CENG 6101 Project Management

Advanced Scheduling Techniques: Line of Balance, Last Planner

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Scheduling Repetitive Construction Projects

(Line of Balance Technique)

Characteristics of Repetitive Construction

1. Network schedules assume activities can be divided into number of relatively small, discrete activities – sequenced in order of their performance.
2. On some projects, same activities performed by same crew progress continuously for duration of project.

Characteristics of Repetitive Construction

<u>Example</u>

Highway construction – same operations repeated section by section

- Linear nature since one operation (crew) follows another sequentially
- Clearing, grubbing, grading, subbase, base course, paving
- Each activity repeated by same crew from one end of project to the other
- **Rate of progress distinguishes between activities**

Characteristics of Repetitive Construction

3. Network scheduling techniques for repetitive activities result in either very small schedule (if activity durations are large) or very repetitious schedule (if activity durations are subdivided by physical location).

4. Bar charts
   - Only relate activities to time scale and do not indicate activity interdependence
   - Can not indicate variations in rate of progress for linear-type projects

Characteristics of Repetitive Construction

5. Line of Balance technique (LOB) and Linear Scheduling Method (LSM) developed for repetitive activities
   – Origins in manufacturing industry for evaluating production-line flow rate
   – Also called vertical production method (VPM) – applied to high rise construction (typical floors in a high-rise building)
   – Applied to airport runways, pipelines, mass transit, precasting or fabrication, tunnels

Characteristics of Repetitive Construction

6. LOB and LSM can be used to schedule entire project or to evaluate interrelationships among few select activities from larger group in network schedule
   – Network schedules can not distinguish rates of progress among activities

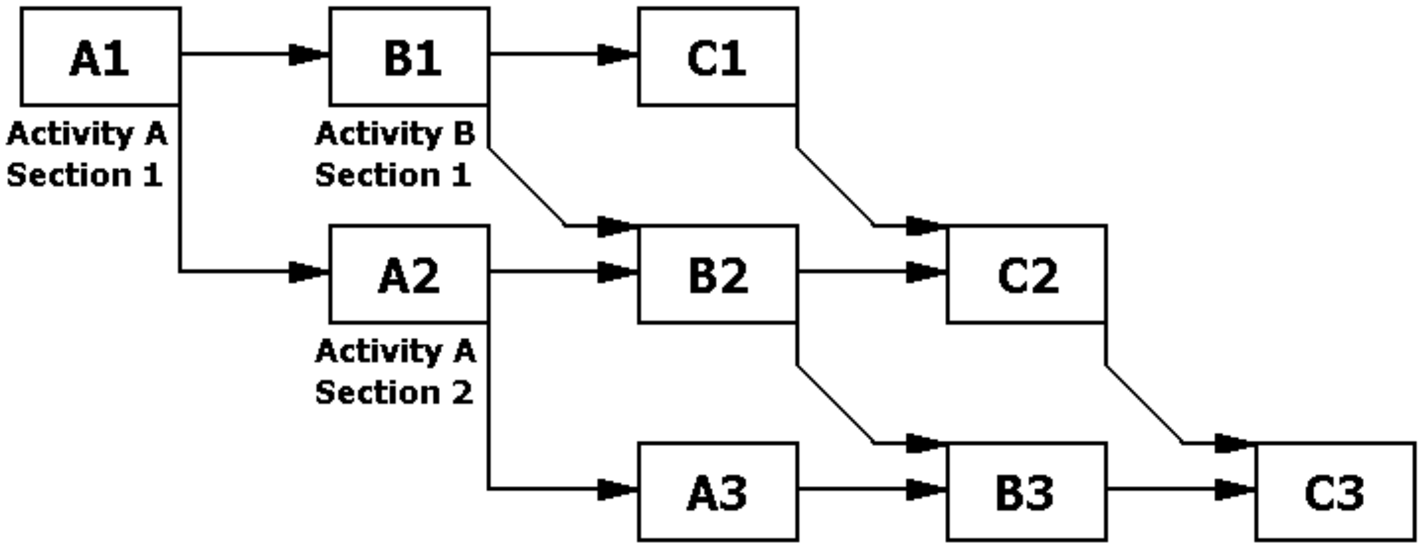
→ Activity duration on network schedule is total time, without showing number of units completed within any period of duration (nor variations in rate of progress of a given activity)

Characteristics of Repetitive Construction

- LOB and LSM display number of units that will be completed within any period of activity's
  - Duration displayed in velocity diagram (shows rates of progress)
- Even if project scheduled by network methods, LOB and LSM can be used to examine rate of progress among few interrelated activities

→ Evaluate activities to adjust, slow, or speed progress among interrelated activities

Logic of Linear Schedule



– Each activity has 2 predecessors:

1. Technological predecessor based on sequence of construction

e.g. drive piles must be complete before construct pile caps can begin.

Logic of Linear Schedule

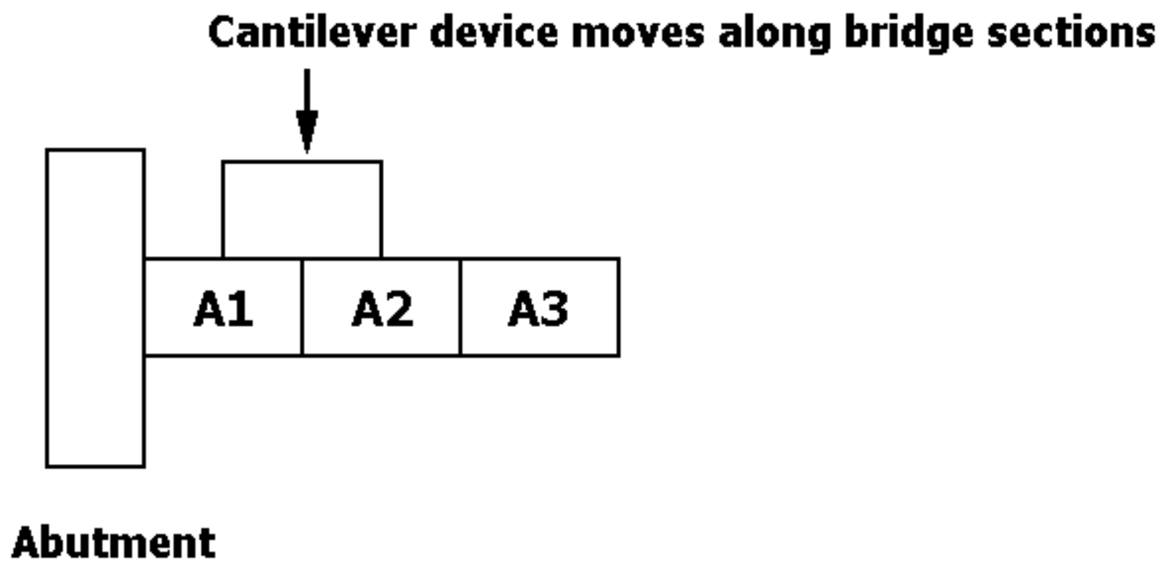
2. Resource (crew) predecessor – if using single crew, crew must have completed work on previous section before moving to next section

e.g. A1 must be complete before A2 begins if using same crew to drive piles.

