Construction Project Scheduling

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Ch.2: Developing a Network Model

➢ Development of a network model

- Steps in building a network model
  - Step 1: **Define** activities
  - Step 2: **Order** activities
  - Step 3: **Establish** activity relationships and draw a network diagram
  - Step 4: **Determine** quantities and assign duration to activities
  - Step 5: **Assign** resources and costs
  - Step 6: **Calculate** early and late start/finish times (Ch.3)
  - Step 7: **Compute** float values and identify the critical path (Ch.3)
  - Step 8: **Schedule** activity start/finish times (Ch.3)
- Iterative when schedule or scope is **changed** by the owner
  - **Redefine** the sequencing of activities

Ch.2: Developing a Network Model

➢ Step 1: Define Activities

- Production/Construction
  - Related to directly to the **physical effort of creating the project**
  - Use traditional resources of labor and materials
- Procurement
  - **Arranging and acquisition tasks** of materials, money, equipment, and manpower
  - **Influencing on timing of production/construction** activities
- Management
  - **Support or administrative tasks** directly impacting the project schedule
  - Such as preparing inspection reports, processing shop drawing approvals, tracking submittal approvals, developing as-built drawings, providing certifications on factory tests performed, etc.

➢ Step 2: Order Activities

: Based on the timing of some activities relative to the occurrence of other activities

: Considering all the immediately **preceding activities (IPAs)** of each activity

: Since describing the IPAs, each activity's **succeeding activities** is generated

: Considering all the immediately preceding activities (IPAs) of each activity

- Physical Constraints
  - Due to the physical process of construction, such as "***needs to erect forms before concrete can be placed***"
- Resource Constraints
  - Conditions of the limited resource availability (e.g. ***amount of the concrete to be placed per day VERSUS the capacity of the batch plant***)
- Safety Constraints
  - Activities **not occur simultaneously** (e.g. ***overhead and ground level work in the same area***)

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Step 2: Order Activities

- Financial Constraints
  - Necessity of **securing loans** prior to undertaking certain portions of a project
- Environmental Constraints
  - Need of carry out (environ. issues)**mitigation procedure** prior to other activities
- Management Constraints
  - Requirements of (managerial)**supervisory time**, cash flow need, etc.
- Contractual Constraints
  - Imposed **constraints on the construction process**
- Regulatory Constraints
  - Governmental regulations (e.g. **Environmental Protection Agency**)

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➢ Step 2: Order Activities (➔ drawing the network diagram)

- "Which activities must **precede** it?"
- "Which activities must **follow** it?"
- "Which activities can be **concurrent** with it?"
  - Determine of all the immediately preceding activities (IPAs) of each activity

Sample Activity List with IPAs
Project to Construct
Concrete Footing

Activity Label	Activity Description	IPAs
A	Lay Out Foundation	—
B	Dig Foundation	A
C	Place Formwork	B
D	Place Concrete	G, H
E	Purchase Steel Reinforcement	—
F	Cut and Bend Steel Reinforcement	E
G	Place Steel Reinforcement	C, F
H	Order Concrete	—

Fig. 2.1 Sample Activity List with IPAs

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➢ Step 2: Order Activities → drawing the network diagram

- Based on the determined IPAs of each activity → Example: Fig. 2.3

Sample Activity List with IPAs
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Fig. 2.1 Sample Activity List with IPAs

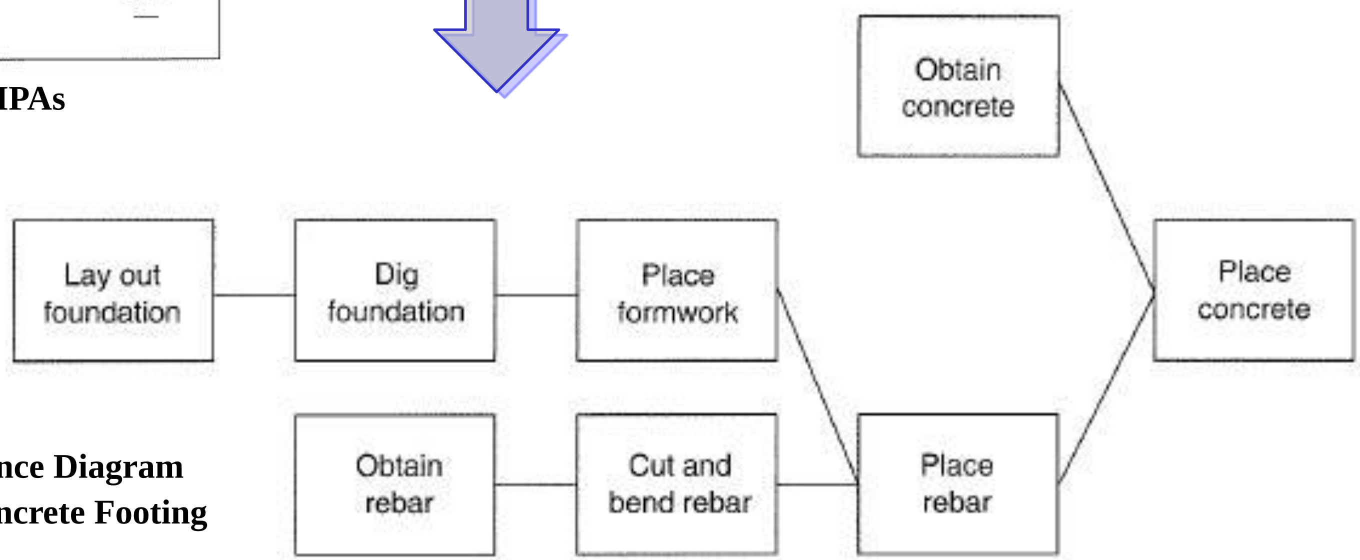

Fig. 2.3 Example of a Precedence Diagram for Constructing a Concrete Footing

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➢ Step 3: Determine quantities and assign duration to activities

- Duration is **the estimated time** required to complete an activity
- Units of time: **hours, days, weeks, months**, etc. (Depended on the size of a project)
- **Cost estimates(related to Cost Mgt.)** are developed by activity's durations
- Durations are based on **historical data of the previous similar projects** if it is available, otherwise, it is estimated by **schedulers' subjective judgments or guesstimates**

➢ Step 4: Assign resources and costs

- Based on the amount of the work to be completed, the amount of resources (e.g. **labor, equipment, and materials**) and their costs are determined **(➔ related to Cost Mgt.)**.
- Major requirements for the effective assignment of resources and costs to individual activities: clear description of the relationship between the CPM activities

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- **Step 5: Compute float values and identify the critical path**
  - Determine **early and late start/finish times**
  - **Identify the critical path (e.g. longest path)** and activities on it, based on the relationships between the activities (e.g. predecessor or successor activities)

- **Step 6: Schedule activity start/finish times**
  - Networks and information generated for each of the activities will be **useful for schedule management**, which is basis on the use of any flexibility or float (float values) that the activities possess

Ch.3: Precedence Diagrams

➢ Precedence networks

- **Most common type** of network schedule
- **Nodes represent "Activities"** with circles, boxes, or other common geometric shapes

  : Read from left to right, and **a link shows clear dependencies** between the activities
- **Lines represent "Activity links"** and use to denote the dependencies between activities

