Allocate and Level Project Resources

< Importance of Resource Management

- The completion of an engineering project at maximum efficiency of time and cost requires the careful scheduling and allocation of available resources.

- Manpower, equipment, materials, subcontractors, and information are important project resources that require close management attention.

- The supply and availability of these resources can seldom be taken for granted because of seasonal shortages, labor disputes, equipment breakdowns, delayed deliveries, and a host of associated uncertainties.

- Money, another project resource that requires close management control during the construction process is discussed fully in separate lectures.

< Objective of Resource Planning

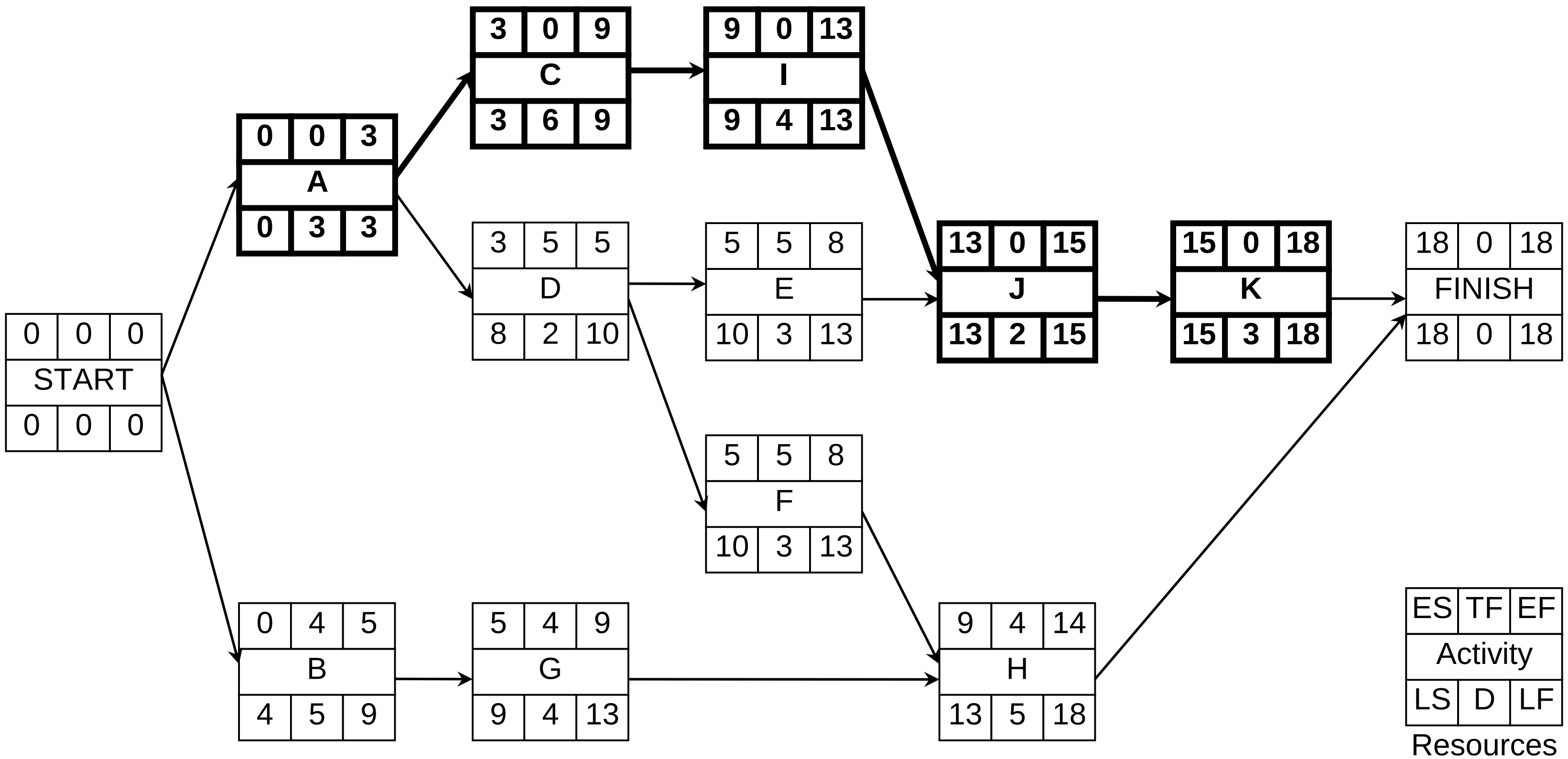
The basic objective of resource management is to supply and support field operations with the resources required so that established time objectives can be met and costs can be kept within the budget.

< Limitation of CPM

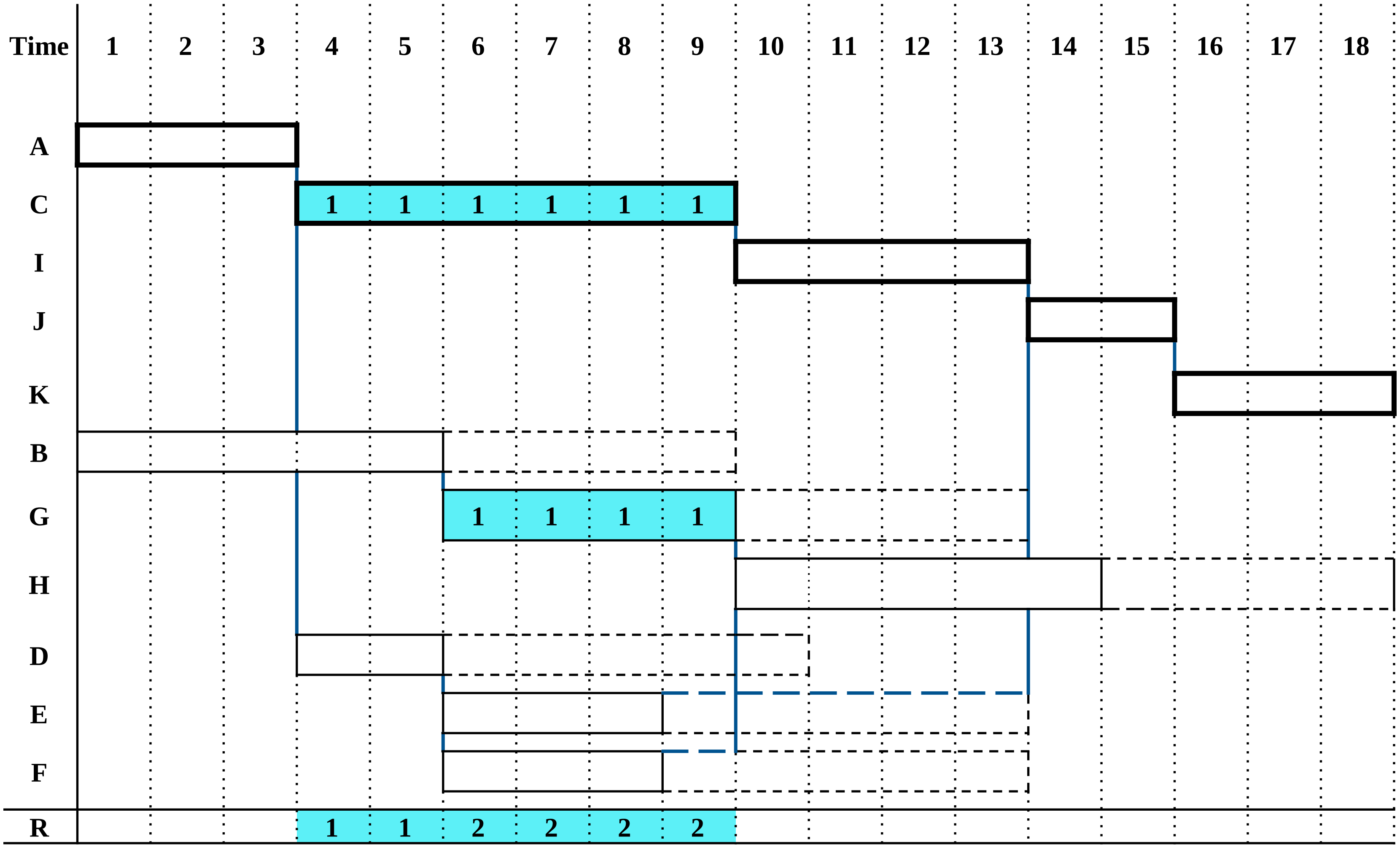
The basic PERT/CPM procedures are limited in the sense that resource availabilities are not considered in the scheduling process. The procedures assume that available resources are **unlimited**.