3. In some cases, technological predecessor of previous section (similar to crew/resource predecessor)

e.g. cantilevering sections of a bridge span (followed by paving, barricading, line marking, etc. on section). Section A2 can not be put in place until section A1 is in place.

Logic of Linear Schedule



∴When performing CPM calculations, ES of activity = latest EF of all 3 types of predecessors

LF of activity = earliest LS of all its successors

Techniques for Scheduling Repetitive Construction

1. Matrix Schedules
   - Fairly common on high-rise buildings with successive floors repeating same plan
   - Fairly narrow application but effective for documenting and communicating a plan

Techniques for Scheduling Repetitive Construction

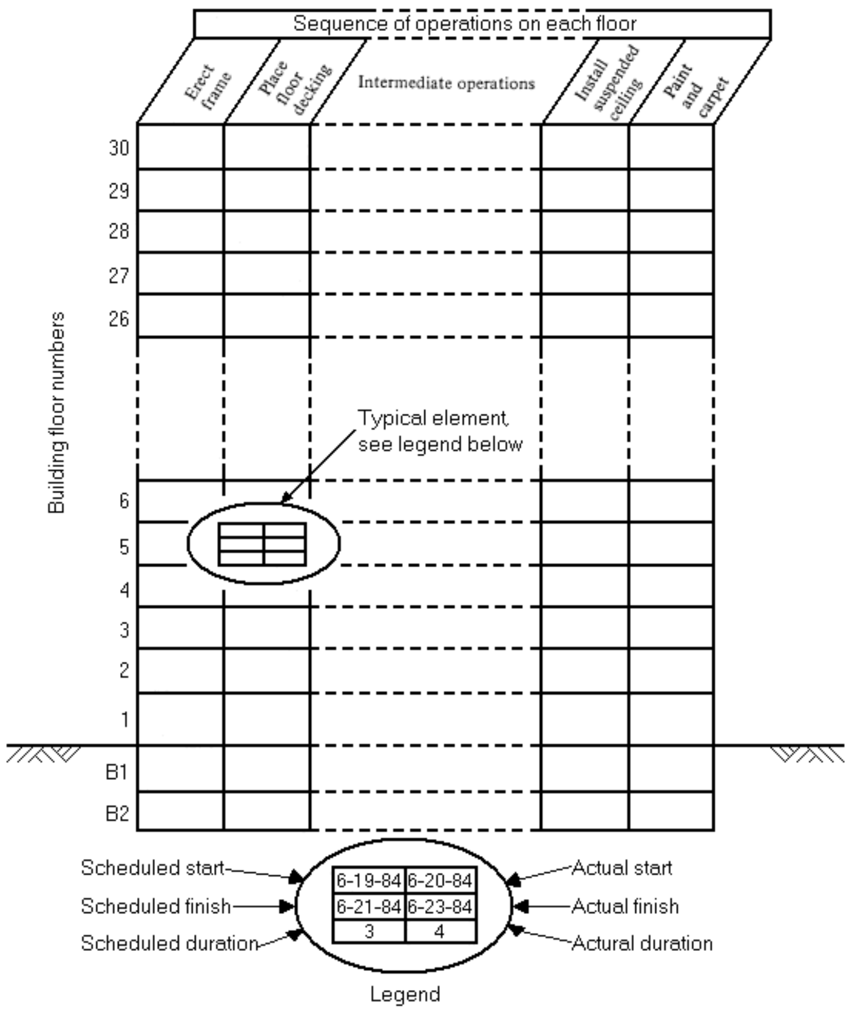


Figure 12-10 Matrix schedule for high-rise building

Techniques for Scheduling Repetitive Construction

Horizontal rows = floors

Vertical columns = operations performed on each floor

- Chronological order is left to right

∴ Building's schedule proceeds from lower left corner to upper right corner

- Each operation at a given location scheduled in box as shown
- Can colour boxes as completed or if delayed
  - gives visual status of progress

Techniques for Scheduling Repetitive Construction

Advantages in communication:

- Vertical correlation of floors to rows obvious – less confusing than arrow and circle notation of CPM
- Chronological Left to Right flow of operations shows logical interrelationships among operations more obviously than in bar chart
- Vertical columns can be made to corresponds to specialty subcontractors

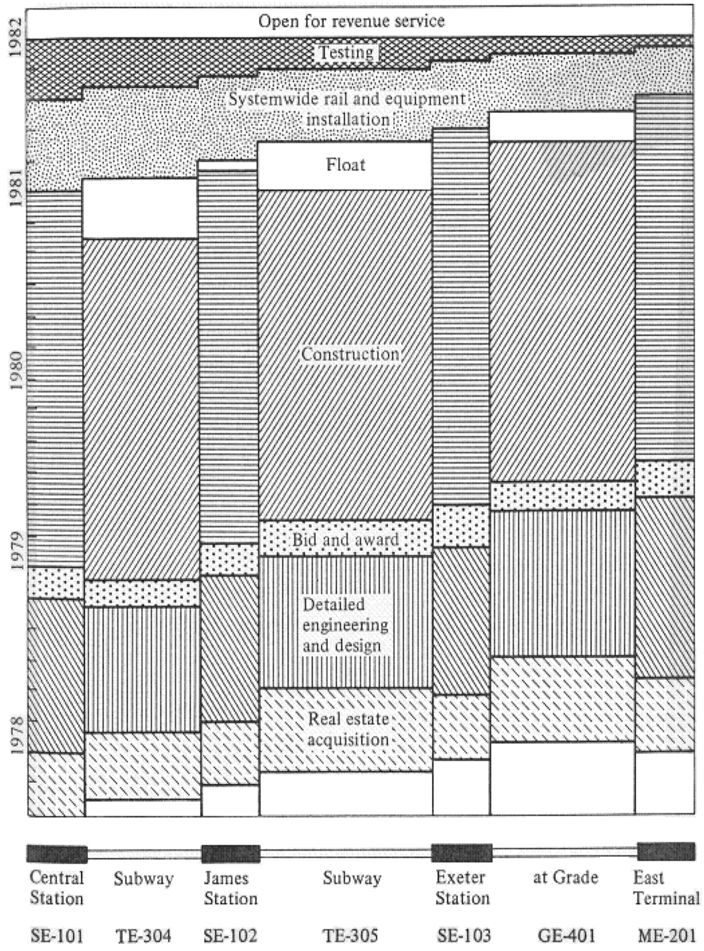
∴ Subcontractors can clearly see all his/her operations in few adjacent columns rather than sorting through maze of activities, and can see relationship to other subcontractors' work

Techniques for Scheduling Repetitive Construction

2. Horse Blanket
   - Variation on matrix schedule, used on some major rail-rapid transit systems
   - Figure 12-11 shows section of transit system intended to go on-line as a unit (all at same date) for revenue service
   - Section contracted for design and construction in several different segments
   - Horizontal axis = line and contractual subdivision
   - Vertical axis = major phases for each contractual section (chronologically from bottom up)

Techniques for Scheduling Repetitive Construction

Figure 12-11
"Hourse blanket" schedule for part of a rail rapid transit system. (Adapted from schedules used on Washington, D.C., and Atlanta, GA rapid transit projects.)



