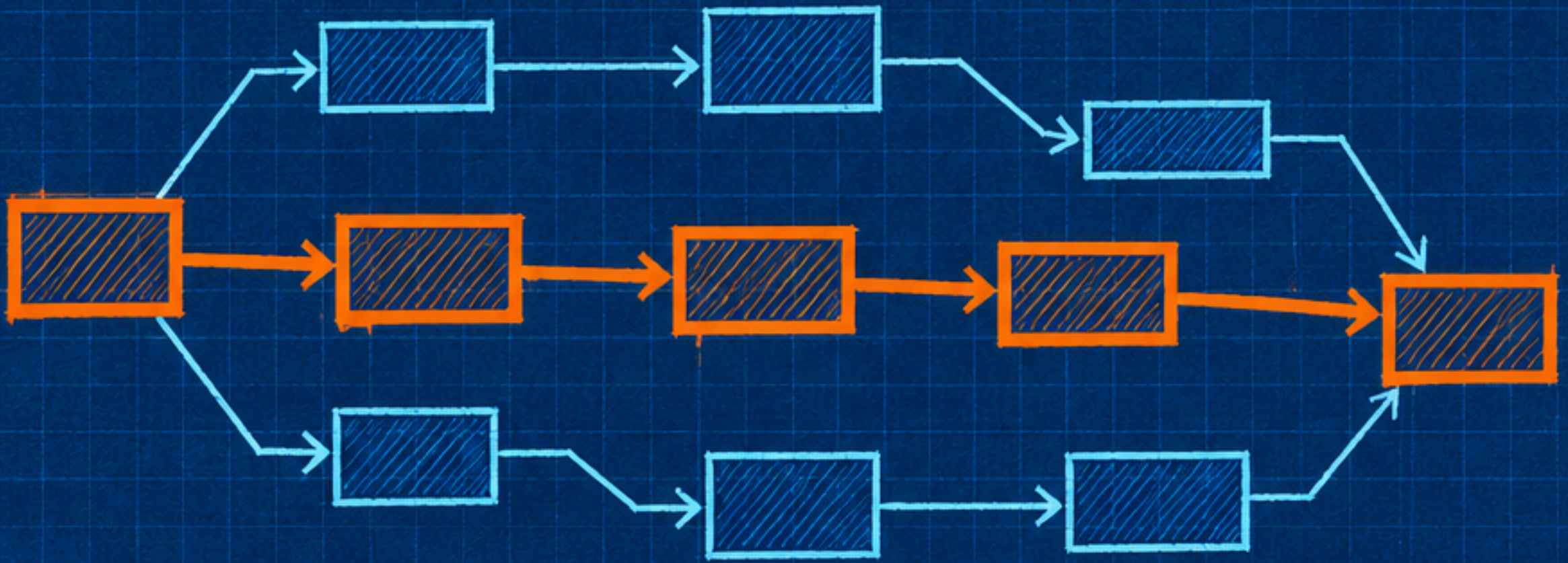
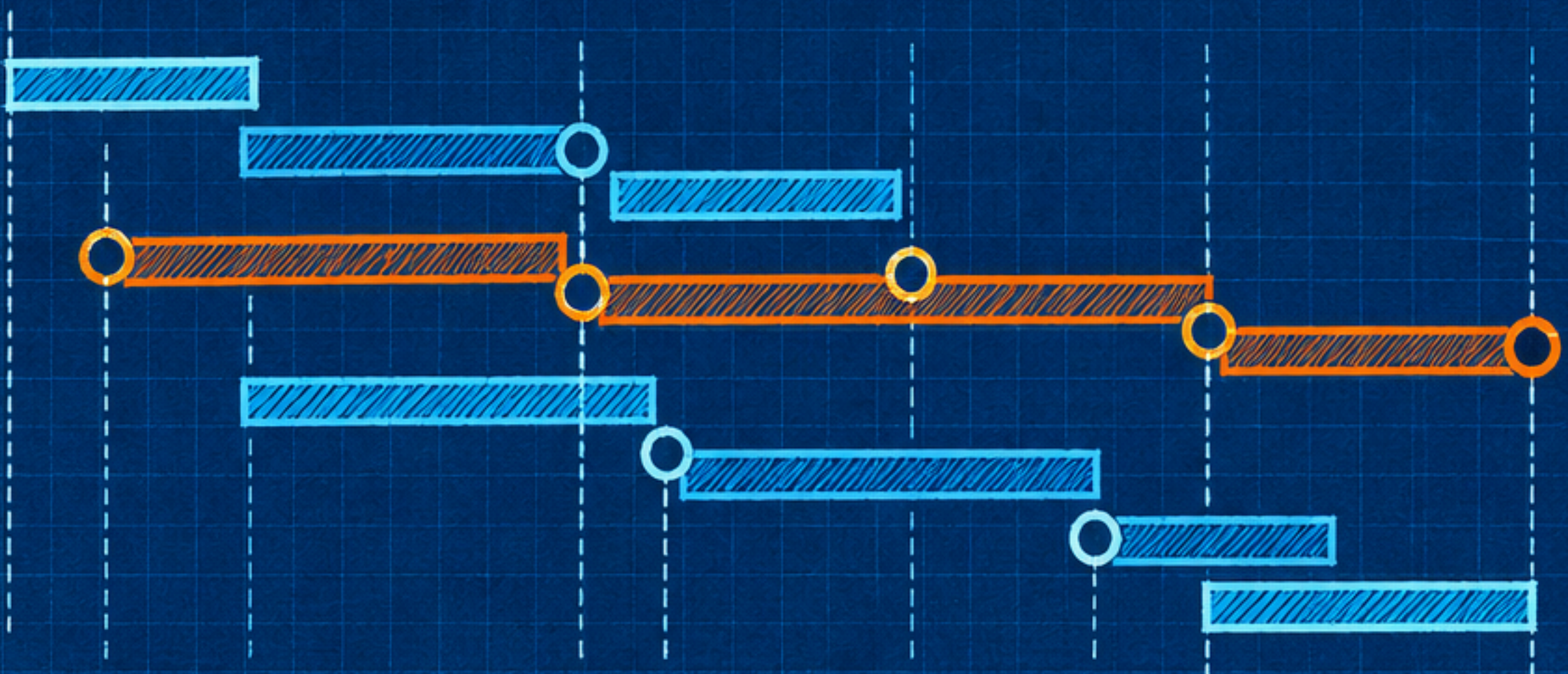