  : One link to denote each dependency between an activity and one of its immediately preceding activities (IPAs)

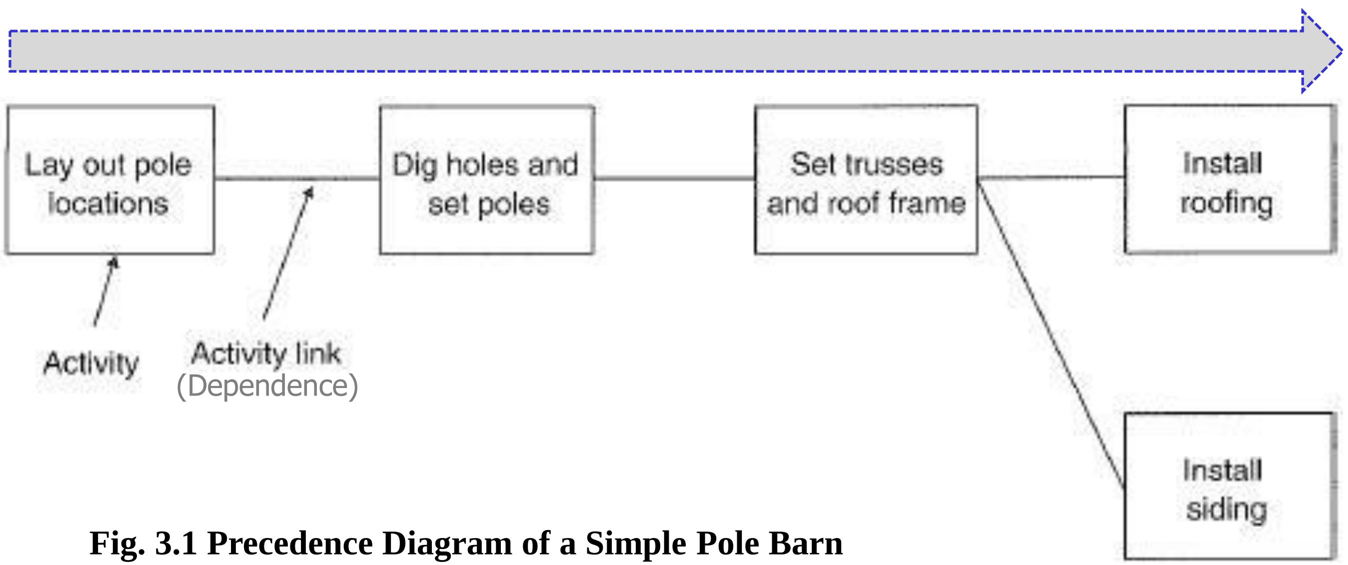


Fig. 3.1 Precedence Diagram of a Simple Pole Barn

Ch.3: Precedence Diagrams

➢ Activity relationships

- Type of relationships (between **preceding** and **succeeding** activity)

  : Finish-to-start (FS)

  : Start-to-start (SS)

  : Finish-to-finish (FF)

  : Start-to-finish (SF)

➢ Activity relationships

- Finish-to-start (FS)

  : Has been **a common relationship in the past**

  : Much **easier and simpler** to develop schedules

  : **Preceding activity must be finished before the succeeding activity** can start

  Ex) **Footing excavation must be completed prior to placing concrete** for the footing

  : Other types make it possible for schedulers to portray accurately the realistic relationships

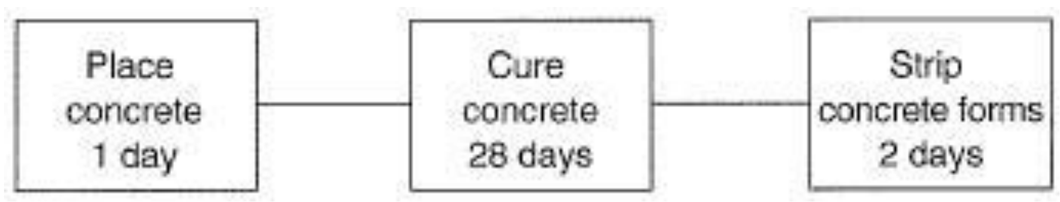


Fig. 3.2 A Typical Sequence of Finish-to-Start(FS) Relationships

➢ Activity relationships

- Finish-to-Finish (FF)

: FF with a delay relationship

: “Construct brick façade(**CBF**)” and “Install windows(**IW**)” must be completed before starting “install exterior trim”

: After finishing “**IW**”, “**CBF**” will be completed - in the meantime, “IW” will be delayed

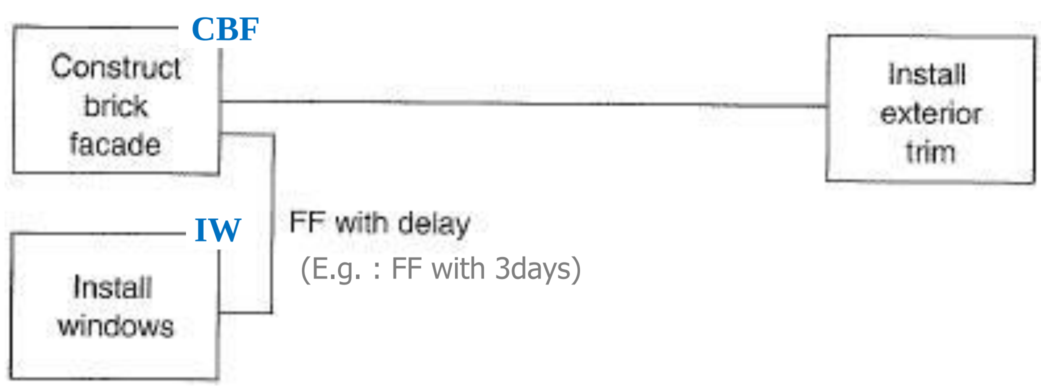


Fig. 3.6 Sequence of Finish-to-Finish(FF) with a Delay Relationship

➢ Activity relationships

- Start-to-Start(SS)

: Task of putting in a new tile floor of a commercial building (Fig. 3.8)

: **Immediately after starting "Spread grout(SG)"**, "Set tile flooring(STF)" will be started