Techniques for Scheduling Repetitive Construction

– Amount of leeway at top of various sections gives management good idea of which parts most critical to project's scheduled start-up

– Schedule is at milestone level

∴ Best for policy-level planning (higher levels of management)

3. Velocity Diagrams/Line of Balance (LOB)
   - Used for scheduling linear or repetitive operations e.g. tunnels, pipelines, highways, high-rise buildings
   - LOB (Vertical Production Method – VPM) uses velocity diagrams to find required resources for each stage or operation so that following stages not interfered with and target output achieved
   - Concepts borrowed from industrial engineering for optimizing output on manufacturing production lines

Techniques for Scheduling Repetitive Construction

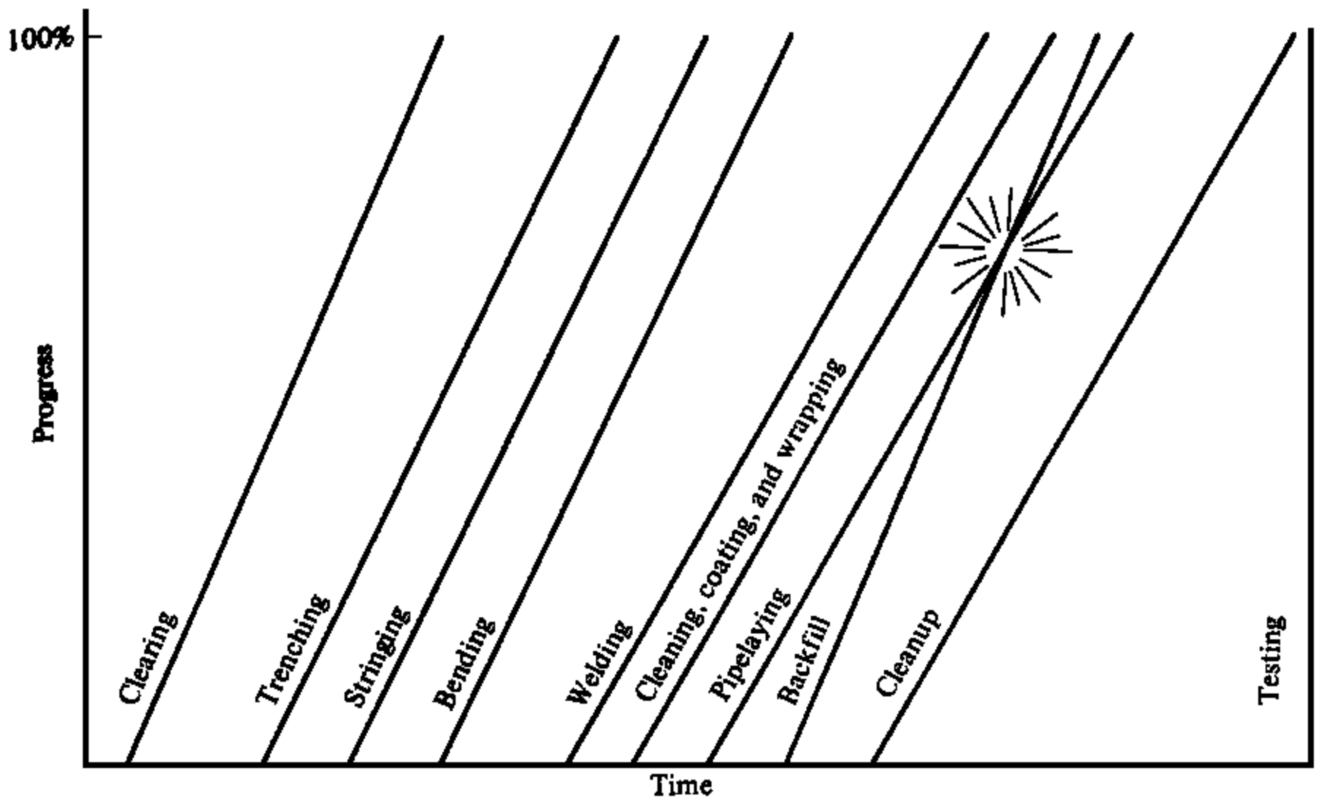


Figure 12-12
Example linear balance chart for pipeline

Techniques for Scheduling Repetitive Construction

- Vertical axis plots cumulative progress or percent completed for different systems of project, e.g. structural, electrical, mechanical, other trade subcontractors on high-rise
- Horizontal axis plots time
- Sloping lines represent rate of production, e.g. trade subcontractors moving up from one floor to another or clearing, excavation, stringing, welding, etc. on pipeline

Techniques for Scheduling Repetitive Construction

– As long as slopes are either equal or decreasing as move to right, project proceeds satisfactorily

– If early scheduling shows one operation proceeding too rapidly, with high slope compared to those preceding it, time and location conflicts become apparent

Example:

Figure 12-12 – Backfill conflicts with pipe laying when each is at 70% complete

Techniques for Scheduling Repetitive Construction

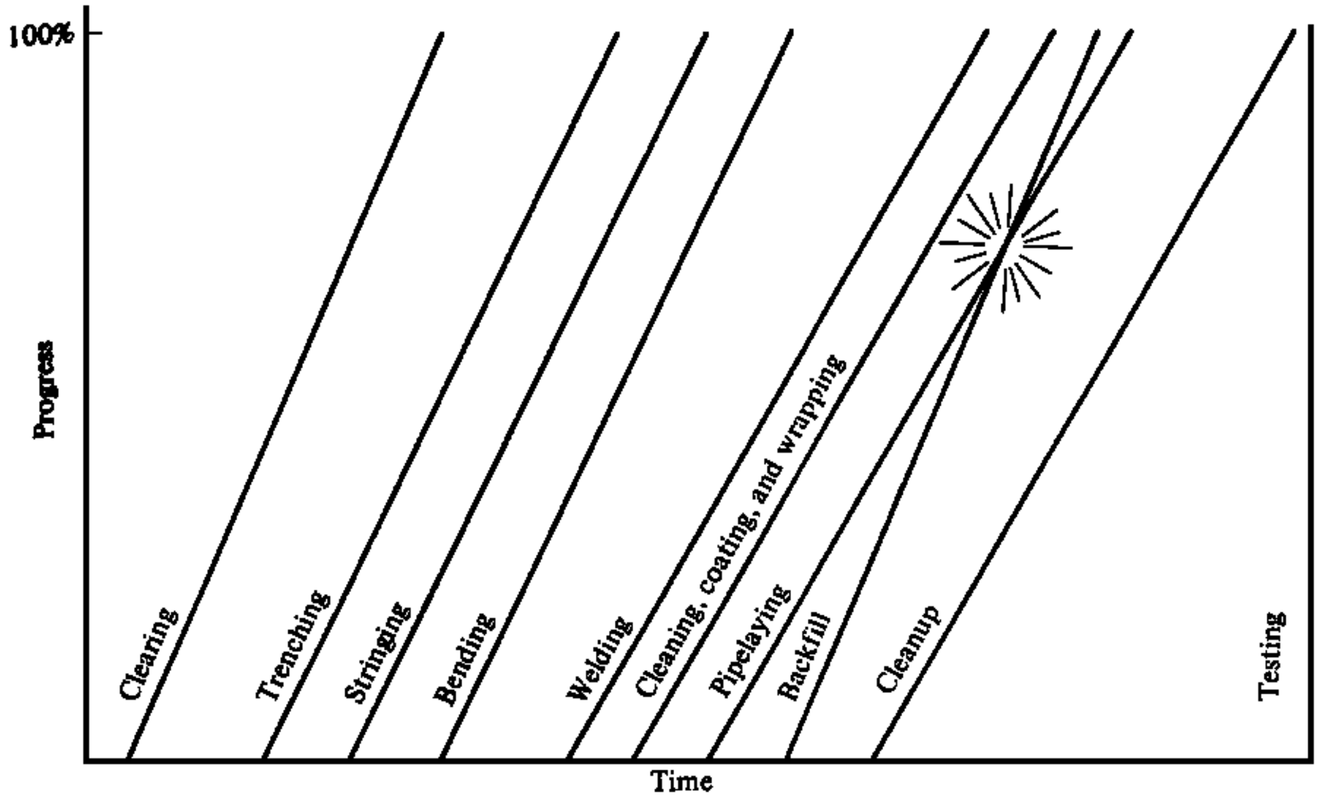


Figure 12-12
Example linear balance chart for pipeline

4. Linear Scheduling Method (LSM)

   – LSM diagram used to plan and record progress on multiple activities performed continually over duration of entire project
   – Horizontal axis plots time, vertical axis plots location or distance along length of project
   – Individual activities plotted separately, resulting in series of diagonal lines

Techniques for Scheduling Repetitive Construction

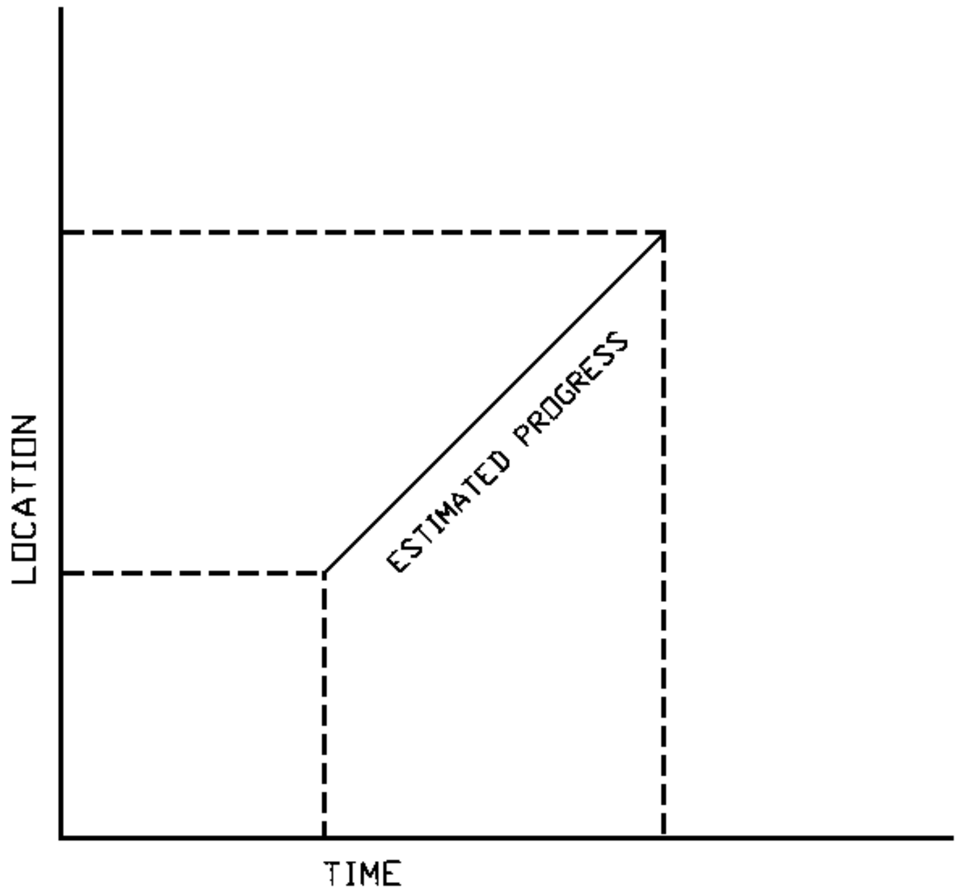


Figure 7-8 Plotting activity progress lines

Techniques for Scheduling Repetitive Construction

- Slopes of lines show planned rate of progress at any location along length of project (can vary at different locations)

- Location can be measured in many ways

e.g. high-rise – floors
Housing – subdivisions, apartments
Transportation – distance (stations 100 ft, km, miles)