PROJECT SCHEDULING CALCULATIONS

Critical Path, Float, and Delays



Read an Activity

Understand the symbols before you calculate a schedule.

THE SIX VALUES

ES	EARLY START First possible start, based on the schedule logic.	EF	EARLY FINISH First possible finish, using the activity duration.
LS	LATE START Last start that preserves the required project finish.	LF	LATE FINISH Last finish that preserves the required project finish.
D	DURATION Working time needed to complete the activity.	TF	TOTAL FLOAT Delay allowed before finish slips or a constraint is violated.

THE CORE FORMULAS

Find the early finish
Find the late start
Measure the float

$$\begin{aligned} EF &= ES + D \\ LS &= LF - D \\ TF &= LS - ES = LF - EF \end{aligned}$$

WORKED EXAMPLE

Activity A takes 4 working days. The network gives $ES = 3$ and $LF = 9$. Calculate the missing values:

ES 3	D 4	EF 7
ACTIVITY A		
LS 5	TF 2	LF 9

$$\begin{aligned} EF &= 3 + 4 = 7 \\ LS &= 9 - 4 = 5 \\ TF &= 5 - 3 = 2 \text{ days} \\ \text{Check: } 9 - 7 &= 2 \text{ days} \end{aligned}$$

WHAT THE RESULT MEANS

A can start 2 working days later and still finish at time 9.
Project finish stays unchanged if the rest of the schedule is unchanged.

COUNT TIME CONSISTENTLY

Use time 0 as the start. From time 3 to time 7 is 4 days; do not add 1.
Basic model: finish-to-start links, zero lag, one working calendar.