< How limited resources affect schedule slack

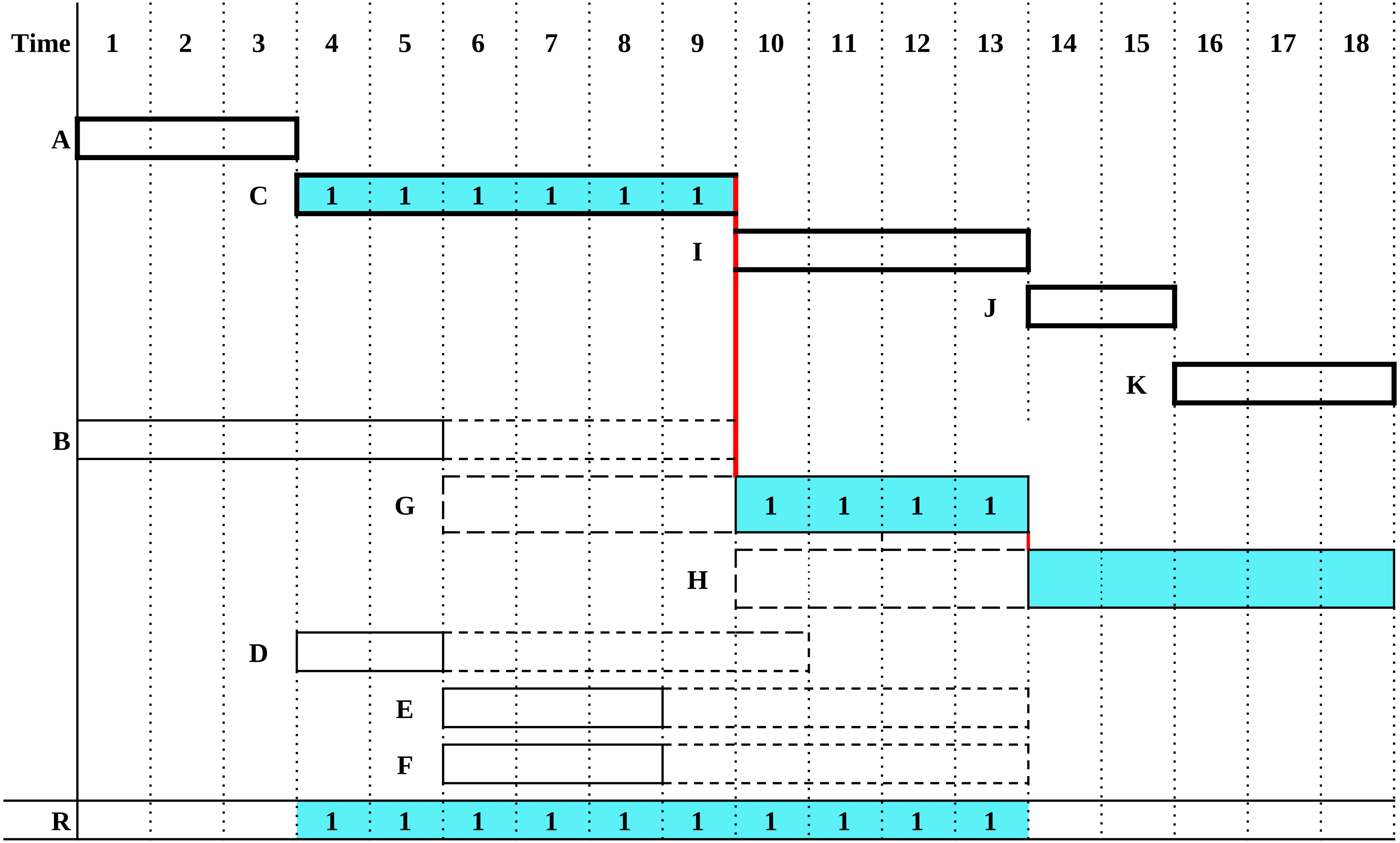
Assume that activities “C” and “G” each require the use of a special piece of equipment, such a hoist crane. But only one crane is available.



< How limited resources affect schedule slack



< How limited resources affect schedule slack



< How limited resources affect schedule slack

The direct result of this resource constraint is that activities “C” and “G” can **not** be performed **simultaneously** as indicated by the *ES* time-only schedule. One or the other of the activities in each pair must be given priority.

In general, the following is true:

- Resource constraints reduce the total amount of schedule slack.
- Slack depends both upon activity relationships and resource limitations.
- The critical path in resource-constrained schedule may not be the same continuous chain (s) of activities as occurring in the unlimited resources schedule.

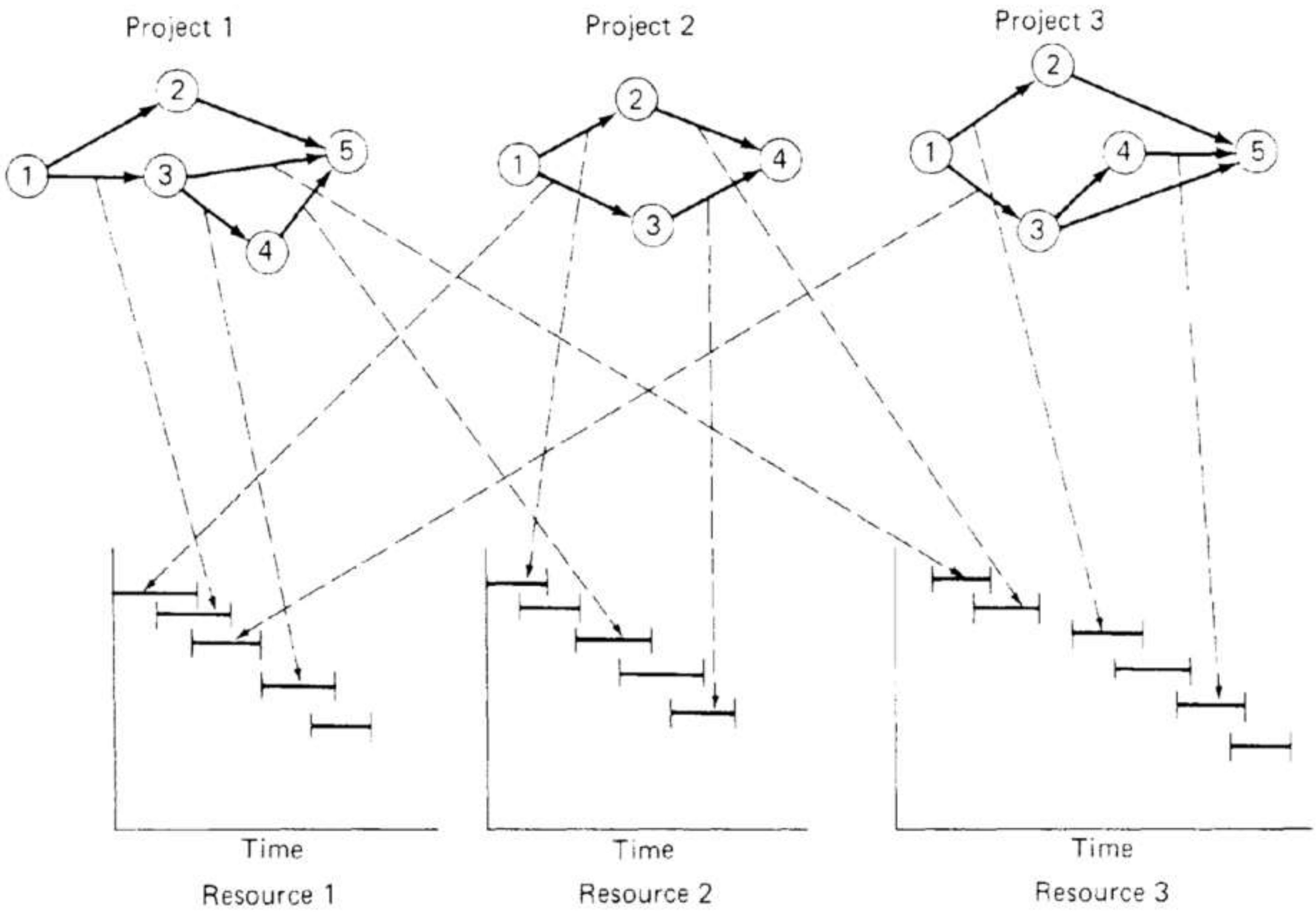


Figure 7-3 Example of multiproject scheduling interactions.