- Time measured in workdays, or hours, weeks, months

Techniques for Scheduling Repetitive Construction

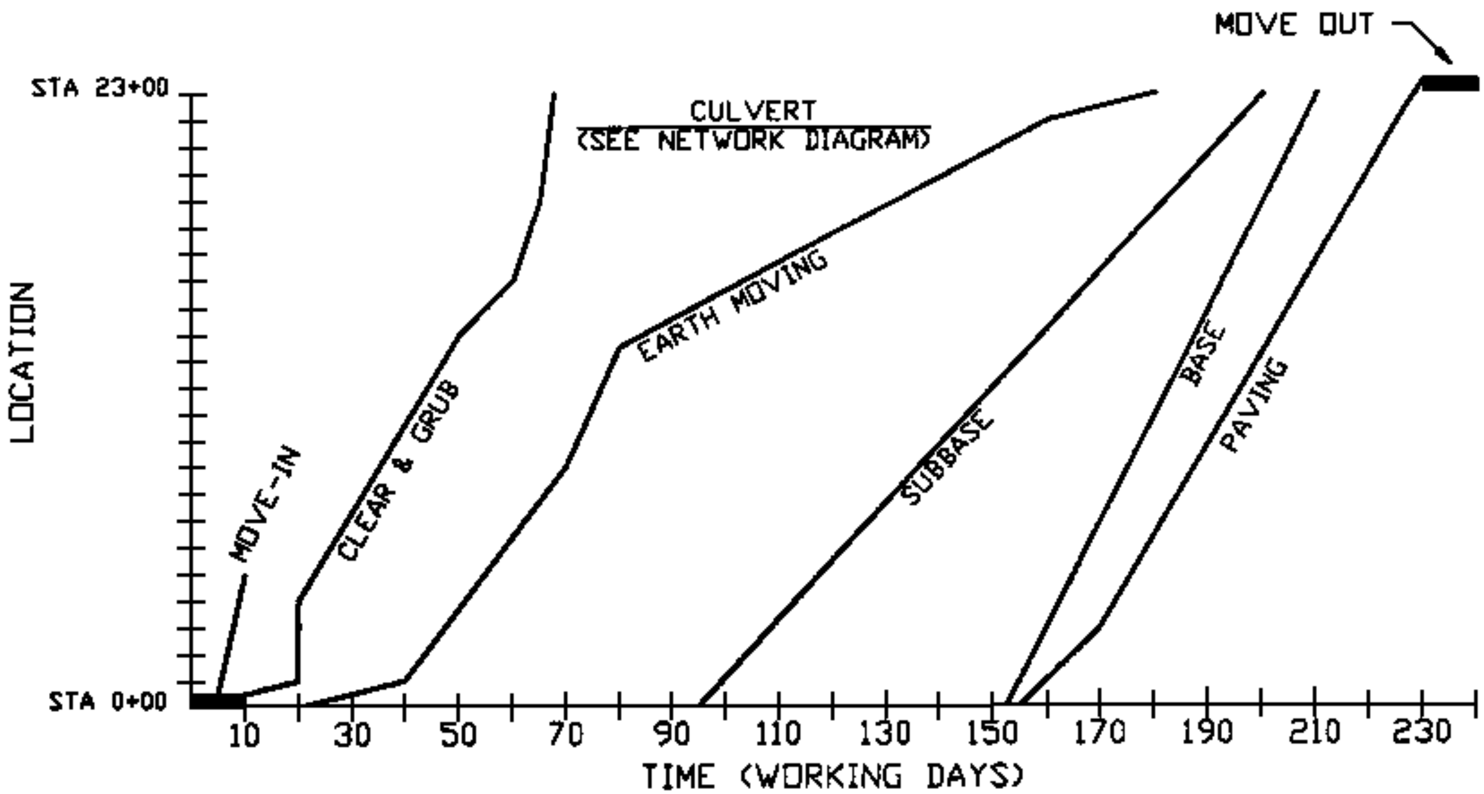


Figure 7-7 **Linear scheduling method diagram**

Techniques for Scheduling Repetitive Construction

- Change in location over time is a measure of activity progress
- Activity durations estimated in same way as for network schedules
- Completion time for each activity function of rate of progress and amount of work to be accomplished
- Initial determination of rate of progress should be based on minimum direct unit cost of completing activity

Techniques for Scheduling Repetitive Construction

- To compress schedule, increase rate of progress
- Generally, either increasing or decreasing rate of progress will <u>increase direct unit cost</u> and therefore completion cost for activity
- <u>Indirect costs</u> may cause shift in optimum rate of progress
  - must do cost comparison and trade-off between direct costs and indirect costs
- <u>Rate of progress may vary</u> due to location or time

Techniques for Scheduling Repetitive Construction

- At beginning of activity, craft productivity lower due to learning curve
- Individual production on activity vary with conditions

e.g. production rates for clearing and grubbing vary with density of forestation

- Known progress variations can be shown on LSM schedule at appropriate location

e.g. Figure 7-7 variation in clear and grub and in earthmoving

Techniques for Scheduling Repetitive Construction

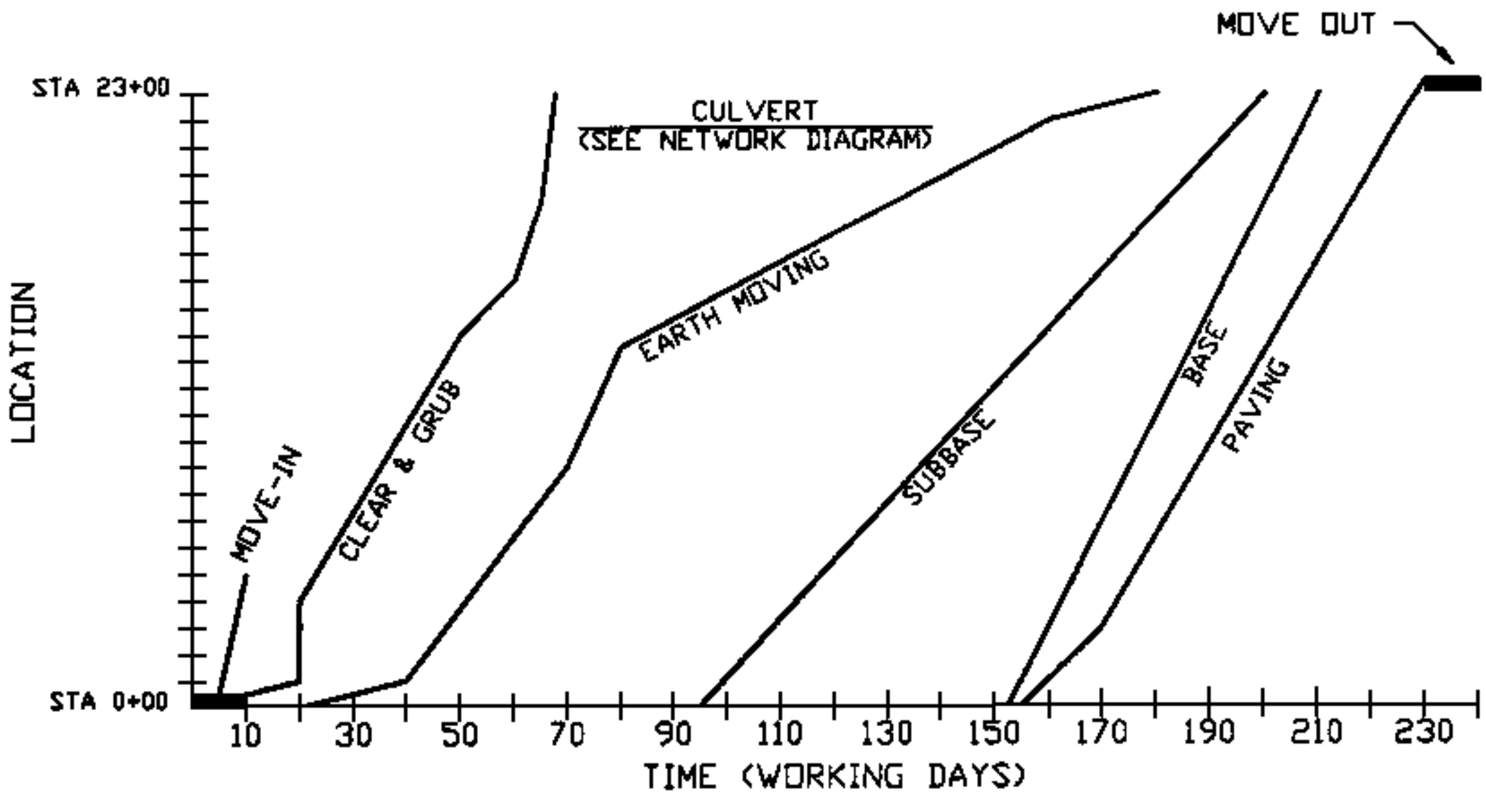


Figure 7-7 Linear scheduling method diagram

Techniques for Scheduling Repetitive Construction

– Progress can be affected by interference from other activities

e.g. equipment maintenance, material restrictions indicated on LSM schedule by restraints

