$	64	113	162	178	227	276	301	326	351	376	401	426	435	444	453	462	471	487	503	*519*	

Contd.(a)
LS Time Scaled Network

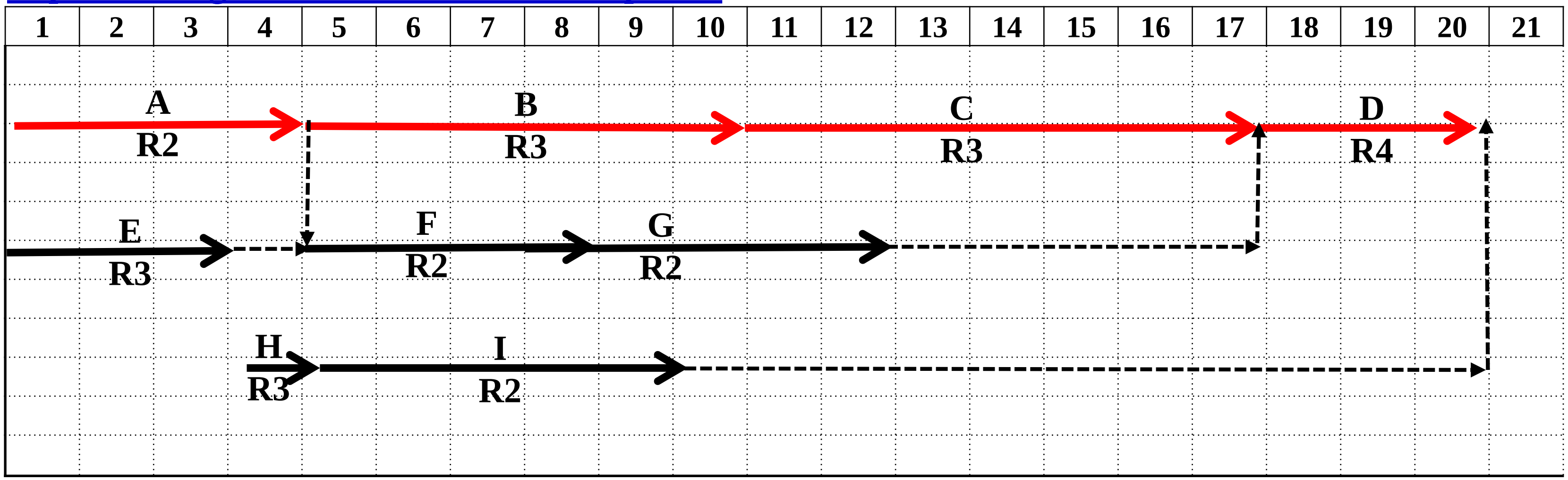
Latest Start project schedule using Time- scaled network



R	2	2	2	2	3	3	6	6	6	5	5	5	5	5	8	7	7	6	6	6	
∑R	2	4	6	8	11	14	20	26	32	37	42	47	52	57	65	72	79	85	91	*97*	
R^2	4	4	4	4	9	9	36	36	36	25	25	25	25	25	64	49	49	36	36	36	
$\sum R^2$	4	8	12	16	25	34	70	106	142	167	192	217	242	267	331	380	429	465	501	*537*	