< Project Resource Requirement

Project Resource Requirement = Resource Loading Diagram = Resource Histogram and S curve

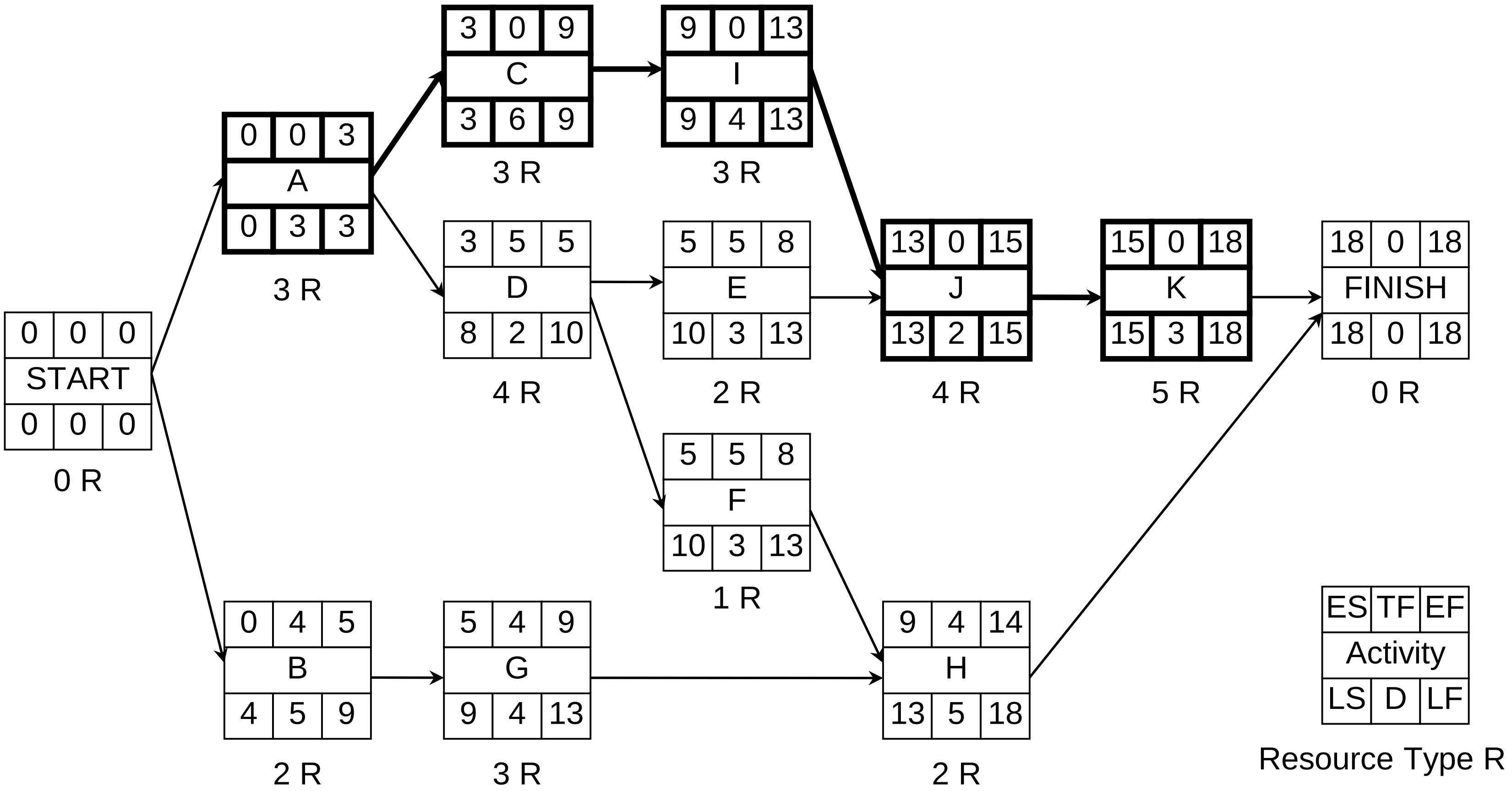
We need:

- Project network.
- Resource requirement for each activity.
- Bar chart or time-scaled network.

We make:

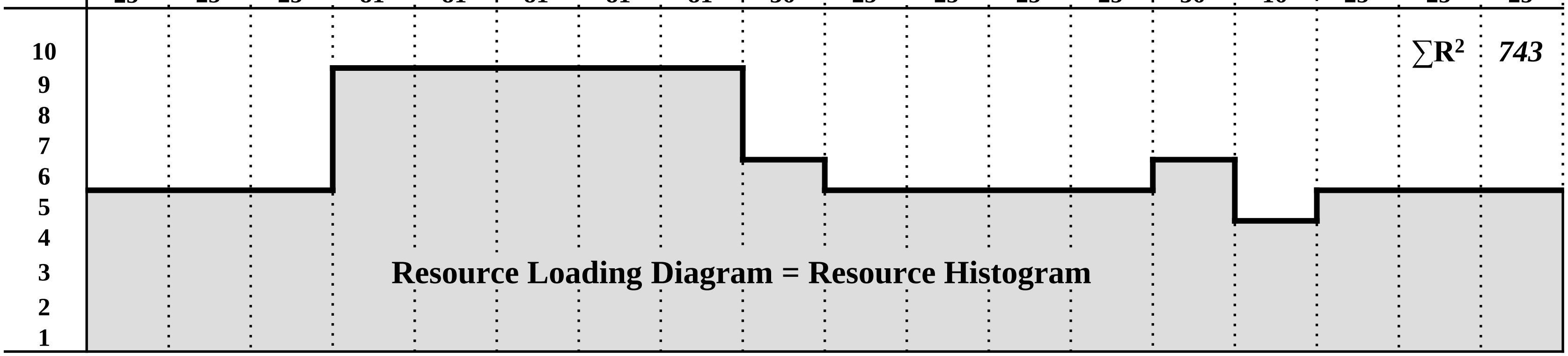
- Resource loading diagram (a diagram that highlights the period-by-period resource implications of a particular project schedule).
- Period-by-period total requirements of units of resources.
- Cumulative resource requirement curve (S curve).

< Resource Loading Diagram

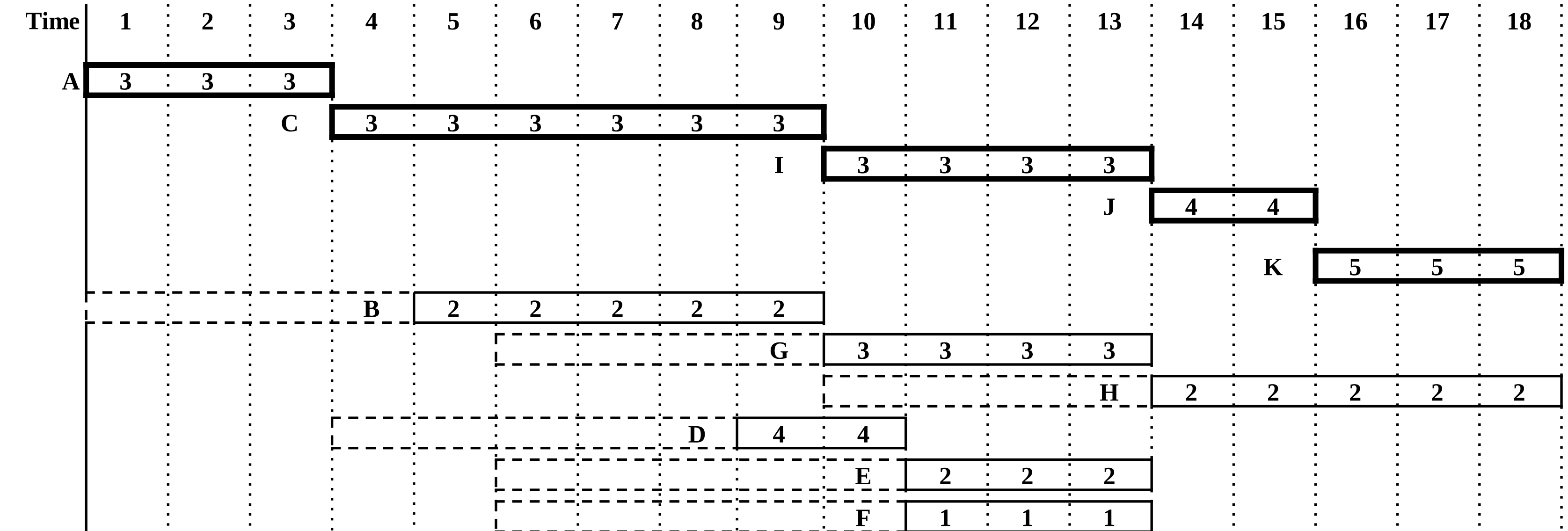


< Resource Loading Diagram based on ES schedule

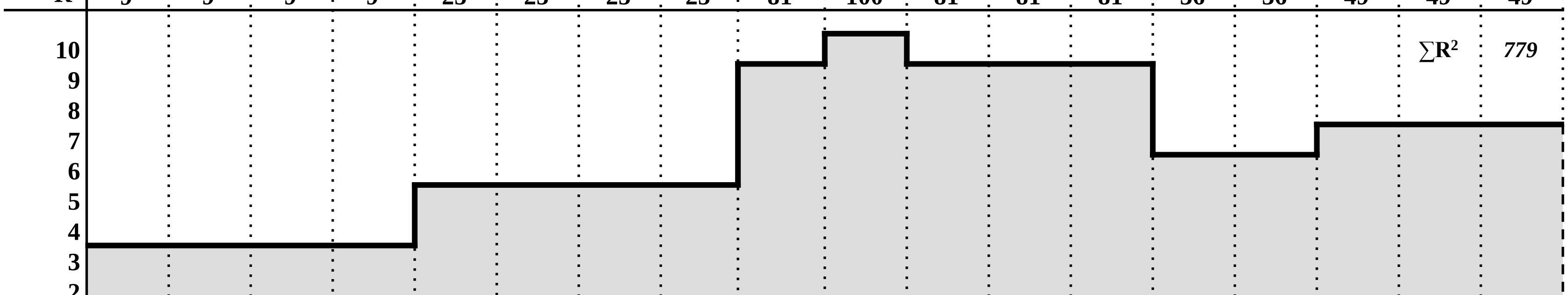
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	3	3	3															
C			C	3	3	3	3	3	3									
I									I	3	3	3	3					
J													J	4	4			
K															K	5	5	5
B	2	2	2	2	2													
G					G	3	3	3	3									
H									H	2	2	2	2	2				
D			D	4	4													
E					E	2	2	2										
F				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