– Figure 7-9: restraint caused by equipment restriction (slip-form paver)

– Paving must be completed on one street before paving can begin on another

– Restraint drawn as dashed line

Techniques for Scheduling Repetitive Construction

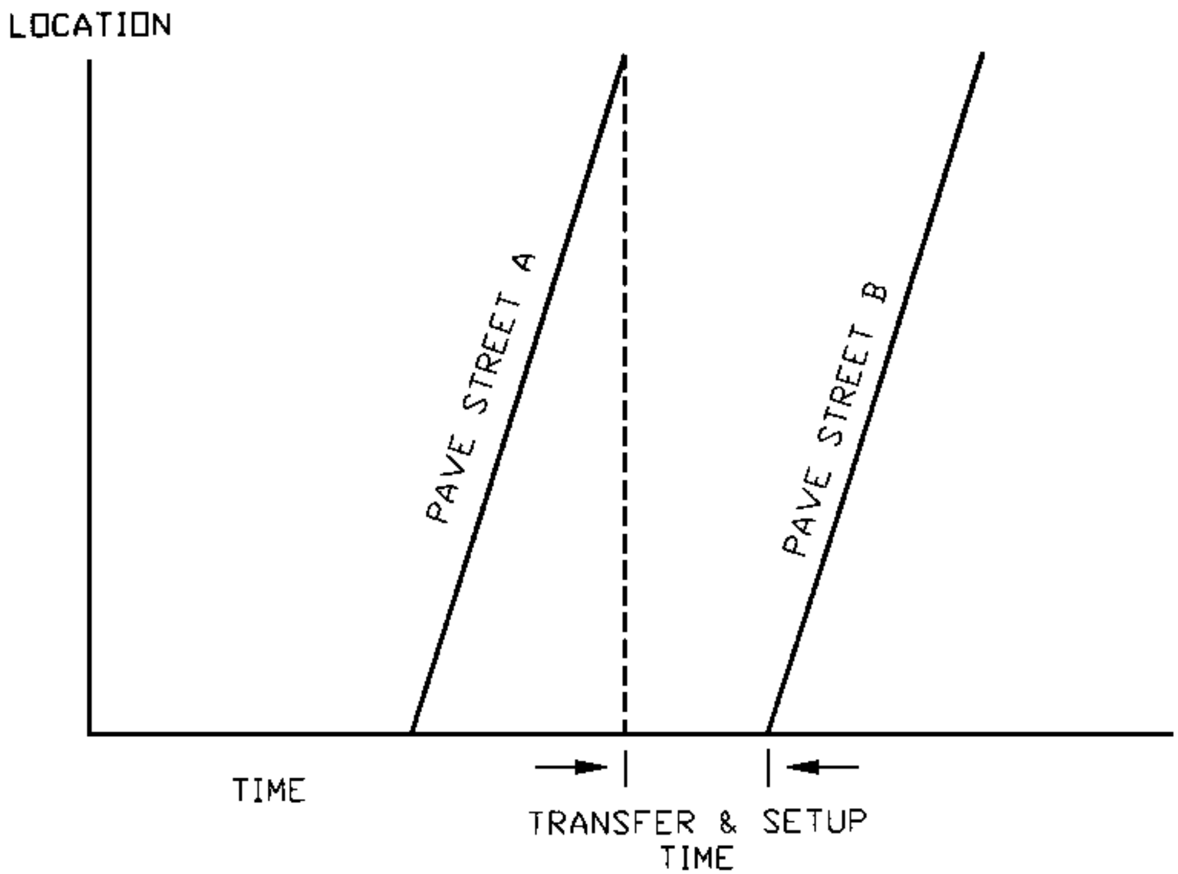


Figure 7-9 Use of restraint on LSM diagram

Techniques for Scheduling Repetitive Construction

– Some spacing on interrelated activities may be required spacing serves as buffer to prevent one activity form interfering with another or to accommodate differences in unit rates

e.g. excavation for new highway may take longer to perform than installation and compaction of subbase material

∴ Subbase delayed from starting until excavation sufficiently ahead to permit subbase work to be performed continuously, alternatively, progress rate slowed of subbase to avoid interference or interruption

Techniques for Scheduling Repetitive Construction

Activity interference between excavation and subbase work – can be avoided by use of buffers

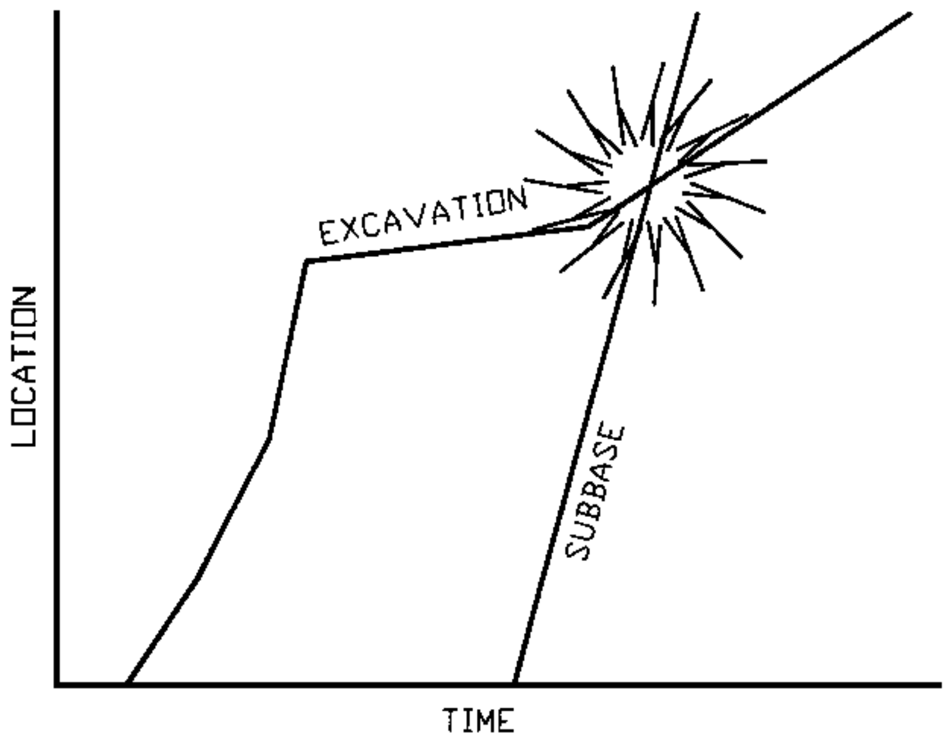


Figure 7-10 Activity interference

Techniques for Scheduling Repetitive Construction

Buffers can indicate required distance or time between activities – drawn as solid lines