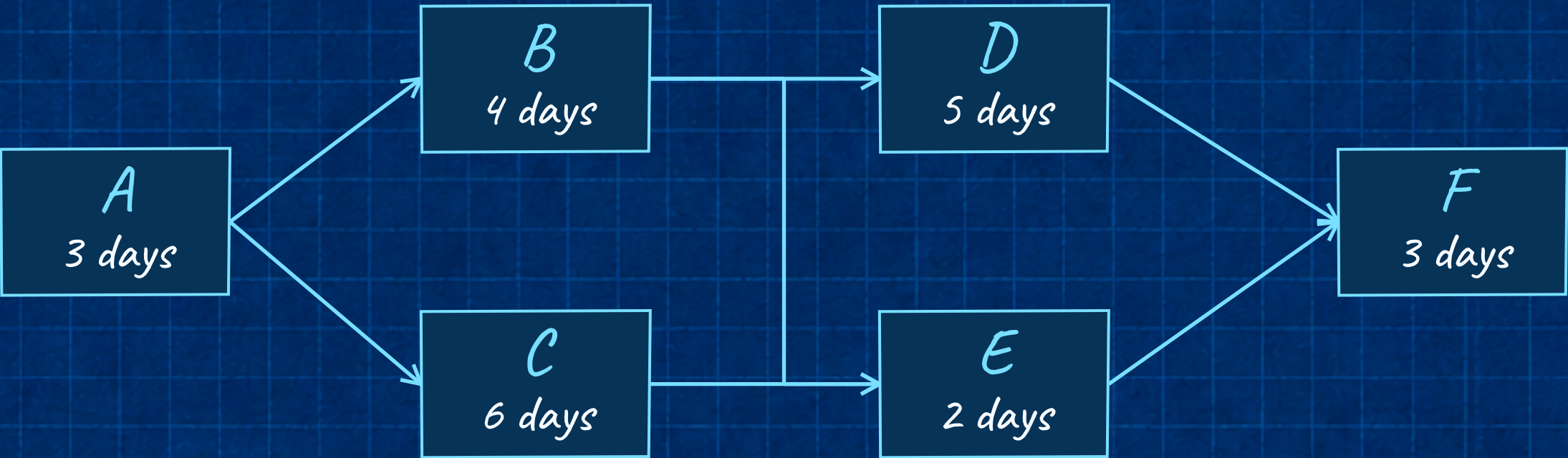
Map the Work

Build a logical network before calculating dates.

RUNNING EXAMPLE: SIX ACTIVITIES

Activity	Work	Duration	Must follow
A	Prepare	3	None
B	Build	4	A
C	Configure	6	A
D	Test build	5	B
E	Integrate	2	B and C
F	Release	3	D and E

DRAW EACH REQUIRED DEPENDENCY



Each box is an activity; each arrow is a required sequence.
B and C may run in parallel after A. E must wait for both.
F waits for both D and E; the later branch controls its start.

THE MODEL WE WILL USE

Start at time 0. Durations are working days on one common calendar.
All links are finish-to-start with zero lag; resources are available.

CHECK THE LOGIC FIRST

Connect every activity to the project start and finish; avoid circular links.
The next pages calculate this same example, then test what happens if it changes.

The Forward Pass

Find the earliest start and finish of every activity.

THE FORMULA

$$EF = ES + D$$

ES = highest EF among immediate predecessors.
For a starting activity in this model, ES = 0.

WORKED EXAMPLE: CALCULATE LEFT TO RIGHT

Activity	ES calculation	ES	D	EF
A	Project start	0	3	3
B	EF of A	3	4	7
C	EF of A	3	6	9
D	EF of B	7	5	12
E	max(7, 9)	9	2	11
F	max(12, 11)	12	3	15

WHY THE LARGER NUMBER WINS

E cannot start at 7: C is still working until time 9.
F cannot start at 11: D is still working until time 12.

EARLIEST PROJECT FINISH = TIME 15

The project needs 15 working days from time 0 under this model.
This is the longest linked route, not the sum of every activity.

COMMON ERROR: CHOOSING THE MINIMUM

At a merge, every required predecessor must be ready.
Use the latest predecessor finish, not an average or the first one to finish.

The Backward Pass

Find how late activities may occur without moving the target finish.

THE FORMULA

$$LS = LF - D$$

LF = lowest LS among immediate successors.
Set final LF = 15, the finish calculated on page 03.

WORKED EXAMPLE: CALCULATE RIGHT TO LEFT

Activity	LF calculation	LF	D	LS
F	Project finish	15	3	12
E	LS of F	12	2	10
D	LS of F	12	5	7
C	LS of E	10	6	4
B	min(7, 10)	7	4	3
A	min(3, 4)	3	3	0

WHY THE SMALLER NUMBER WINS

B must finish by 7 for D, even though E can wait until 10.
A must finish by 3 for B, even though C can wait until 4.

EARLY AND LATE DATES ARE NOW AVAILABLE

For C: ES = 3, EF = 9, LS = 4 and LF = 10.
The one-day gap between its early and late dates is its total float.