: Relationship between "SG" and "STF" is a ***SS***

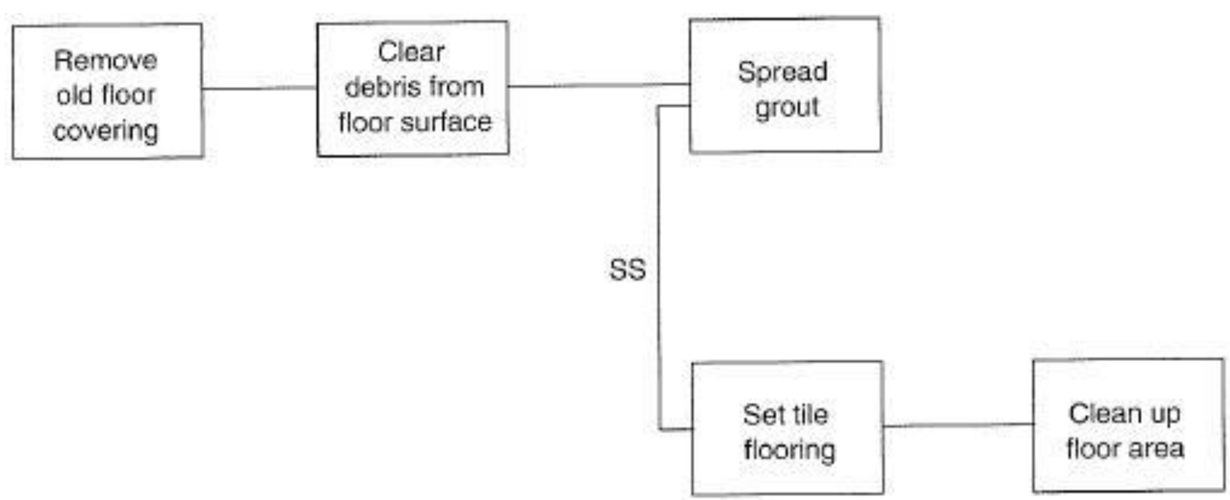


Fig. 3.8 Activities with a Start-to-Start(SS) Relationship

➢ Activity relationships

- Start-to-Finish (SF)

: Least used in the past

: Assumption that the orders for ready-mix concrete should be made at least 5 days prior to the day the concrete is to be delivered

: Relationship between **ordering of the concrete** and **concrete placement** activities is SF with a delay

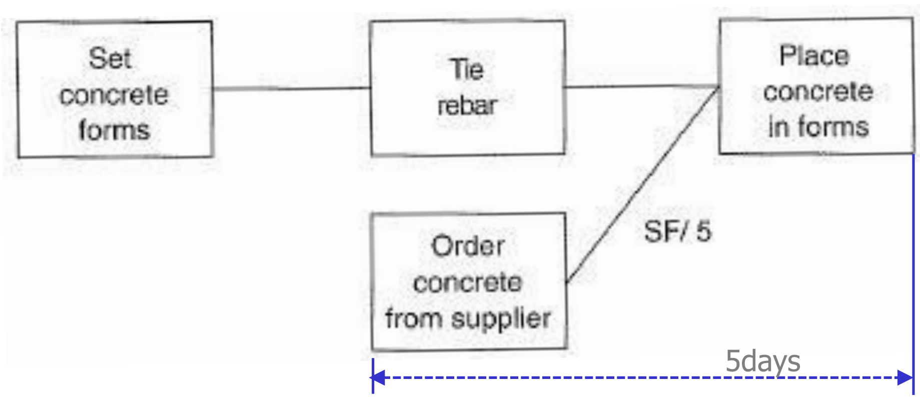


Fig. 3.14 Sequence of Start-to-Finish(SF) with a Delay Relationship for Concrete Placement

Ch.3: Precedence Diagrams

➢ Basics about Precedence Diagrams

- **Easy to draw and simple procedure** to add an activity to a network
- Link lines represent dependencies and should be avoided to confuse them
- Use list of activities and their immediately preceding activities (IPAs)

  : **IPAs is efficient for determining and presenting the sequence steps**
- Two approaches to draw a time-scaled version of the precedence diagram

  : Geometric shapes

  : Sequence steps

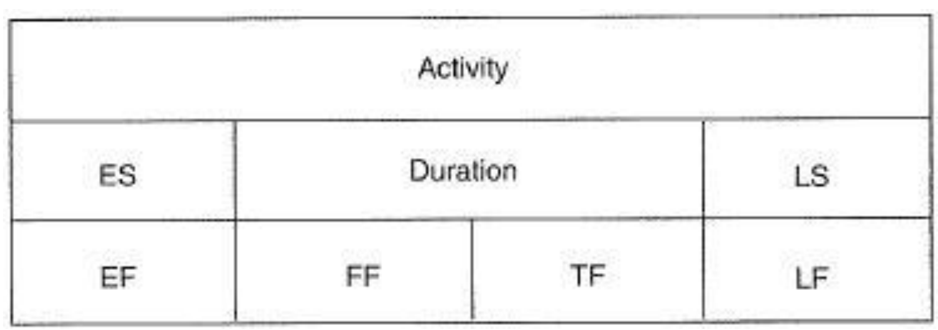


Fig. 3.18 A Simplified Yet Informative Format for a Precedence Activity

Ch.3: Precedence Diagrams

➢ Basics about Precedence Diagrams

- Sequence steps

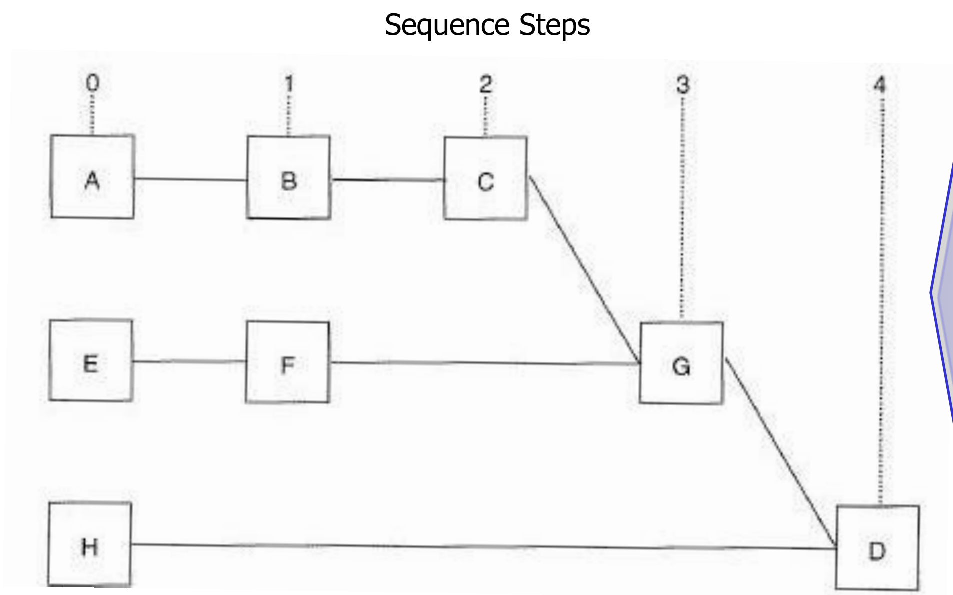


Fig. 3.20 Activities Organized in a Network with Sequence Steps

Activity	IPAs	Sequence Step
A	-	0
B	A	1
C	B	2
D	G, H	4
E	-	0
F	E	1
G	C, F	3
H	-	0

Fig. 3.19 Activities and Their Immediate Preceding Activities(IPAs)

➢ Calculations on a precedence network

- Early Activity Start (ES)

  : **Earliest time that an activity can start** as determined by the latest of the early finish times of all immediately preceding activities (IPAs)

- Early Activity Finish (EF)

  : Earliest time that ac activity can finish **(EF = ES + Duration)**

- Late Activity Start (LS)

  : Latest time that an activity can start without delaying the project completion **(LS = LF – duration** or **LS = ES + TF)**

- Late Activity Finish (LF)

  : Latest time that an activity can be finished without delaying the entire project completion (LF = EF + TF)