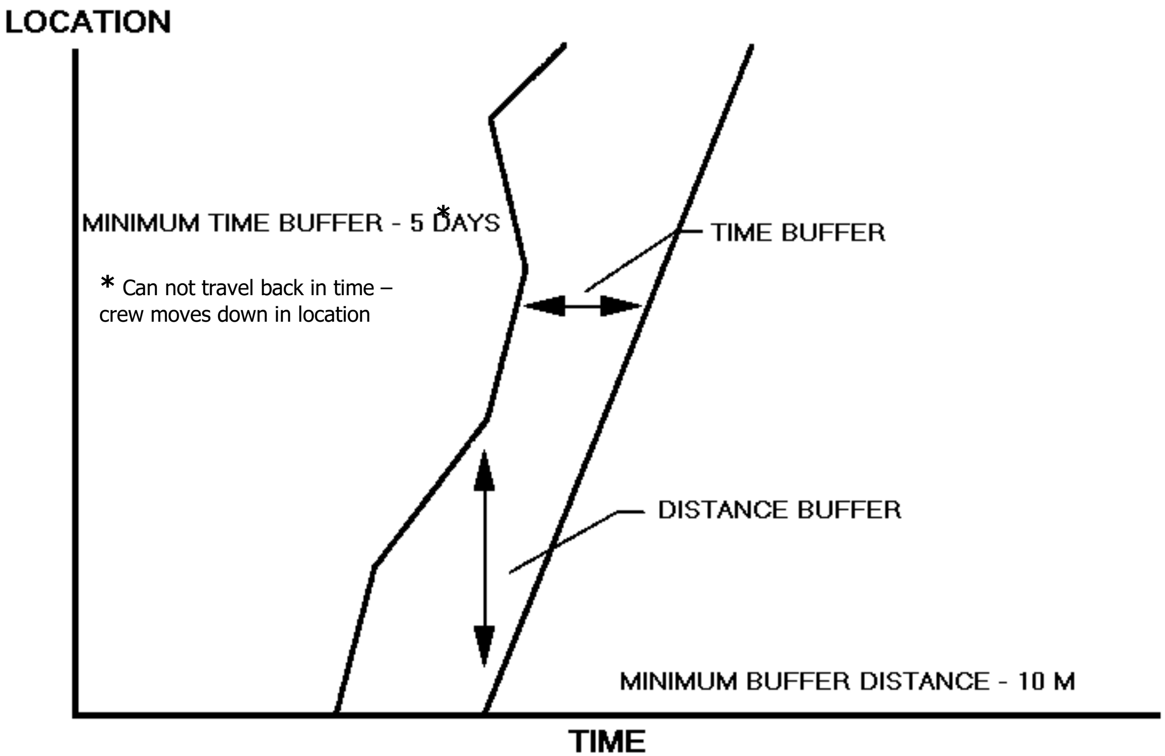


Figure 7-11 Use of activity buffers in LSM schedules

Techniques for Scheduling Repetitive Construction

- Buffers also used to identify critical activities
- Critical activity in LSM schedule has minimum buffer at both start and finish of activity

Minimum (or zero) buffers at either end of activities indicate them to be critical

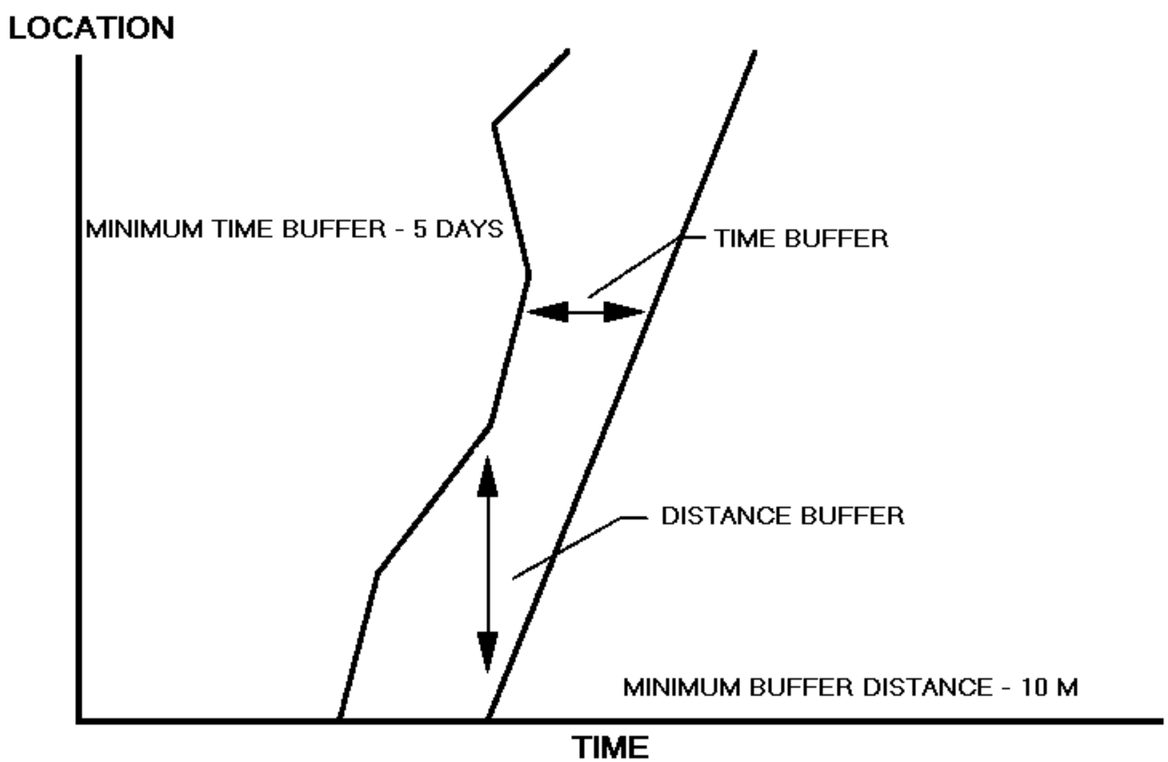


Figure 7-11 Use of activity buffers in LSM schedules

Different ways of showing activity intervals (time between start and finish of activity at any location)