KEEP THE FINISH TARGET VISIBLE

This pass uses LF = 15. A different required finish changes late dates and float.
For several ending activities, connect them to one zero-duration finish milestone.

Find the Critical Path

Identify the linked route that controls project completion.

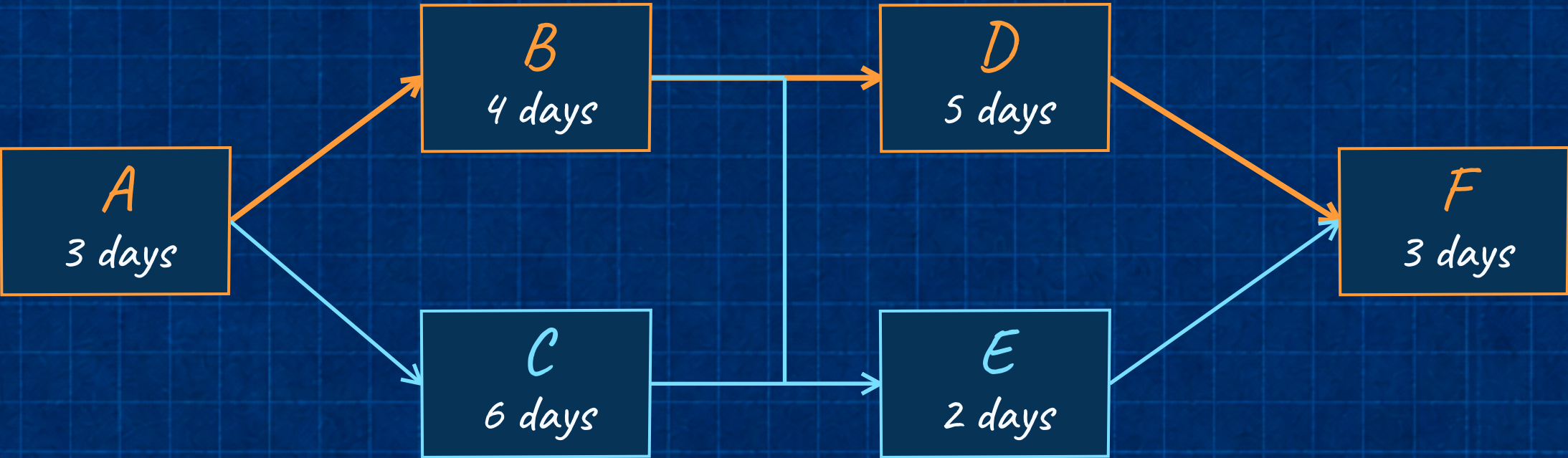
THE FORMULA

Project duration = longest path duration

For this FS, zero-lag network, add durations along each complete path.

Complete path	Duration calculation	Total
A - B - D - F	3 + 4 + 5 + 3	15 days
A - C - E - F	3 + 6 + 2 + 3	14 days
A - B - E - F	3 + 4 + 2 + 3	12 days

CRITICAL ROUTE IN ORANGE



CRITICAL PATH: A - B - D - F

This route takes 15 days. Its activities have zero total float in this model. A - C - E - F is only one day shorter, so monitor it closely.