Activity			
ES	Duration		LS
EF	FF	TF	LF

Fig. 3.18 A Simplified Yet Informative Format for a Precedence Activity

Ch.3: Precedence Diagrams

➢ Calculations on a precedence network

- Free Float(FT)

  : Amount of time that an activity can be delayed **before it impacts the start of any succeeding activity**

- Total Float(TF)

  : Amount of time that an activity can be delayed **before it impacts the completion date of the project**

- LAG

  : Amount of time that exists **between the early finish of an activity and the early start of a specified succeeding activity**

Ch.3: Precedence Diagrams

- **Calculations on a precedence network**

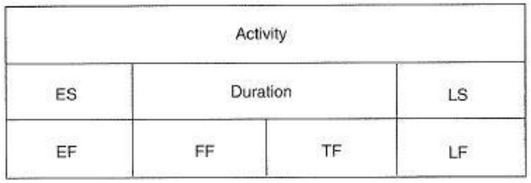


Fig. 3.18 A Simplified Yet Informative Format for a Precedence Activity

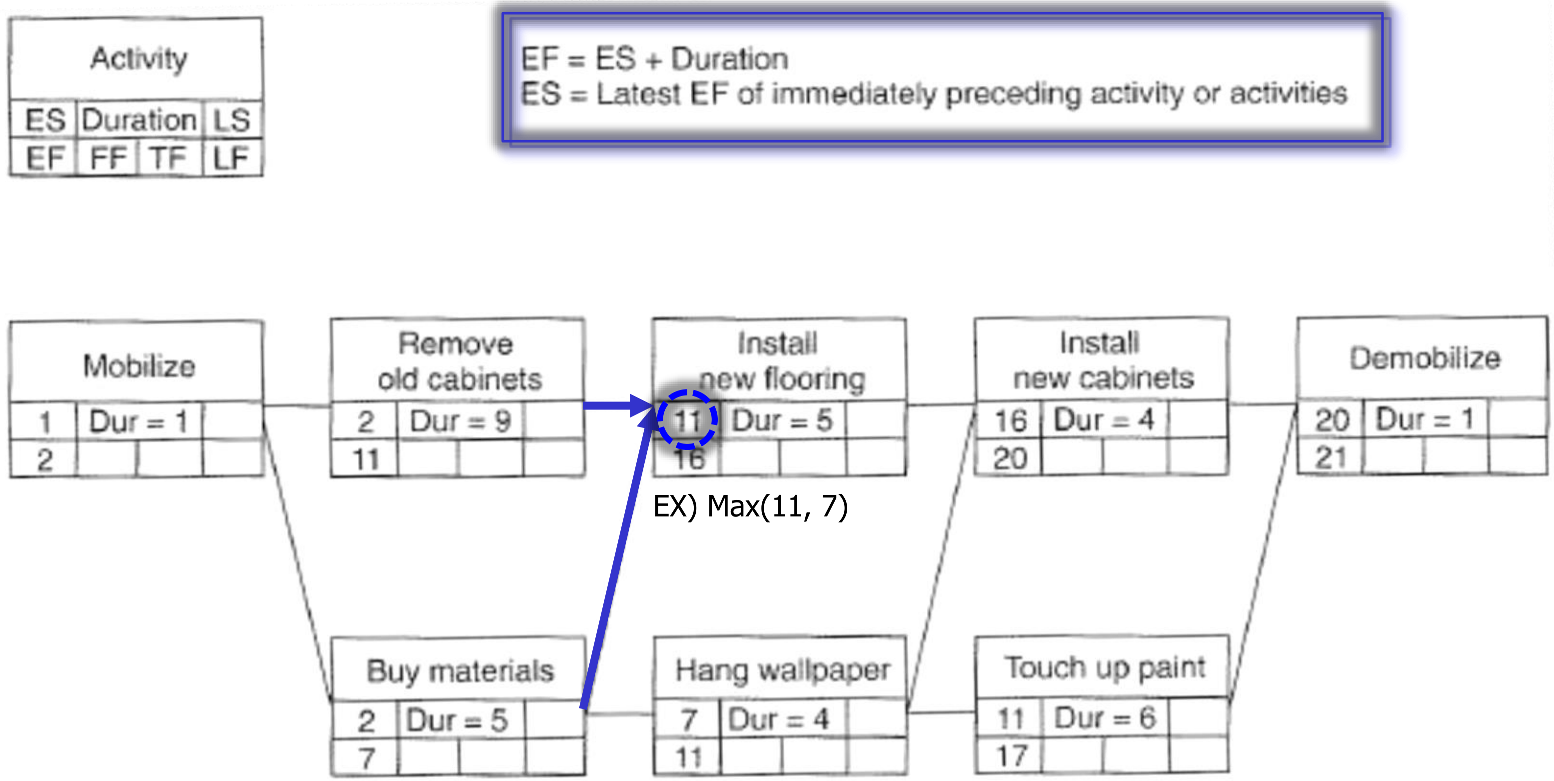


Figure 3.22 Network for a Simple Remodeling Project Showing ES and EF for Each Activity