< Resource Loading Diagram based on LS schedule



Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R	3	3	3	3	5	5	5	5	9	10	9	9	9	6	6	7	7	7
∑R	3	6	9	12	17	22	27	32	41	51	60	69	78	84	90	97	104	111
R^2	9	9	9	9	25	25	25	25	81	100	81	81	81	36	36	49	49	49

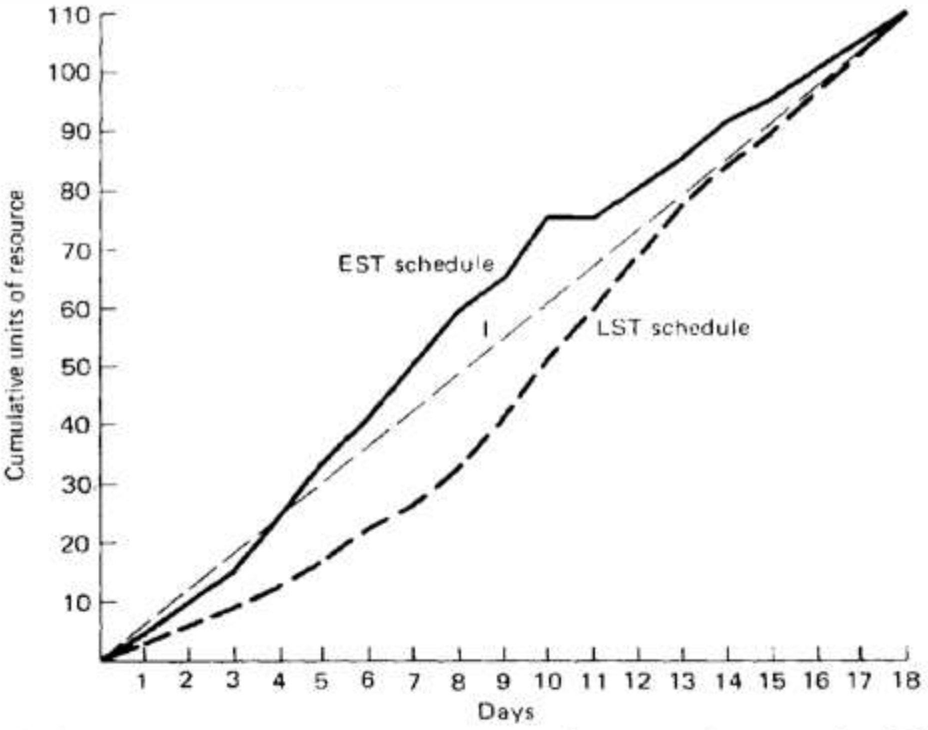


Resource Loading Diagram = Resource Histogram

< Cumulative Resource Requirement Curve

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

- ❑ Planning and Control of progress
- ❑ Preliminary resource allocation



< Resource Constraint "Criticality"

1. Average Daily Requirement

Avg. daily requirement = Total unit of resources / Project duration

Avg. daily requirement = 111 / 18 = 6.2 units/day

Suppose the analyzed resource is available at a maximum level of 7 units/day.

∴ 126 units could be expended over the 18-day project duration, which is more than 111 units. ∴ Project delay is unlikely.

2. Resource Criticality Index

Criticality index= avg. daily units req'd / max. am't avail. Daily

∴ Criticality index = 6.2/7.0 = 0.88 < 1 ∴ project on time

Suppose the analyzed resource is available at a maximum level of 6 units/day.

∴ Criticality index = 6.2/6.0 = 1.03 > 1 ∴ project will delay

In 18 days a total of only 108 units are will be expended (< 111 units), leaving some work unfinished and thus requiring an extension of the project beyond 18 days.

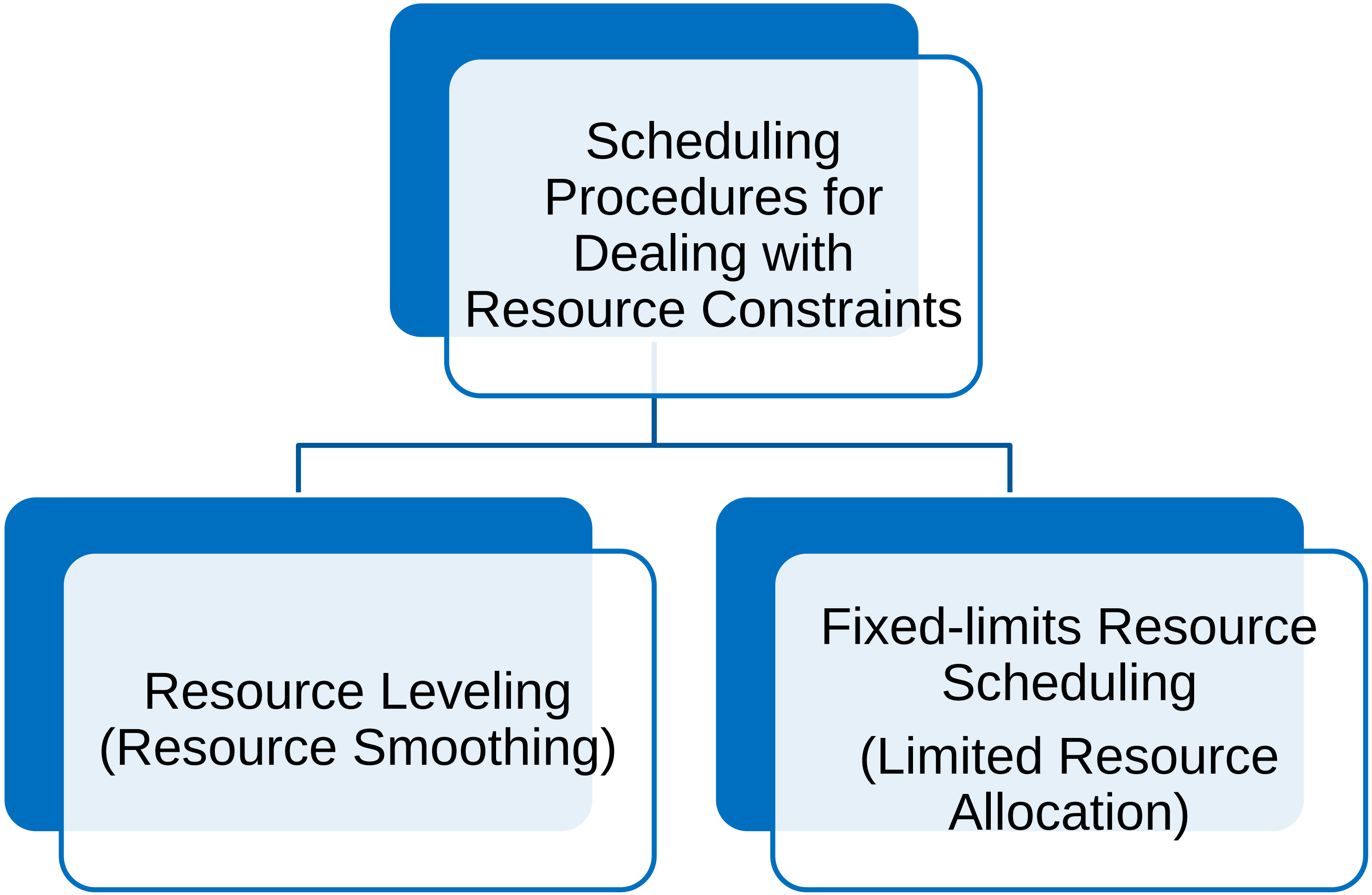
< Resource Constraint “Criticality”

2. Resource Criticality Index

- Values of resource criticality index significantly **below** 1.0 typically are associated with **non-constraining** resources, while values around and above 1.0 indicate that project delays beyond the original critical path duration will be encountered.