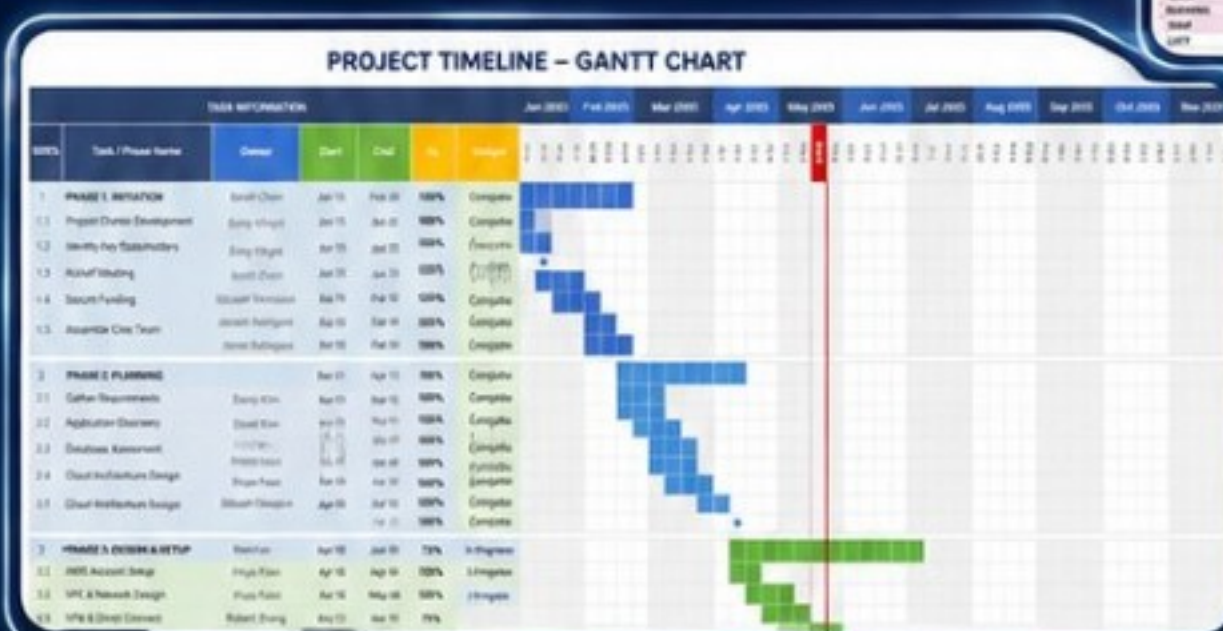
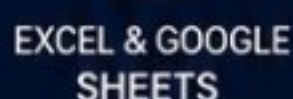
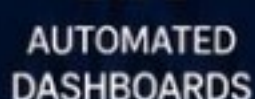
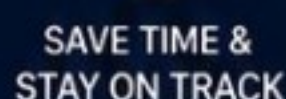
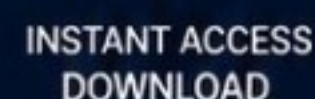
RECALCULATE AFTER A CHANGE

More than one path can be critical; the controlling route can also change. Constraints, calendars and resource limits can complicate the zero-float rule.

940+ Premium Templates • One Payment • Lifetime Access

SAVE 94%

Worth \$3,300+



GET LIFETIME ACCESS

Calculate Total Float

Measure room to move before the project finish is affected.

THE FORMULA

$$TF = LS - ES = LF - EF$$

Use early and late dates from the same schedule calculation.

WORKED EXAMPLE: THE COMPLETE FLOAT CHECK

Activity	ES	LS	EF	LF	TF
A	0	0	3	3	0
B	3	3	7	7	0
C	3	4	9	10	1
D	7	7	12	12	0
E	9	10	11	12	1
F	12	12	15	15	0

READ ONE ACTIVITY TWO WAYS

C: $TF = 4 - 3 = 1$ working day.

Cross-check: $TF = 10 - 9 = 1$ working day.

C CAN USE ONE DAY BEFORE PROJECT FINISH MOVES

A, B, D and F have no total float. C and E each show one day.

Those values are not separate allowances you can simply add together.

FLOAT IS A CURRENT CALCULATION

It depends on durations, logic, calendars and the finish target.

Positive float does not guarantee that every successor can stay at its early date.

Calculate Free Float

Measure delay that leaves every immediate successor at its early start.

THE FORMULA

$$FF = \min(ES \text{ of successors}) - EF$$

This formula is for finish-to-start links with zero lag on one calendar.

WORKED EXAMPLE: LOOK AT THE NEXT ACTIVITIES

Activity	Successor ES	EF	FF
A	$\min(3, 3)$	3	0
B	$\min(7, 9)$	7	0
C	9	9	0
D	12	12	0
E	12	11	1
F	Finish milestone: 15	15	0

TOTAL FLOAT AND FREE FLOAT ANSWER DIFFERENT QUESTIONS

C has $TF = 1$ but $FF = 0$. Delaying C moves E immediately.

E has $TF = 1$ and $FF = 1$. It can finish at 12 without moving F.

FREE FLOAT PROTECTS THE SUCCESSOR DATES

C can use one day of total float, but E must then start one day later.
The project still finishes at 15 because E has room before F starts.

DO NOT REUSE THIS SHORTCUT FOR EVERY LINK

With FS lag L: use $\min(ES \text{ of successor} - L) - EF$.

Other relationship types and calendars require the corresponding scheduling rules.

Float Is Shared

Two activities showing one day of float do not create two spare days.