Ch.3: Precedence Diagrams

➢ **Calculations on a precedence network**

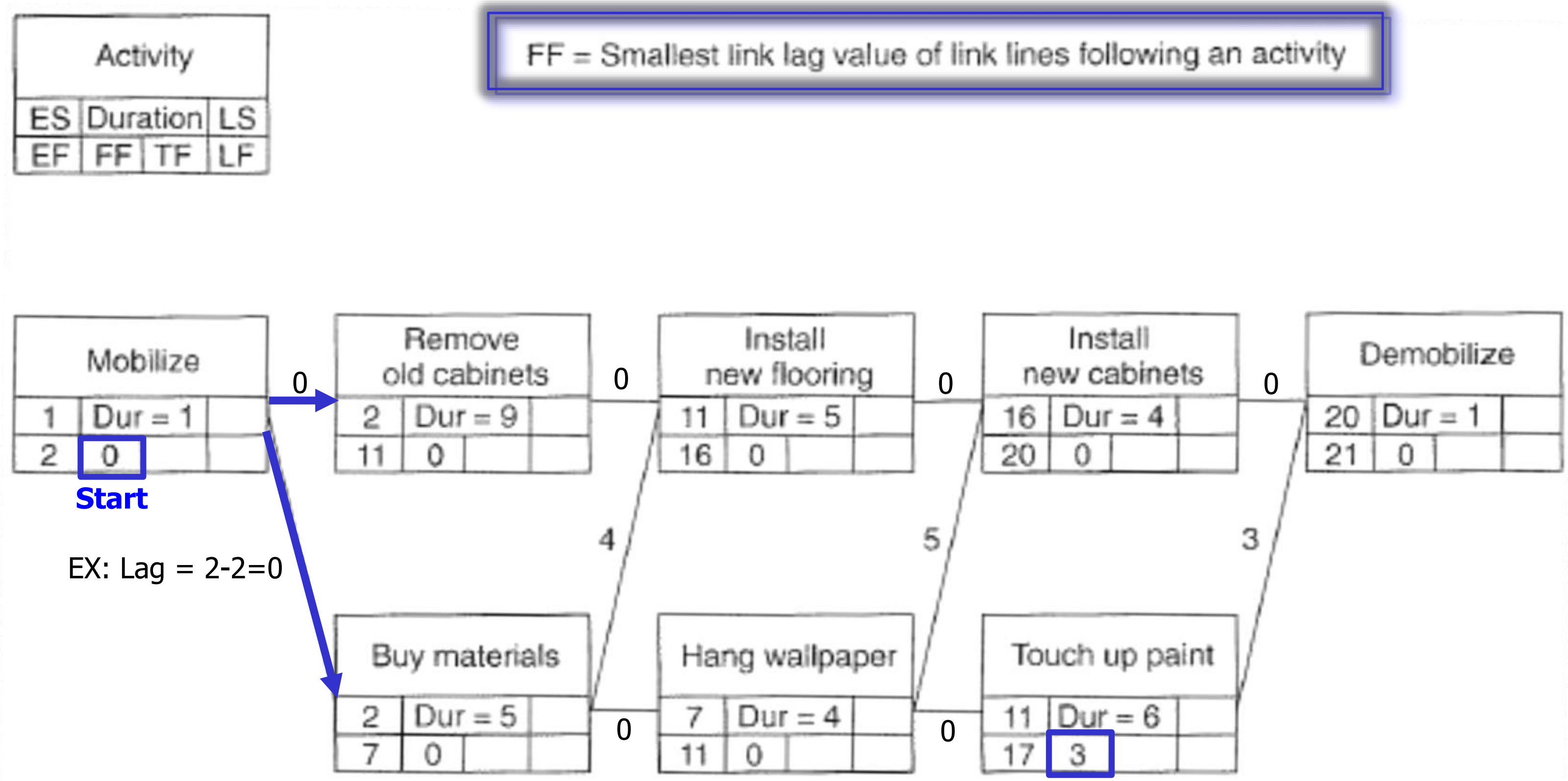


Figure 3.23 Network for a Simple Remodeling Project Showing ES, EF, and FF

Ch.3: Precedence Diagrams

- **Calculations on a precedence network**

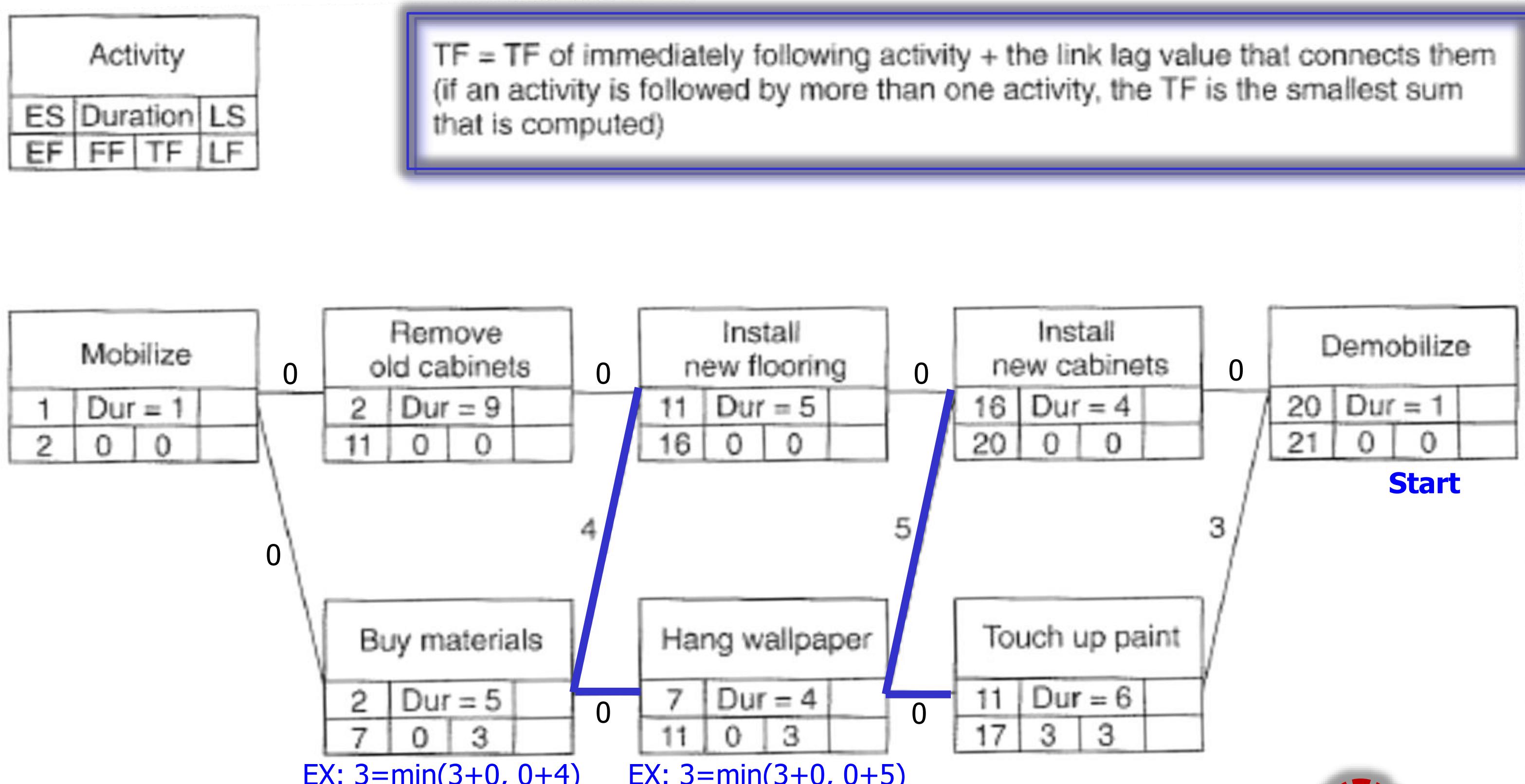


Figure 3.24 Network for a Simple Remodeling Project Showing ES, EF, FF, and TF

Ch.3: Precedence Diagrams

➢ Calculations on a precedence network

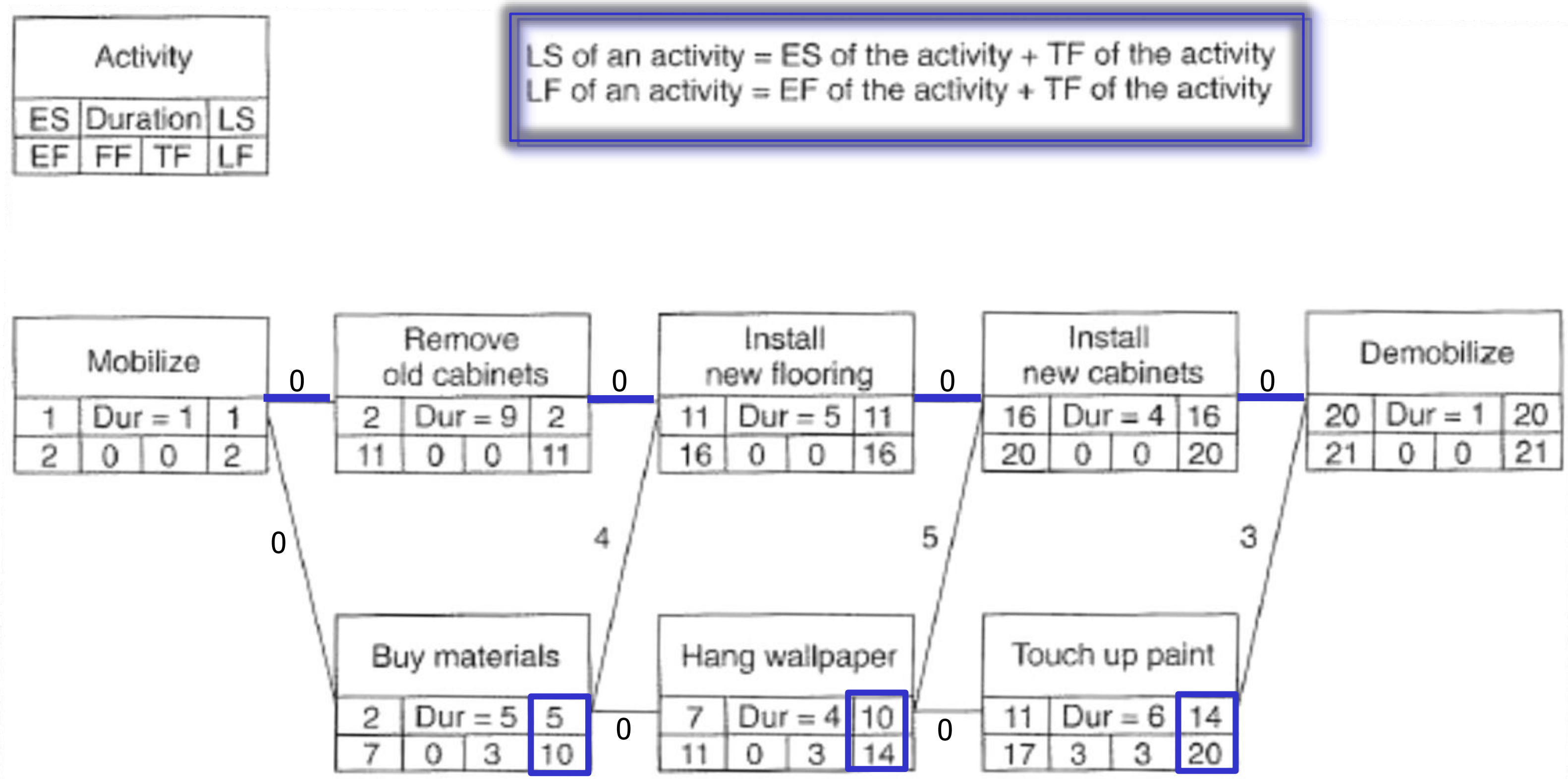


Figure 3.25 Network for a Simple Remodeling Project Showing ES, EF, FF, TF, LS, and LF

➢ **Result means that the project will be completed at the beginning of the workday on day 21**

➢ Independent float and interfering float

- **Total float(TF) and free float(FF) are the most commonly used types**
- **Independent float (safe float) and interfering float (shared float) are seldom used**