- **Higher values** of resource criticality index are associated with the most critical (i.e., most tightly **constrained**) resources.

< Resource Leveling and Allocation



< Resource Leveling (Smoothing)

Main Aspects

- Sufficient total resources are available
- Project must be completed by a specified due date
- It is desirable or necessary to reduce the amount of variability (peak and valley) in the pattern of resource usage over the project duration.
- The objective is to **level**, as much as possible, the demand for each specific resource during the life of the project.
- **Project duration is not allowed to increase** in this case.

< Fixed Resource Limits Scheduling

Main Aspects

- Also often called **constrained-resource scheduling**, or **limited resource allocation**
- Much more common
- There are definite limitations on the amount of resources available to carry out the project (or projects) under consideration.
- Project duration may increase beyond the initial duration determined by the usual “time only” CPM calculations.
- The scheduling objective is equivalent to minimizing the duration of the project (or projects) being scheduled, subject to stated constraints on available resources.

< Basic General Approach

The basic general approach followed in both resource leveling and fixed resource limits scheduling is similar:

- Set activity priorities according to some criterion and then
- Schedule activities in the order determined, as soon as their predecessors are completed and adequate resources are available

< Resource Leveling (Smoothing)

- Resource leveling techniques provide a means of distributing resource usage over time **to minimize the period-by-period variations** in manpower, equipment, or money expended.
- The essential idea of resource leveling centers about the **rescheduling of activities within the limits of available float** to achieve better distribution of resource usage.
- A systematic procedure for leveling resources was developed by **Burgess**.
- Burgess method utilized a **simple measure of effectiveness** given by the **sum of the squares of the resource requirements for each "day"** (period) in the project schedule.

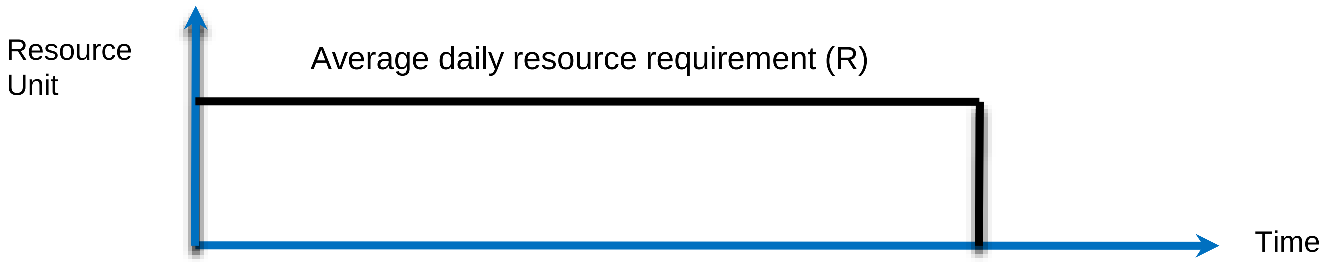
< Resource Leveling (Smoothing)

- While the **sum of daily resource requirements** over the project duration is **constant** for all complete schedule, the **sum of the squares of the daily requirements decreases as the peaks and valleys are leveled.**

- The measure of effectiveness reaches a minimum for a schedule that is level and equals

$$= \textbf{(Average daily requirement)}^2 * \textbf{Project duration}$$

$$= R^2 * \textbf{Project duration}$$



< Burgess Leveling Procedure

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

Step 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.

Step 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.

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

< Burgess Leveling Procedure

Step 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.

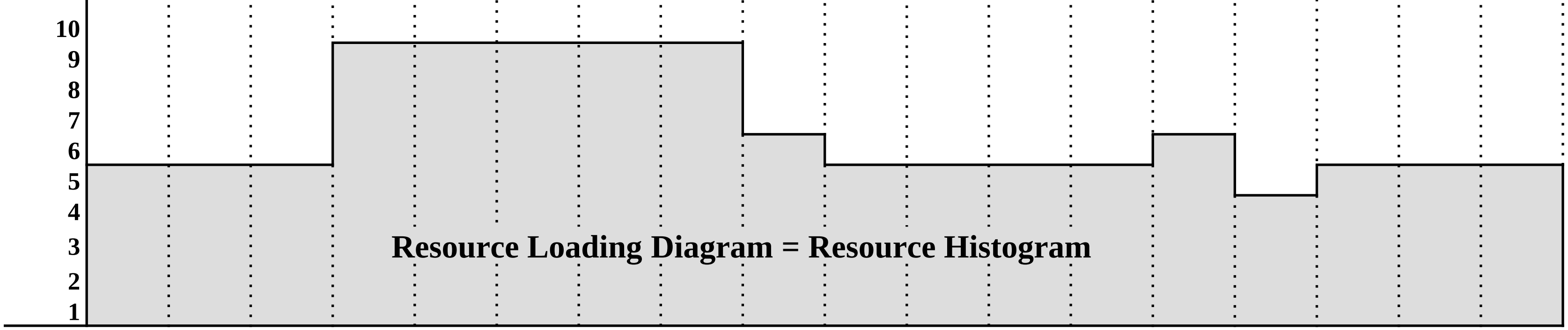
Step 6. If this resource is particularly critical, repeat Steps 1 through 5 on a different ordering of the activities. which, of course, must still list the activities in order of precedence.

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

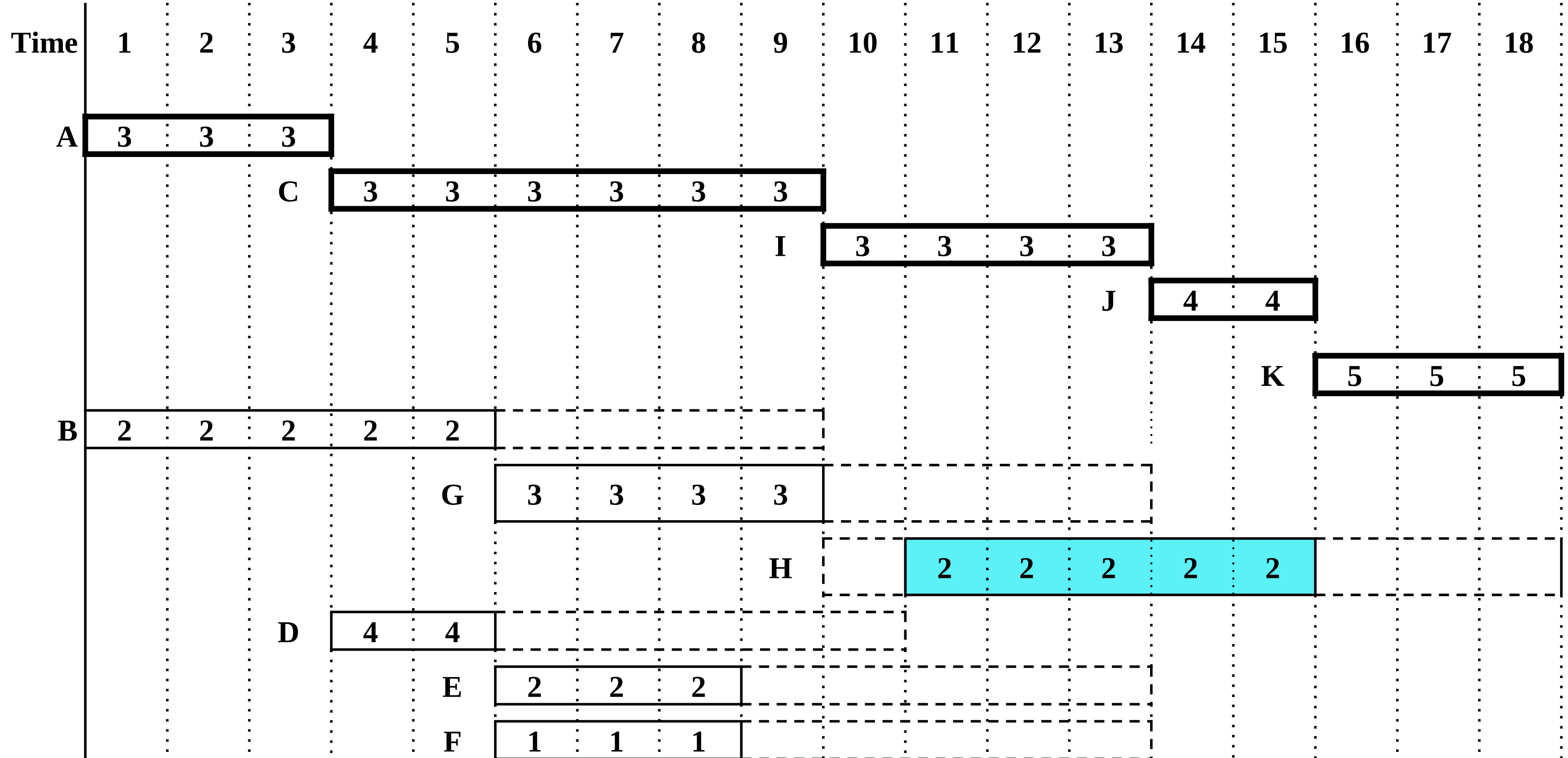
Step 8. Make final adjustments to the schedule chosen in Step 7, taking into account factors not considered in the basic scheduling procedure.