THE KEY IDEA

C and E share a one-day path margin

$A - C - E - F = 3 + 6 + 2 + 3 = 14$ days.
The controlling route takes 15 days: the difference is only 1.

WORKED EXAMPLE: CHANGE THE DURATIONS

Scenario	C duration	E duration	Project finish
Original plan	6	2	15
C takes 1 extra day	7	2	15
E takes 1 extra day	6	3	15
Both take 1 extra day	7	3	16

TRACE THE COMBINED CHANGE

C now finishes at $3 + 7 = 10$.
E starts at $\max(7, 10) = 10$ and finishes at $10 + 3 = 13$.
F starts at $\max(12, 13) = 13$ and finishes at 16.

TWO EXTRA DAYS CAUSE ONE DAY OF PROJECT DELAY

The first extra day consumes the margin; the second pushes the finish.
C and E are on the same route, so their float cannot be spent twice.

ASSESS CHANGES TOGETHER

After consuming float, recalculate the whole network and update the remaining float.
A separate one-activity check can miss the effect of several changes on one path.

Four Dependency Types

A relationship tells you which start or finish must wait.

FS / FINISH TO START

$$\text{Start}(B) \geq \text{Finish}(A)$$

B must wait to start until A finishes.
Example: build before testing.

SS / START TO START

$$\text{Start}(B) \geq \text{Start}(A)$$

B may start once A has started.
They need not start together.

FF / FINISH TO FINISH

$$\text{Finish}(B) \geq \text{Finish}(A)$$

B cannot finish before A finishes.
B may start earlier than A.

SF / START TO FINISH

$$\text{Finish}(B) \geq \text{Start}(A)$$

B cannot finish until A starts.
Example: incoming shift releases old shift.

WORKED EXAMPLE: FOUR SEPARATE ALTERNATIVES

A runs from time 5 to 10. B takes 3 days. Assume zero lag,
no other links and no restriction other than starting at or after time 0.

Link from A to B	Earliest B start	Earliest B finish
FS	10	13
SS	5	8
FF	7	10
SF	2	5

These are alternative links, not four requirements applied at once.

A LINK IS A LIMIT, NOT A FORCED EQUALITY

The symbol $\geq$ means "at or after". Another predecessor may make B later.
SF is uncommon: check which activity is the predecessor before choosing the link.

Calculate Lags & Leads

Add waiting time or model a justified overlap between activities.

THE FORMULA

$$ES(next) = \max[EF(pred) + L]$$

For FS links: positive L adds lag; negative L represents lead.
Apply every predecessor link, then take the latest permitted start.

WORKED EXAMPLE: A TAKES 6 DAYS; B TAKES 4

A starts at 0 and finishes at 6. B has no other predecessor.
All durations and offsets below use the same working calendar.

FS link	B start calculation	B start	B finish
Lag +2	$6 + 2$	8	12
Zero lag	$6 + 0$	6	10
Lead 2 ($L = -2$)	$6 - 2$	4	8

BACKWARD PASS: REVERSE THE OFFSET

$$LF(pred) = \min[LS(next) - L]$$

If the successor LS is 8 and the lag is +2, predecessor $LF = 6$.
If the successor LS is 4 and the lag is -2, predecessor $LF = 6$.

OVERLAP NEEDS A REAL WORKING ASSUMPTION

An FS lead permits B to begin before A ends; it does not prove readiness.
Identify the deliverable that allows the overlap and assess rework exposure.

KEEP THE OFFSET VISIBLE

Use an explicit activity for a wait that needs its own tracking, resources or status.
Software may use a different calendar for lag; check the setting before comparing dates.

When an Activity Slips

Test how an isolated duration increase changes the project finish.

THE FORMULA

$$\text{Finish delay} = \max(0, \text{extra duration} - TF)$$

Limited shortcut: one duration increase in this basic FS, zero-lag model.
Use original TF; hold all other durations, logic and calendars fixed.

WORKED EXAMPLE: START FROM THE 15-DAY PLAN

Isolated change	Original TF	Extra days	New finish
D: 5 to 7 days	0	2	17
C: 6 to 7 days	1	1	15
C: 6 to 8 days	1	2	16

VERIFY THE LAST ROW THROUGH THE NETWORK

C finishes at $3 + 8 = 11$.
E runs from $\max(7, 11) = 11$ to 13.
F runs from $\max(12, 13) = 13$ to 16.
The new controlling route is A - C - E - F.