  - Independent float is the amount of independent time on **late finish times** of preceding activities and on **early start times** of succeeding activities

    ➔ Amount of time that an activity **can be accelerated for time management**

$$\text{Independent Float}_{\text{Activity A}} = \text{ES}_{\text{Successor}} - \text{LF}_{\text{Predecessor}} - \text{Duration}_{\text{Activity A}}$$

  - Interfering float of an activity is the portion of total float(TF) of activity A that is shared with other activities

    ➔ Amount of time that **an activity(A) can be delayed without impacting on the delay of total project duration**

$$\text{Interfering Float}_{\text{A}} = \text{TF}_{\text{A}} - \text{FF}_{\text{A}}$$

➢Independent float

$$\text{Independent Float}_{\text{Activity A}} = \text{ES}_{\text{Successor}} - \text{LF}_{\text{Predecessor}} - \text{Duration}_{\text{Activity A}}$$

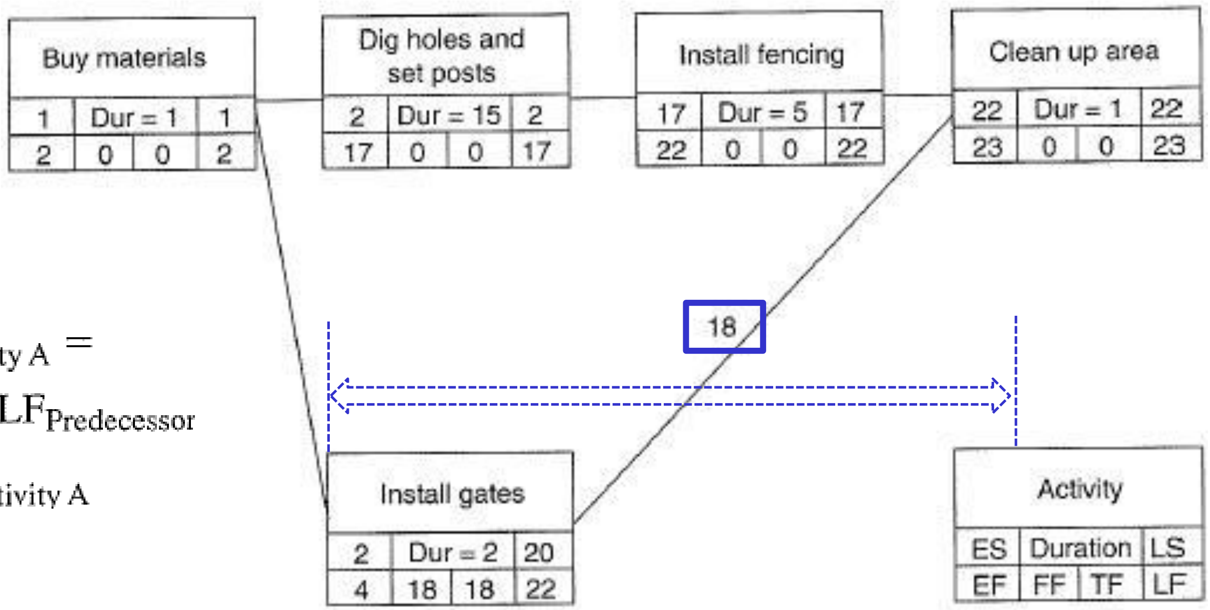


Figure 3.27 Simple Network to Determine Independent Float

Independent Float of Activity "Install Gates"