< Application of Burgess Procedure

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	3	3	3															
C			C	3	3	3	3	3	3									
I									I	3	3	3	3					
J													J	4	4			
K															K	5	5	5
B	2	2	2	2	2													
G					G	3	3	3	3									
H									H	2	2	2	2	2				
D			D	4	4													
E					E	2	2	2										
F					F	1	1	1										
Daily R	5	5	5	9	9	9	9	9	6	5	5	5	5	6	4	5	5	5
∑R	5	10	15	24	33	42	51	60	66	71	76	81	86	92	96	101	106	111
$\sum R^2$	25	50	75	156	237	318	399	480	516	541	566	591	616	652	668	693	718	*743*



< Application of Burgess Procedure



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

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

< Application of Burgess Procedure

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
B	2	2	2	2	2													
G						3	3	3	3									
H												2	2	2	2	2		
D				4	4													
E						2	2	2										
F						1	1	1										
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" **2** periods ∴ $\sum R^2 = 755$

< Application of Burgess Procedure

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
B	2	2	2	2	2													
G						3	3	3	3									
H													2	2	2	2	2	
D				4	4													
E						2	2	2										
F						1	1	1										
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" **3** periods ∴ $\sum R^2 = 763$

< Application of Burgess Procedure

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
B	2	2	2	2	2													
G						3	3	3	3									
H														2	2	2	2	2
D				4	4													
E						2	2	2										
F						1	1	1										
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

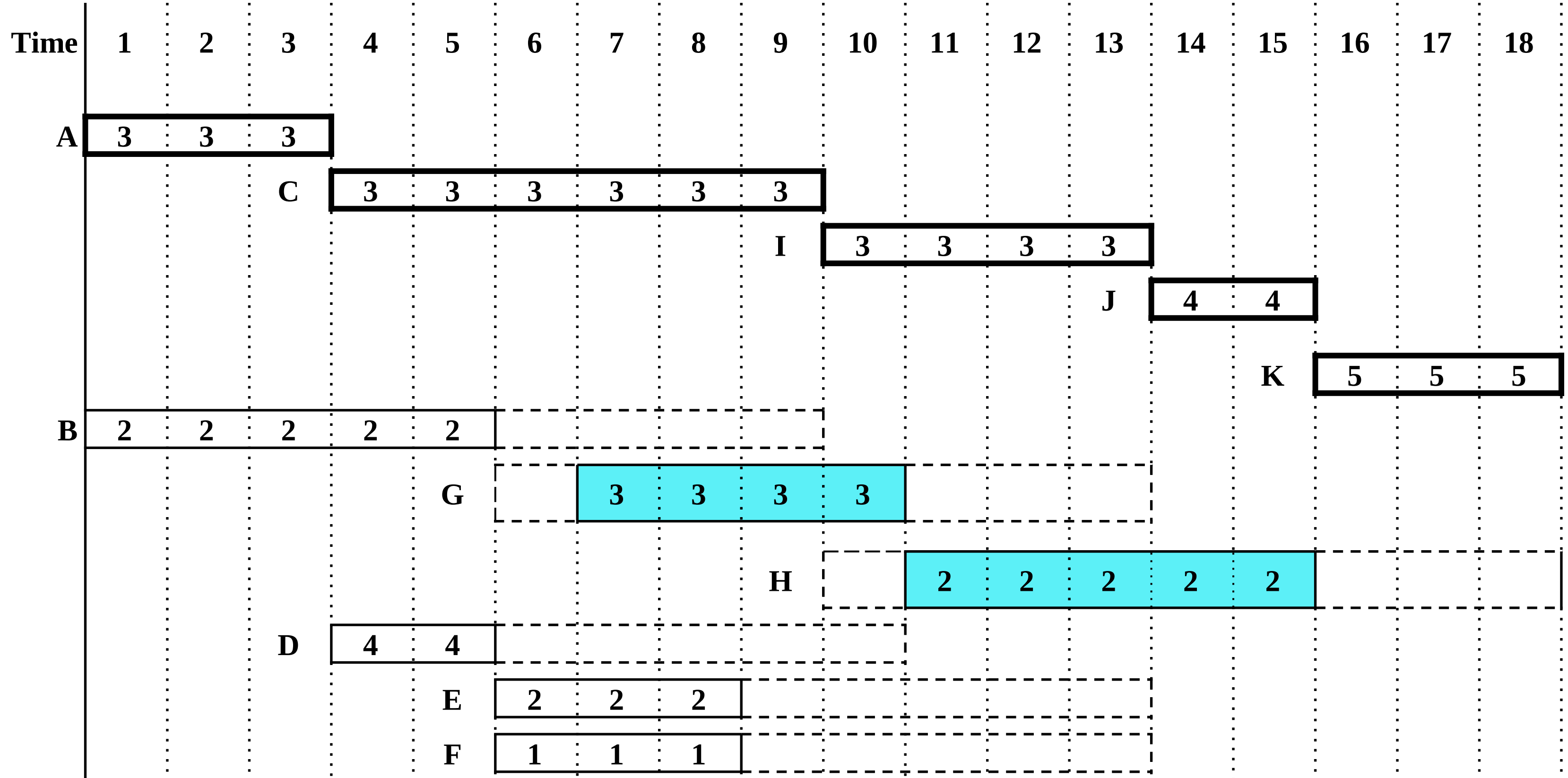
Delay activity "H" **4** periods ∴ $\sum R^2 = 771$

< Application of Burgess Procedure

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
B	2	2	2	2	2													
G						3	3	3	3									
H											2	2	2	2	2			
D				4	4													
E						2	2	2										
F						1	1	1										
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 ∴ $\sum R^2 = 747$

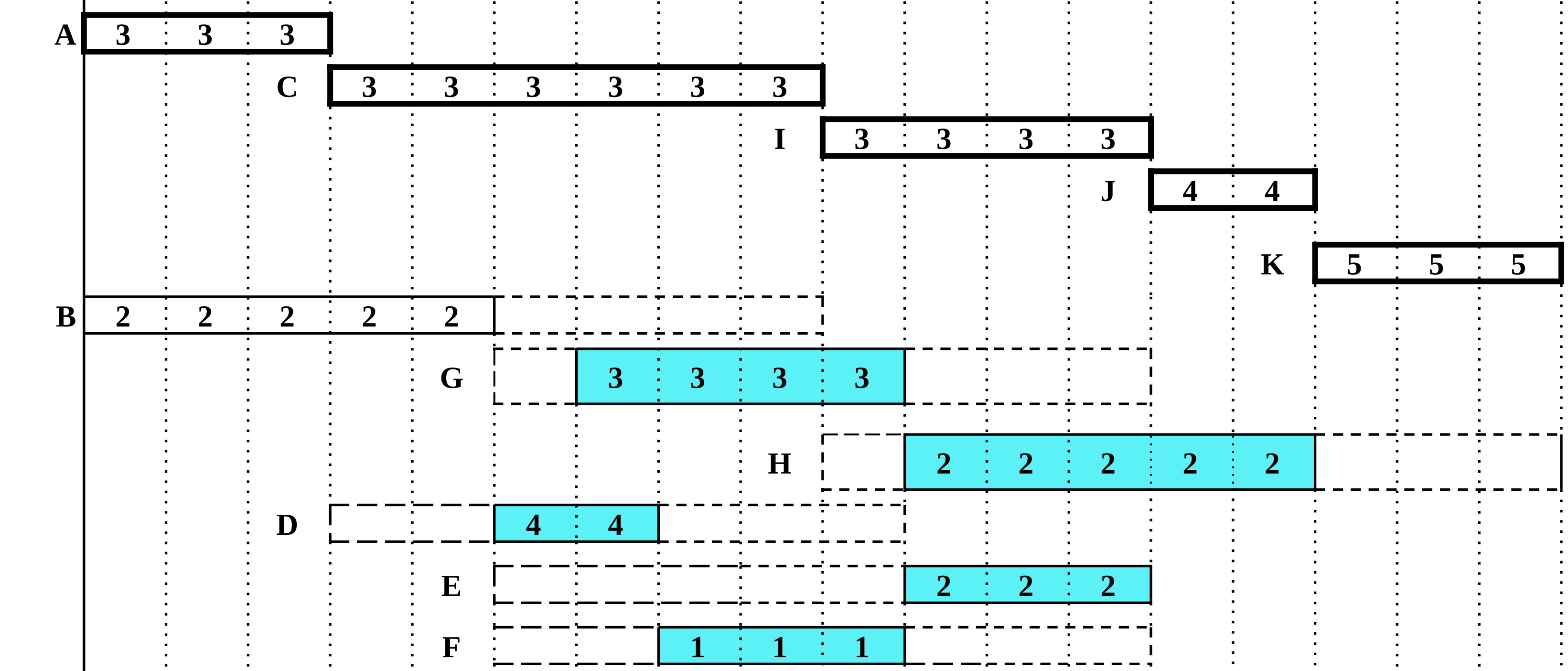
< Application of Burgess Procedure



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	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 ∴ $\sum R^2 = 729$