A TWO-DAY ACTIVITY SLIP CAN MEAN A ONE-DAY FINISH SLIP

For C: $\max(0, 2 - 1) = 1$ day of project delay.
For D: no float is available, so the full two days reach project finish.

DO NOT ADD SEPARATE DELAY ESTIMATES

For multiple changes, recalculate the combined scenario; page 08 shows why.
This estimates schedule impact, not responsibility, compensation or contractual entitlement.

Deadlines & Negative Float

Separate a required completion date from the finish the logic can achieve.

THE FORMULA

$$\text{Finish margin} = \text{required finish} - \text{forecast finish}$$

For the running example: required finish 13 - forecast finish 15 = -2.

The plan is two working days longer than the allowed completion time.

WORKED EXAMPLE: RUN THE BACKWARD PASS FROM 13

Activity	ES	EF	LS	LF	TF
A	0	3	-2	1	-2
B	3	7	1	5	-2
C	3	9	2	8	-1
D	7	12	5	10	-2
E	9	11	8	10	-1
F	12	15	10	13	-2

CHECK ACTIVITY D

D: $LS = 10 - 5 = 5$; $TF = 5 - 7 = -2$.

The required late start is earlier than its feasible early start.

THE DEADLINE DOES NOT SHORTEN THE WORK

Early dates still forecast completion at 15. The target remains 13.

A recovery change or an agreed target change is needed to close the gap.

KEEP CONSTRAINTS EXPLICIT

Negative float is a warning that the current model misses a required date.

Check logic and the justified deadline before choosing a practical recovery option.

Update Remaining Work

Use actual progress and a fresh estimate of the work still to do.

THE FORMULA

$$\text{Remaining finish} = \text{remaining start} + RD$$

*RD = remaining duration, measured in working time.
For unfinished work, respect the data date and all remaining dependencies.*

WORKED EXAMPLE: DATA DATE = TIME 7

*A finished at 3; B finished at 7. C started at 3 and is still in progress.
C now needs 4 more days. D, E and F have not started.
Assume work can continue from time 7 with no resource interruptions.*

Activity	Status at time 7	RD	Remaining start	Finish
C	In progress	4	7	11
D	Not started	5	7	12
E	Not started	2	$\max(7, 11) = 11$	13
F	Not started	3	$\max(12, 13) = 13$	16

READ THE UPDATED FORECAST

*The remaining C - E - F chain takes $4 + 2 + 3 = 9$ days.
From data date 7: forecast finish = $7 + 9 = 16$.*

$$\text{FINISH SLIPPAGE AGAINST THE ORIGINAL PLAN} = 16 - 15 = 1 \text{ DAY}$$

Record the forecast and its cause; retain the approved baseline for comparison.

ESTIMATE REMAINING DURATION FROM THE WORK

*Physical percent complete does not automatically tell you the time still needed.
Preserve actual history. Assess unfinished work from the data date onward.*

Recover Time: Crashing

Compare added direct cost with the project time actually saved.

THE FORMULA

$$\text{Cost slope} = (CC - NC) / (ND - CD)$$

NC / CC = normal / crash cost; ND / CD = normal / crash duration.
Assume a feasible, linear cost increase over the stated duration range.

WORKED EXAMPLE: ONLY C AND D CAN BE SHORTENED

Activity	ND	CD	NC	CC	Cost / day
D	5	3	\$1,000	\$1,600	\$300
C	6	5	\$1,200	\$1,600	\$400

D slope = (\$1,600 - \$1,000) / (5 - 3) = \$300 per day.

RECALCULATE AFTER EACH CHANGE

Scenario	Project finish	Added direct cost
No change	15	\$0
D: 5 to 4	14	\$300
D: 5 to 3	14	\$600
D: 5 to 3 AND C: 6 to 5	13	\$1,000

After the first day saved, two paths tie at 14; shortening D alone cannot beat the C route. Saving a second project day needs both routes reduced.

CRASH THE CONTROLLING WORK, WITHIN FEASIBLE LIMITS

A low activity cost per day does not guarantee a day saved on the whole project.
Fast-tracking instead overlaps work; validate handoffs and the added rework risk.

Worked Case: Full Calculation

A new network to practise the complete calculation in one place.