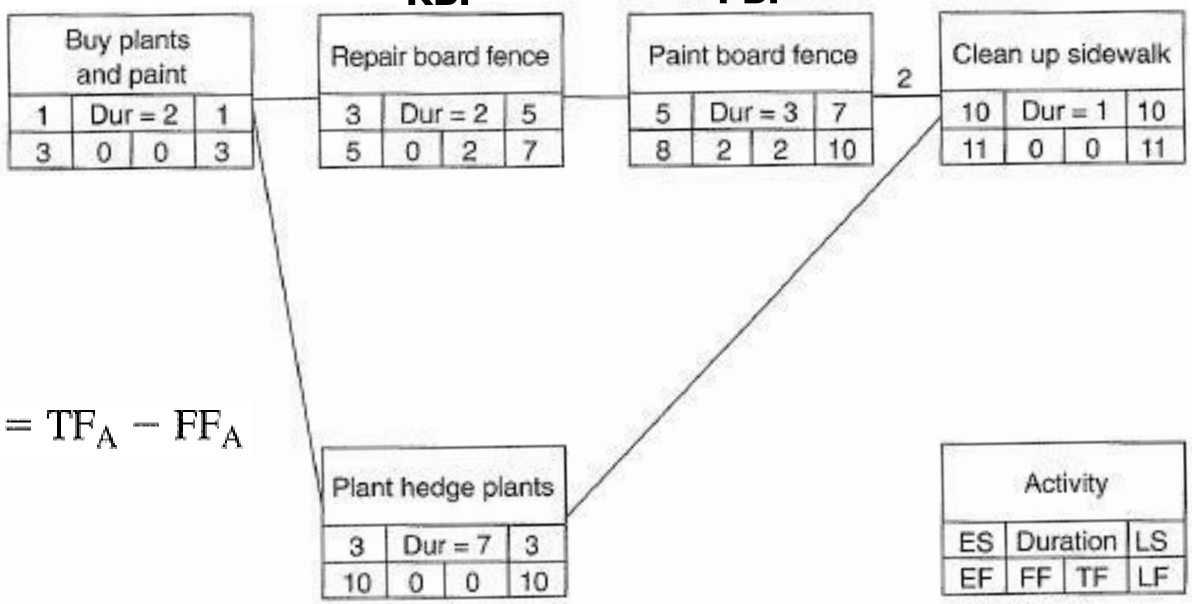
= ES of "Clean Up Area" − LF of "Buy Materials" − Duration of "Install Gates"

= 22 − 2 − 2 = $\boxed{\text{18 days}}$

- "Install Gates" can be completed before the completion "Clean up area" and after the completion "Buy materials"
- This activity("Install Gates") has some ***flexible scheduling strategy*** without delaying total project

➢Interfering float

RBF **PBF**



$$\text{Interfering Float}_A = TF_A - FF_A$$

Figure 3.28 **Simple Network to Determine Interfering Float**

Interfering Float of Activity "Repair Board Fence" **(RBF)**

$$= TF_{\text{Repair Board Fence}} - FF_{\text{Repair Board Fence}}$$
$$= 2 - 0 = 2$$

- **"Repair Board Fence(RBF)" has two hours (or days) of interfering float**
  - **Total float of the RBF is shared with "Paint Board Fence(PBF)"**, which is a successor
  - **If RBF is delayed by one hour, this will interfere with the scheduled start time of PBF** by one hour, **but the project will finish on time**

Ch.3: Precedence Diagrams

➢Interfering float

FOR ACTIVITY "HANG WALLPAPER"

Independent Float of Activity "Hang Wallpaper"

$= ES_{\text{Touch-up Paint}} - LF_{\text{Buy Materials}} - \text{Duration}_{\text{Hang Wallpaper}}$

$= 11 - 10 - 4 = -3$ days (reported as 0)

Interfering Float of Activity "Hang Wallpaper"

$= TF_{\text{Hang Wallpaper}} - FF_{\text{Hang Wallpaper}}$

$= 3 - 0 = 3$ days

FOR ACTIVITY "TOUCH UP PAINT"

Independent Float of Activity "Touch up Paint"

$= ES_{\text{Demobilize}} - LF_{\text{Hang Wallpaper}} - \text{Duration}_{\text{Touch up Paint}}$

$= 20 - 14 - 6 = 0$ days

Interfering Float of Activity "Touch up Paint"

$= TF_{\text{Touch up Paint}} - FF_{\text{Touch up Paint}}$

$= 3 - 3 = 0$ days

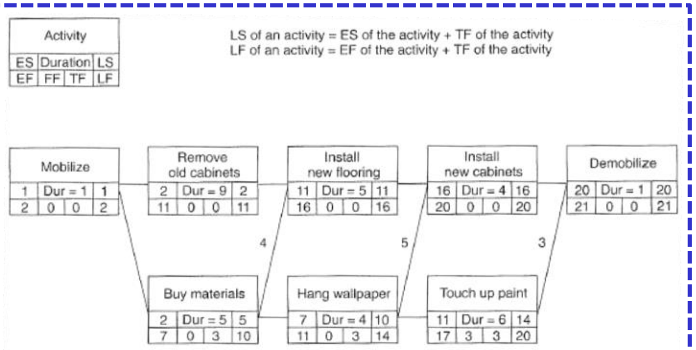


Figure 3.25 Network for a Simple Remodeling Project Showing ES, EF, FF, TF, LS, and LF

- **Negative value of independent float will be interpreted as zero independent float**
  - ***Time is never a negative value (Illogical)***

Ch.4: Determining Activity Durations

- **Estimating Costs**
  - **Conceptual Estimates**
  - **Detailed Estimate**
- **Estimating Durations**
- **Factors Influencing Choice of Activity Schedules**
  - **Weather and Schedule**
  - **Uncertainty in Duration Estimates**

Ch.4: Determining Activity Durations

➢ Estimating Costs

- **Conceptual Estimates**
  - **Approximate cost of a project** before making a final decision to construct it
  - Generally prepared by **architects**, **engineers**, or other **consultants**
- **Detailed Estimate**
  - Usually **prepared by contractors** prior to **bidding** competition
  - Include the costs of materials, labor, equipment, subcontracted work, overhead, and profit
- **Conducting a detailed estimate**
  - **Detail quantity take-off** (thorough analysis of the physical that must be incorporated in the final project)
  - Costs of **unit price** (i.e. labor, equipment, materials etc.)
  - Computing **home-office overheads**
  - Should form the **foundations** on which the schedule is actually based

Ch.4: Determining Activity Durations

- **Estimating Durations *(<u>Considerations</u>)***
  - **Size of the activity**
    - Quantity take-off
    - **Production rate**
  - **Amount of accuracy to be required**
  - **Historically reliable data of the similar projects in the past**

Ch.4: Determining Activity Durations

➢ Factors Influencing Choice of Activity Schedules

- **Weather and Schedule**
  - Potential of **weather-dependent activity** would be based on the likelihood that a delay would occur as well as the extent of the delay
- **Uncertainty in Duration Estimates**
  - **Amount of unexpected potential** that an activity fails to achieve successfully an expected time (Quantifying approach -> See Table 4.3)
  - Based on **historical data of similar cases** in the past

➢ Computing the amount of uncertainty

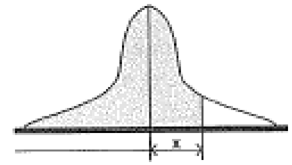
- **Standard Normal Distribution:** $f(x) = \frac{1}{\sqrt{2\pi}} \exp\left(\frac{1}{2}x^2\right)$
- **Z-score:** $\frac{x-\mu}{\sigma}$ (μ : mean and σ : standard deviation)

Ch.4: Determi

- Area of the curve = 1
- Mean = 0
- Standard deviation = 1

AREA UNDER A STANDARD NORMAL CURVE

x = The number of standard deviations to the right of the mean



The area under the curve (as shown in the table) always includes the portion containing the mean.