< Application of Burgess Procedure



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 ∴ $\sum R^2 = 715$

< Application of Burgess Procedure

Sequence of major moves of the first rescheduling cycle:

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

Delay activity "G" one period $\therefore \sum \mathbf{R^2 = 729}$

Delay activity "F" two periods $\therefore \sum \mathbf{R^2 = 727}$

Delay activity "E" five periods $\therefore \sum \mathbf{R^2 = 723}$

Delay activity "D" two periods $\therefore \sum \mathbf{R^2 = 715}$

< Estimated method

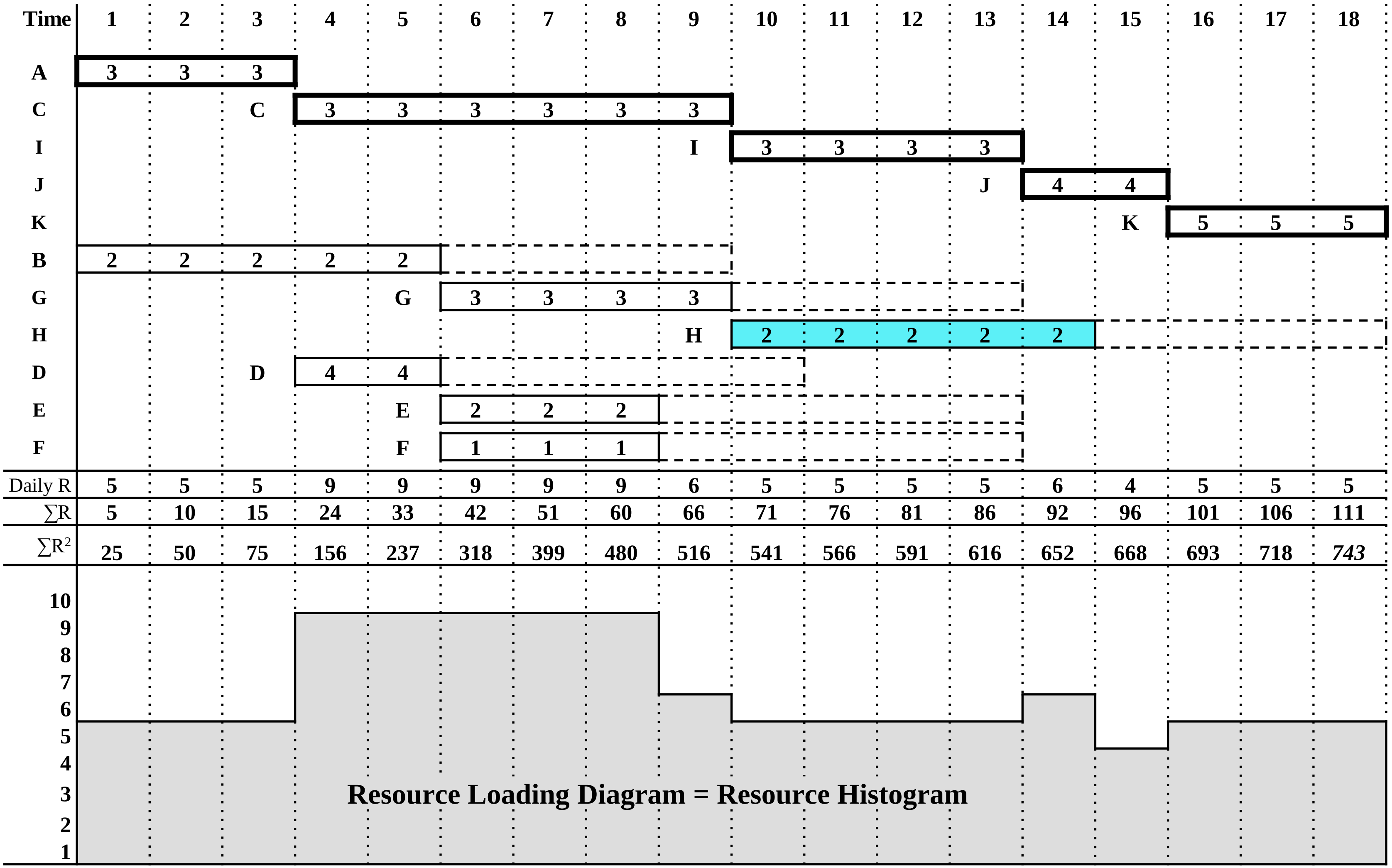
Step 1: Draw the network in a time scaled diagram using the early start schedule method.

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 Y_i^2, where Y_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 Y_i^2.

< Resource Leveling within the limits of available Floats



Resource Leveling within the limits of available Floats

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
B	2	2	2	2	2													
G										3	3	3	3					
H														2	2	2	2	2
D				4	4													
E						2	2	2										
F						1	1	1										
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 $\therefore \sum R^2 = 717$

< Resource Leveling within the limits of available Floats

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
B	2	2	2	2	2													
G										3	3	3	3					
H														2	2	2	2	2
D						4	4											
E								2	2	2								
F								1	1	1								
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 ∴ $\sum R^2 = 703$

< Resource Leveling within the limits of available Floats

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
B	2	2	2	2	2													
G										3	3	3	3					
H														2	2	2	2	2
D						4	4											
E								2	2	2								
F											1	1	1					
R	5	5	5	5	5	7	7	5	5	8	7	7	7	6	6	7	7	7
$\sum R^2$	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 $\therefore \sum R^2 = 703$

< Limited Resource Allocation

START

calculate initial early start (ES) and late start (LS) time for each activity in the project, and set time now equal to 0, i.e., T = 0.

Determine the initial eligible activity set (EAS), i.e., those activities with all predecessor activities scheduled.

From among the members of the current EAS, determine the ordered scheduling set (OSS) of activities, i.e., activities with all predecessor activities completed, ordered according to LS with smallest values first and within this characteristic, according to least activity duration first.

Consider the activities in OSS in the order listed and schedule those activities for which sufficient resources are available for the duration of the activity. As activities are scheduled update the level of resources available, and update the members of EAS.

Have all activities been scheduled, i.e., is EAS an empty set?

Yes

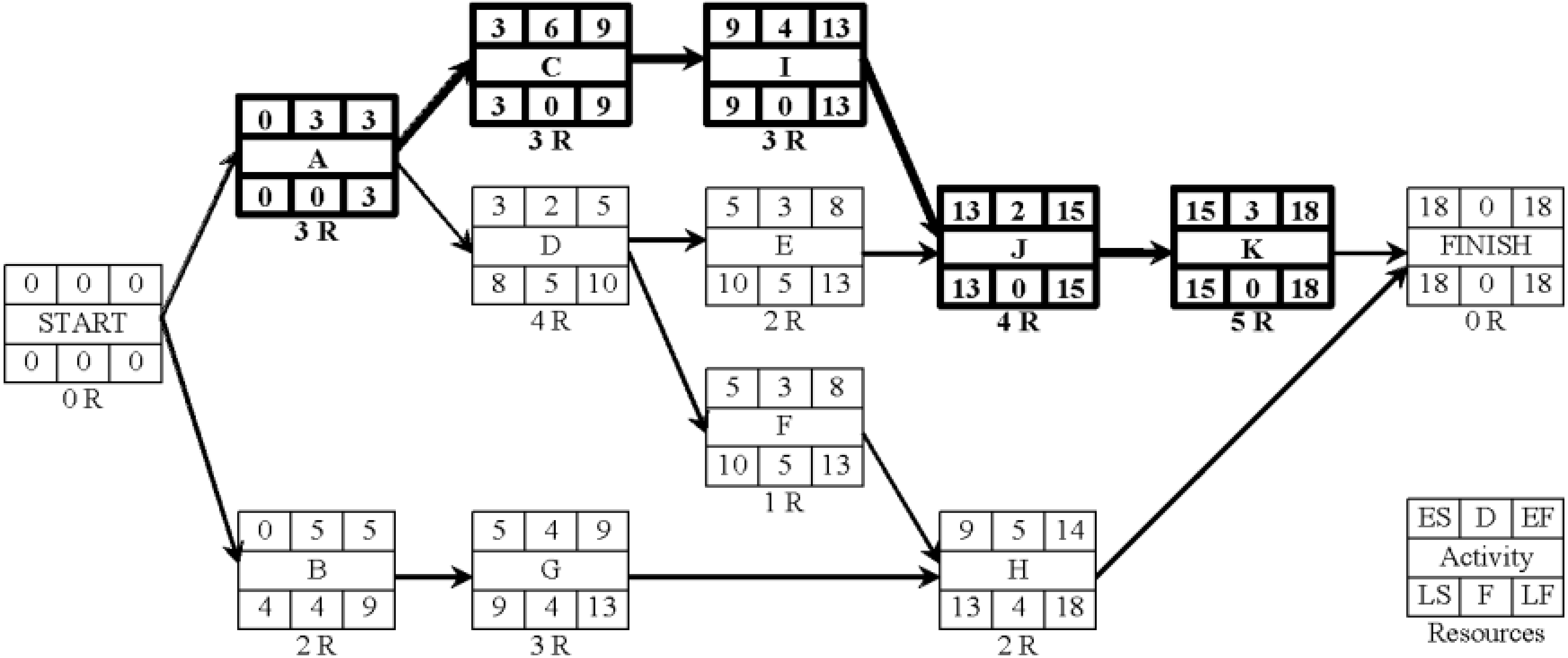
STOP

No

Set $T_{new} = T_{old} + 1$ and updated EAS.