GIVEN: START AT 0; ALL LINKS FS WITH ZERO LAG

Activity	Duration	Must follow
A	2	None
B	5	A
C	3	A
D	4	B, C
E	2	C
F	1	D, E

SOLUTION: FORWARD PASS, BACKWARD PASS, THEN FLOAT

Act.	D	ES	EF	LS	LF	TF	FF
A	2	0	2	0	2	0	0
B	5	2	7	2	7	0	0
C	3	2	5	4	7	2	0
D	4	7	11	7	11	0	0
E	2	5	7	9	11	4	4
F	1	11	12	11	12	0	0

Merge at D: $ES = \max(7, 5) = 7$. Merge at F: $ES = \max(11, 7) = 11$.

Backward at C: $LF = \min(LS \text{ of } D \ 7, LS \text{ of } E \ 9) = 7$.

CRITICAL PATH: A - B - D - F = 2 + 5 + 4 + 1 = 12 DAYS

C has TF = 2 but FF = 0; E has TF = FF = 4.

A delay in C moves E immediately, even before the final completion date changes.

THIS CASE HAS DIFFERENT DURATIONS AND LINKS

Use this page as the input for page 16; do not mix it with the earlier 15-day example.
All dates are working-time boundaries on the same calendar, with no resource limits.



Learn from 350+ top universities and companies

 ILLINOIS

 Duke
UNIVERSITY

 Google



 IBM

 VANDERBILT
UNIVERSITY

 JOHNS HOPKINS
UNIVERSITY

Invest in your career



Explore new skills

Access 10,000+ courses in AI, business, technology, and more.

Worked Case: Delay & Recovery

Continue the new case from page 15 and trace the changed critical route.

THE CHANGE TO TEST

C duration increases from 3 to 6 days

Extra duration = 3 days; original total float of C = 2 days.
All other inputs stay fixed. Expected finish delay = $\max(0, 3 - 2) = 1$.

1. RECOMPUTE EARLY DATES

Activity	ES	Duration	EF
A	0	2	2
B	2	5	7
C	2	6	8
D	8	4	12
E	8	2	10
F	12	1	13

D must wait until C finishes at 8. F must wait until D finishes at 12.
The controlling path is now A - C - D - F: $2 + 6 + 4 + 1 = 13$.

2. TEST ONE FEASIBLE RECOVERY OPTION

If D can be shortened from 4 to 3 days, D runs from 8 to 11.
F then runs from 11 to 12: the original finish is recovered.

RECOVERY TARGET: $13 - 1 = 12$ WORKING DAYS

A - C - D - F now takes $2 + 6 + 3 + 1 = 12$ days.
Confirm the cost, staffing and quality implications before adopting the change.

RECOVERY MUST AFFECT THE CURRENT CONTROLLING PATH

Reducing B alone cannot recover the lost day after the C route becomes critical.
After any accepted change, rerun both passes and update float for every activity.

Your Formula Desk Reference

Match the formula to its assumptions before using the result.

BASIC CPM: FS LINKS, ZERO LAG, ONE CALENDAR

$$ES = \max(EF \text{ of predecessors}) \quad EF = ES + D$$

$$LF = \min(LS \text{ of successors}) \quad LS = LF - D$$

Start at 0; use project finish as the final LF unless a target is specified.

TOTAL FLOAT

$$TF = LS - ES = LF - EF$$

Room before the required project finish.

FREE FLOAT

$$FF = \min(ES \text{ next}) - EF$$

Room before any immediate successor.

FS LINKS WITH SIGNED LAG L

$$ES(\text{next}) = \max[EF(\text{pred}) + L]$$

$$LF(\text{pred}) = \min[LS(\text{next}) - L]$$

Positive L = lag. Negative L = lead. Use a consistent lag calendar.

$$\text{Crash slope} = (\text{crash cost} - \text{normal cost}) / (\text{normal time} - \text{crash time})$$

Linear cost assumption; shorten controlling work and then recalculate.

BEFORE YOU TRUST THE ANSWER

Check links, duration units, calendars, constraints and the data date.

Float can be shared. Check all critical and near-critical routes.

Recalculate combined changes; a deadline does not compress the work.

REFERENCES / TAP TO OPEN IN THE PDF

[1] PMI: Critical Path Method Calculations

[2] PMI: Practice Standard for Scheduling

[3] Microsoft: Task Links and Scheduling

[4] GAO: Schedule Assessment Guide

[5] Oracle: Remaining Duration Definitions

[6] NPTEL: Project Crashing and Cost Slope

[7] Microsoft: Predecessors, Lead and Lag

[8] PMI: Float Analysis