Solution (b)
1st Trial for resource leveling

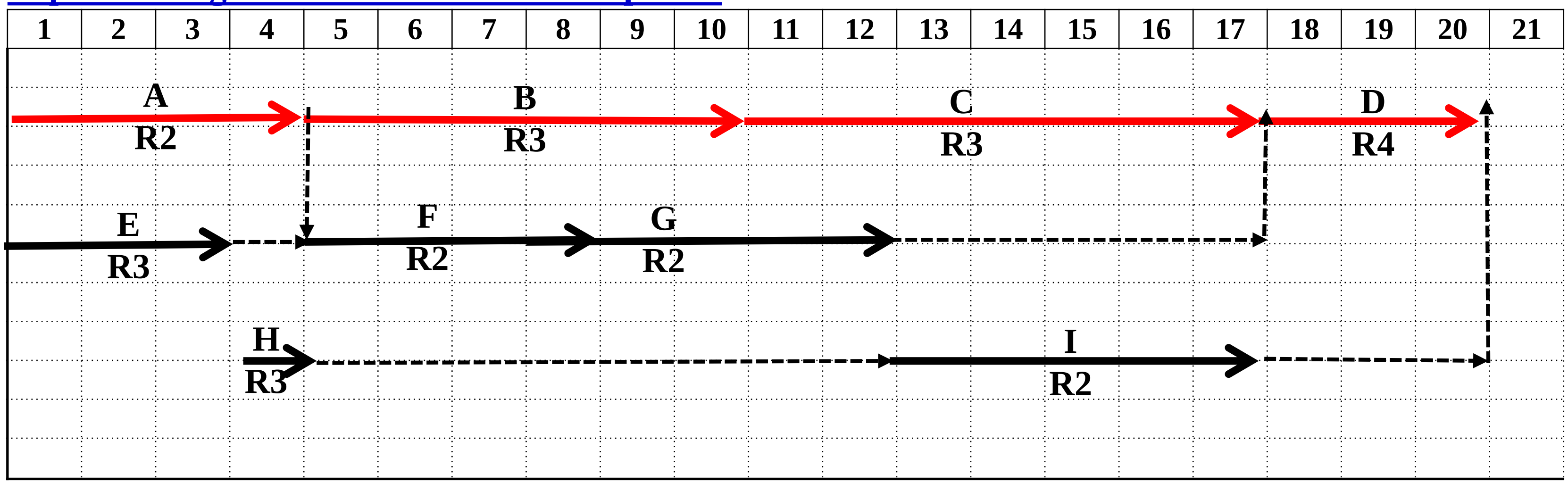
step 1- moving task H to start end of 3rd period



R	5	5	5	5	7	7	7	7	7	5	5	5	3	3	3	3	3	4	4	4	
∑R	5	10	15	20	27	34	41	48	55	60	65	70	73	76	79	82	85	89	93	*97*	
R^2	25	25	25	25	49	49	49	49	49	25	25	25	9	9	9	9	9	16	16	16	
∑R^2	25	50	75	100	149	198	247	296	345	370	395	420	429	438	447	456	465	481	497	*513*	

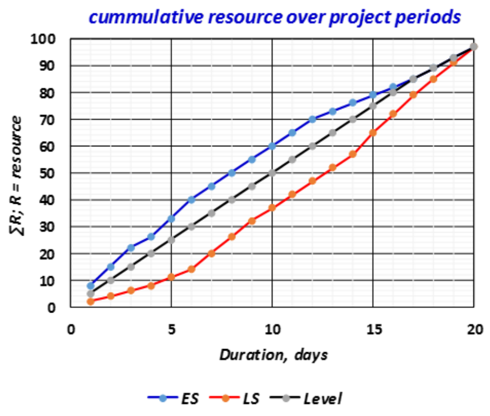
Contd.(b)
2nd Trial for Resource Leveling

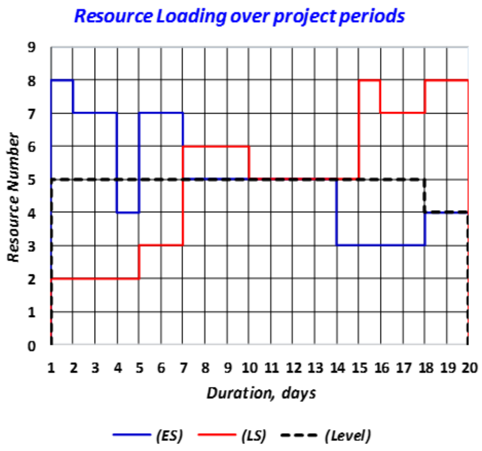
step 2- moving task I to start end of 12th period



R	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	
∑R	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	89	93	*97*	
R^2	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	16	16	16	
$\sum R^2$	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	441	457	*473*	

Leveling Result and Solution of part (c)





The levelling result clearly indicates that 5 worker(s)/day will be enough for this project.

Criticality index, $I_C = \frac{DR_A}{A_{\max}} = \frac{4.85}{5} = 0.97$ OK

The graphs shows the resource is nearly constant over time, and has been leveled.

Resource requirement

Average daily requirement, $DR_A = \frac{T}{D} = \frac{\sum R}{D} = \frac{97}{20} = 4.85$ workers/day

Effectiveness, $Eff = (DR_A)^2 \times D = 4.85^2 \times 20 = 470.45$

Further Reading

Read more about the resource leveling from:

Jimmie W. Hinze. "Construction Planning and Management," Fourth Edition, 2012, Pearson.

Thank You

Questions Please