X	0	1	2	3	4	5	6	7	8	9
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5754
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7258	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7518	.7549
0.7	.7580	.7612	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7996	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9649	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9919	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990

Ch.4: Determining Activity Durations

➢Computing the amount of uncertainty

- Ex.) Historical information of two activities ("Masonry" and "Carpet")

	Masonry Data		Carpet Data	
Project #	Duration (Dur)	(Dur-Mean)^2	Duration (Dur)	(Dur-Mean)^2
1	14	36	18	4
2	17	9	21	1
3	27	49	19	1
4	16	16	22	4
5	18	4	17	9
6	25	25	22	4
7	23	9	21	1
	$\text{Sum}_1 = 140$	$\text{Sum}_2 = 148$	$\text{Sum}_1 = 140$	$\text{Sum}_2 = 24$
	$\text{Mean}_1 = 20$	$(\text{Sum}_2/n-1)^{1/2} = 4.97$	$\text{Mean}_1 = 20$	$(\text{Sum}_2/n-1)^{1/2} = 2$
	$n = 7$	Std. Dev. = 5 (approx.)	$n = 7$	Std. Dev. = 2

- **Masonry** ($\mu_{Masonry}$: 20 and $\sigma_{Masonry}$: 4.97)
- **Carpet** (μ_{Carpet} : 20 and σ_{Carpet} : 2)

Ch.4: Determining Activity Durations

- **Computing the amount of uncertainty**
  - **Ex.) Historical information of two activities ("Masonry" and "Carpet")**
  - **Masonry** ($\mu_{Masonry}$: 20 and $\sigma_{Masonry}$: 4.97) >> Z-score = (22-20)/4.97 = 0.4 -> 0.6554 (65.54%)
  - **Carpet** (μ_{Carpet} : 20 and σ_{Carpet} : 2) >> Z-score = (21-20)/2 = 0.5 -> 0.6915 (69.15%)
  - **Probability that "Masonry" will be completed within "x" is 0.8023, Find "x"?**
  - **Probability that "Carpet" will be completed within "x" is 0.9015, Find "x"?**

    >> 22.58

Ch.4: Determining Activity Durations

- Exercise #1: Scaffolding is to be constructed on all faces of a **six-story building** in order major masonry rehabilitation work to be performed. The exposed surface area of the exterior walls of the building has been estimated to be **432,000 sq.ft**. **Historical records** of the company show that for this simple type of structure, **production rate** for erecting scaffolding is **0.002 hours per square foot** of building surface area. If **10 workers** (working 8-hour days) are assigned to do the entire scaffolding erection, **what duration** (in working days) should be used for this activity?

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Worker hours to erect scaffolding	= 432,000 sq. ft. * .002 hours per sq. ft. = 864 hours
Hours required per worker	= 864 hours / 10 workers = 86.4 hours per worker
Time required per worker in days	= 86.4 hours / 8 hours per day = 10.8 days or 11 days

Ch.4: Determining Activity Durations

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➢ Probabilistic determination of activity duration

- **Estimated on "Optimistic (a)", "Most Likely (m)", and "Pessimistic (b)"**
  - Uncertain to compute the hours per square foot of building surface area

    : Could not be a exact number (0.002), but a range-estimation (0.001~0.003)

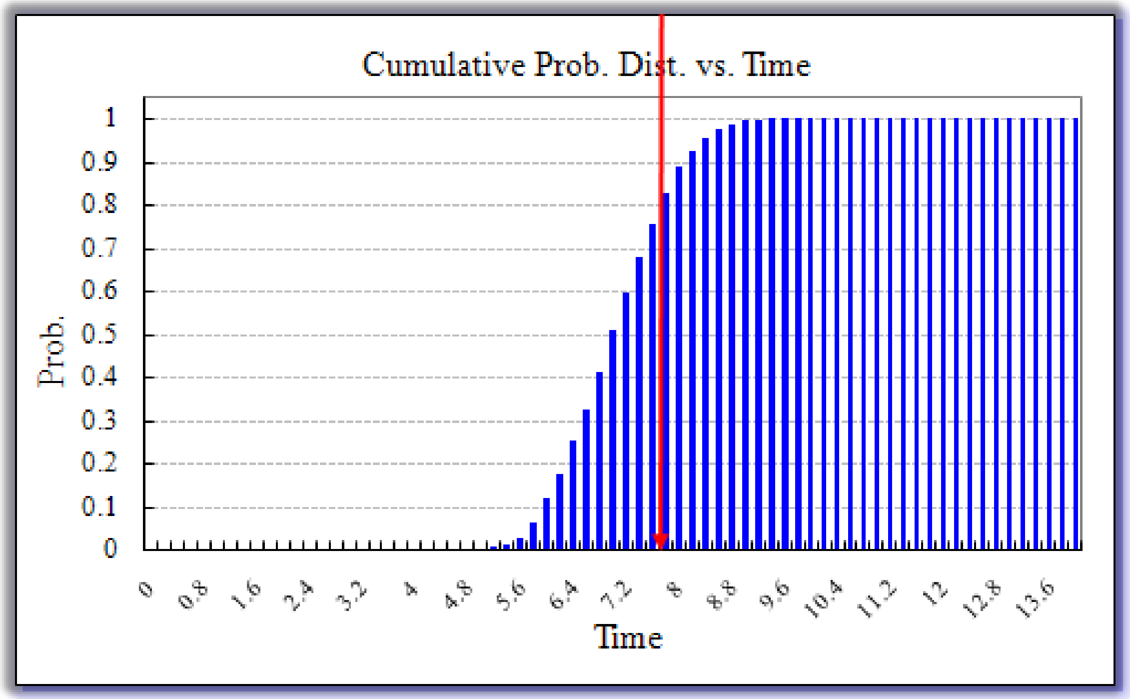
$$Expectation(\mu) = \frac{(a + 4m + b)}{6}$$

$$Variance(\sigma^2) = \left(\frac{(b-a)}{6}\right)^2$$

$$Z\_score = \frac{Expectation - x}{\sigma}$$

Ch.4: Determining Activity Durations

- **Probabilistic determination of activity duration**
  - **Provide "probability distribution" on the expected duration of an activity**
    - This distribution presents valuable information for decision-makers or schedulers to adjust the flexibility of total project duration



Ch.4: Determining Activity Durations

- Exercise #2: Tiles (6” x 6”) can be installed at a rate of 50 per worker hour. The floor of a large lobby area (80’ x 40’) is to be covered with these tiles. If 3 workers are assigned to this task, what duration (to the nearest whole day) should be assigned to this activity?
  - 6 inch = 0.5 ft.

Ch.4: Determining Activity Durations

- Exercise #2: Tiles (6" x 6") can be installed at a rate of 50 per worker hour. The floor of a large lobby area (80' x 40') is to be covered with these tiles. If 3 workers are assigned to this task, what duration (to the nearest whole day) should be assigned to this activity?
  - 6 inch = 0.5 ft.

Number of tiles per square foot	= 1 sq. ft. / (.5 ft. * .5 ft.) per tile = 4 tiles per sq. ft.
Total number of tiles in the lobby	= 80' * 40' * 4 tiles per sq. ft. = 12,800 tiles
Worker hours to install the tiles	= 12,800 tiles / 50 tiles per hour per worker = 256 hours for one worker
Time to install tiles for 3 workers	= 256 worker hours / 3 workers per crew = 85.33 hours per crew
Time in days to do the job	= 85.33 hours / 8 hours per day = 10.67 days or 11 days