< Example

The work of a small engineering project is planned according to the AON shown below. The labour requirement of each activity is shown below each activity box. What will be the minimum contract duration if no more than **6** labours can be made available for the work and if it is assumed that having started an activity it must be completed without a break?

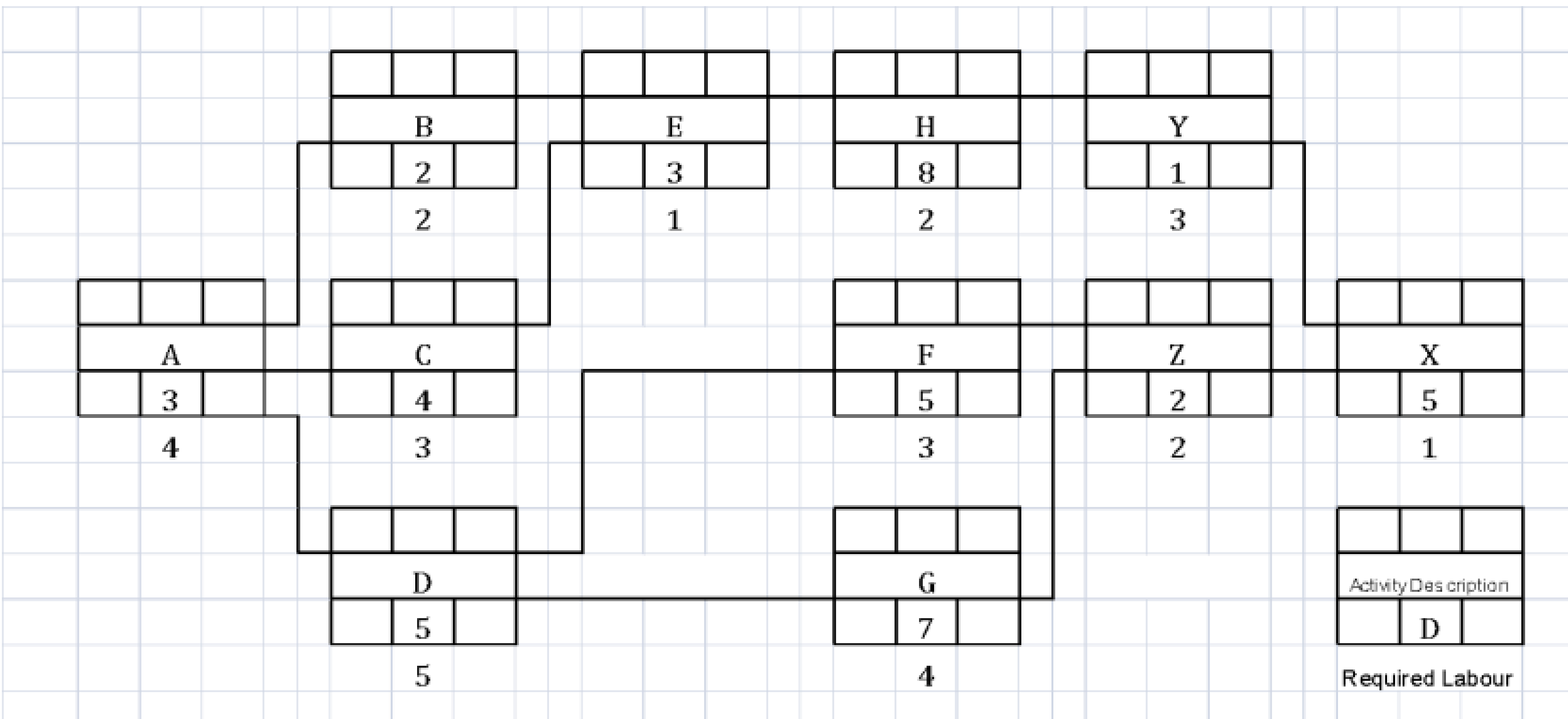


EAS																							
OSS																							
Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

EAS[1]	A B	C D G	C D G	C D G	D G I	D G I	D I	D I	D I	D I	I E F	I E F	J H	J H	J H	J	K	K	K	K	–	–
OSS[2]	A B	–	–	C D	D	D G	D	D	D	D I	I	I E F	–	–	H	J	–	K	K	K	–	–
A	3	3	3																			
B	2	2	2	2	2																	
C				3	3	3	3	3	3													
G						3	3	3	3													
D										4	4											
I												3	3	3	3							
E												2	2	2								
F												1	1	1								
H															2	2	2	2	2			
J																2	2					
K																				5	5	5
Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
UR[3]	$\cancel{6}$ $\cancel{3}$ 1	$\cancel{6}$ $\cancel{3}$ 1	$\cancel{6}$ $\cancel{3}$ 1	$\cancel{6}$ $\cancel{4}$ 1	$\cancel{6}$ $\cancel{4}$ 1	$\cancel{6}$ $\cancel{3}$ 0	$\cancel{6}$ $\cancel{3}$ 0	$\cancel{6}$ $\cancel{3}$ 0	$\cancel{6}$ $\cancel{3}$ 0	$\cancel{6}$ 2	$\cancel{6}$ 2	$\cancel{6}$ $\cancel{3}$ $\cancel{1}$ 0	$\cancel{6}$ $\cancel{3}$ $\cancel{1}$ 0	$\cancel{6}$ $\cancel{3}$ $\cancel{1}$ 0	$\cancel{6}$ $\cancel{3}$ 1	$\cancel{6}$ $\cancel{4}$ 2	$\cancel{6}$ $\cancel{4}$ 2	$\cancel{6}$ 4	$\cancel{6}$ 4	$\cancel{6}$ 1	$\cancel{6}$ 1	$\cancel{6}$ 1
AR[4]	5	5	5	5	5	6	6	6	6	4	4	6	6	6	5	4	4	2	2	5	5	5

< Example

The work of a small engineering project is planned according to the AON shown below. The labour requirement of each activity is shown below each activity box. What will be the minimum contract duration if no more than **6** labours can be made available for the work and if it is assumed that having started an activity it must be completed without a break?



EAS																															
OSS																															
Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

< Example

T	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		A																													
	4	4	4		C																										
				3	3	3	3																								
				B																											
				2	2					D																					
								5	5	5	5	5																			
									E																						
								1	1	1						G															
													4	4	4	4	4	4	4												
																H															
													2	2	2	2	2	2	2	2											
																						F									
																				3	3	3	3	3							
																					Y										
																					3				Z						
																									2	2					
																													X		
																											1	1	1	1	1
R	4	4	4	5	5	3	3	6	6	6	5	5	6	6	6	6	6	6	6	5	6	3	3	3	2	2	1	1	1	1	1

< Example

Step 1: T = 1
ES ≤ 1
E.A.S. {A}
O.S.S. {A}

Step 2: T = 4
ES ≤ 4
E.A.S. {B, C, D}
LS 6, 4, 6
D 2, 4, 5
O.S.S. {C, B, D}

Step 3: T = 8
ES ≤ 8
E.A.S. {E, D}
LS 8, 6
O.S.S. {D, E}

Step 4: T = 13
ES ≤ 13
E.A.S. {H, F, G}
LS 11,13, 11
D 8, 5, 7
O.S.S. {G, H, F}

Step 5: T = 20
ES ≤ 20
E.A.S. {F}
O.S.S. {F}

Step 6: T = 21
ES ≤ 21
E.A.S. {Y}
O.S.S. {Y}

Step 7: T = 25
ES ≤ 25
E.A.S. {Z}
O.S.S. {Z}

Step 8:T = 27
ES ≤ 27
E.A.S. {Y}
O.S.S. {Y}