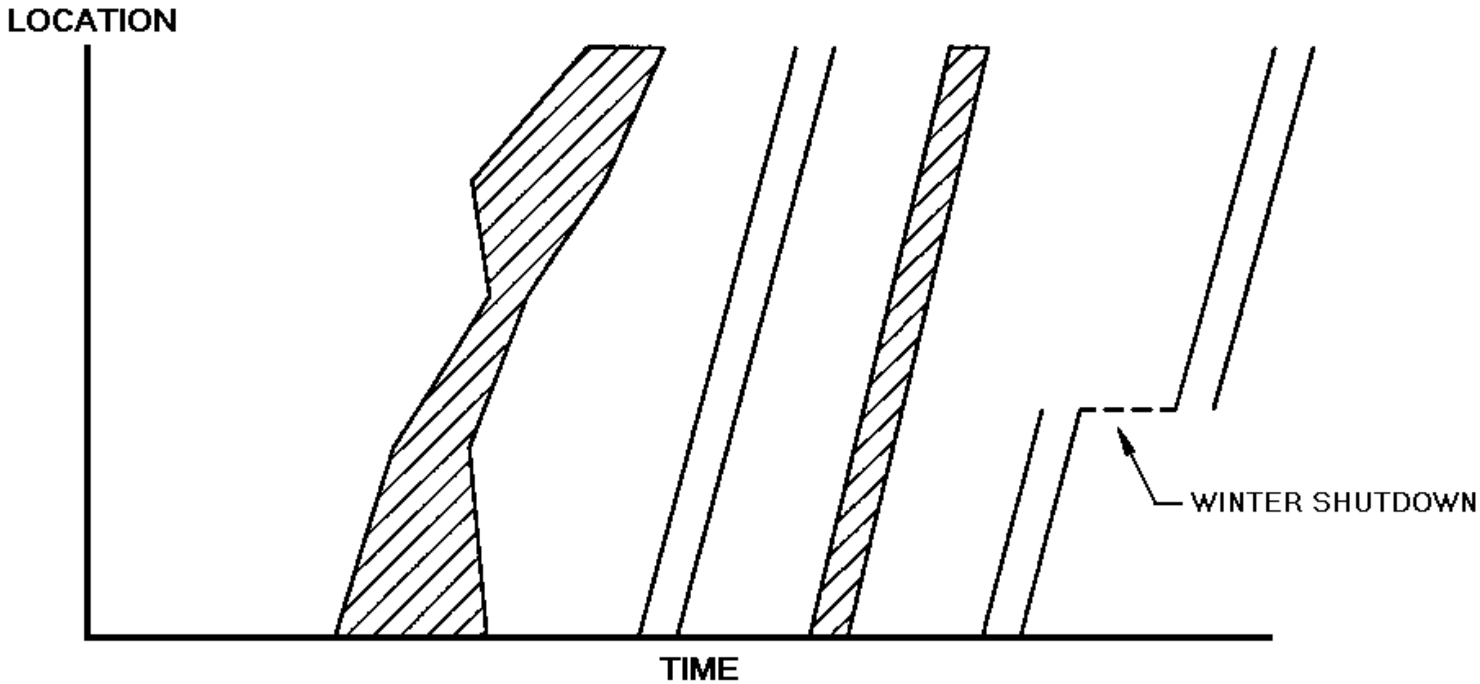


Figure 7-12 Activity intervals for LSM schedules

Techniques for Scheduling Repetitive Construction

Difference Between LOB and LSM

- LOB (Line of Balance) deals with repetitive construction without non-typical durations in sections or non-typical activities
- LSM (Linear Scheduling Method) – designed to incorporate variations in production rates/durations at different sections and non-typical activities

Example of Linear Schedule

Example:

Construction of a Jetty

- Drive piles
- Construct pile cap
- Fix deck

Three activities repeated 10 times.

Example of Linear Schedule

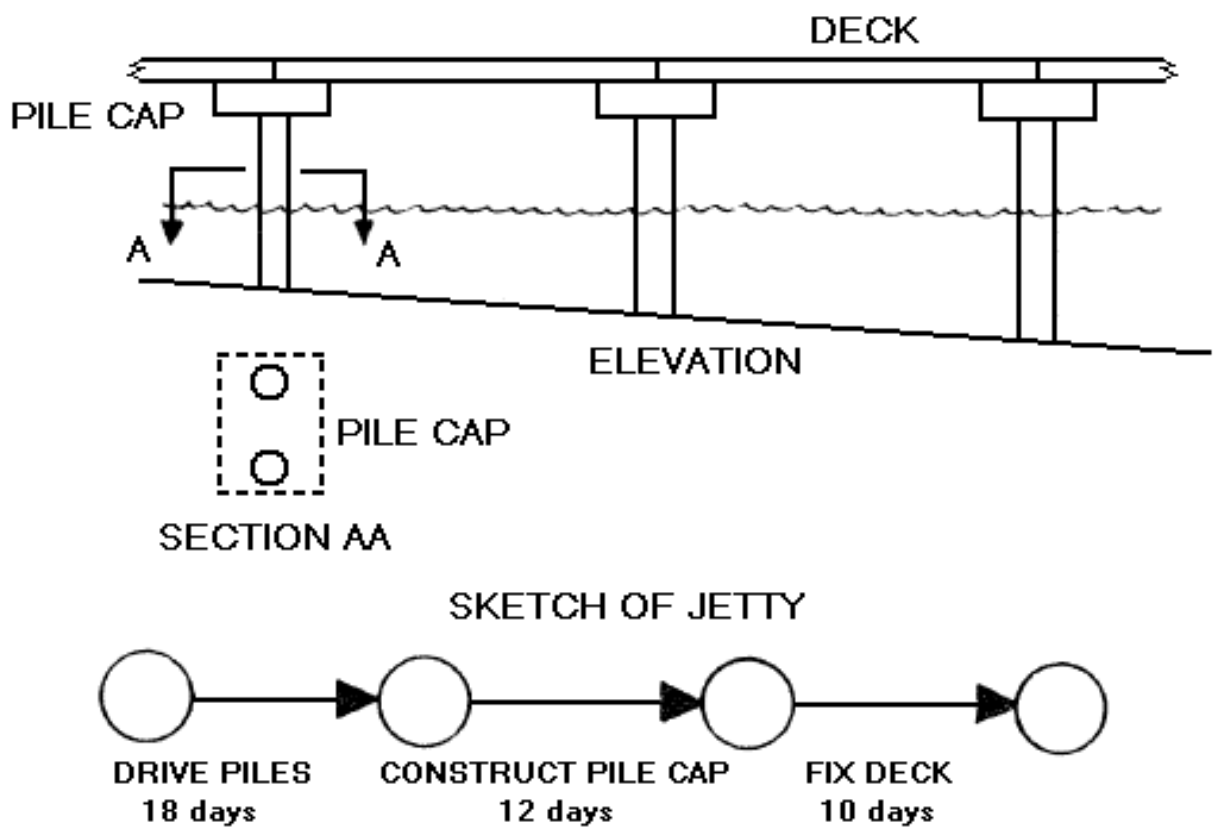


Figure 2.14(a) Simple linear logic diagram

Example of Linear Schedule

Figure 2.14(b) Logic diagram with buffers

– Time buffer between activities

Example of Linear Schedule

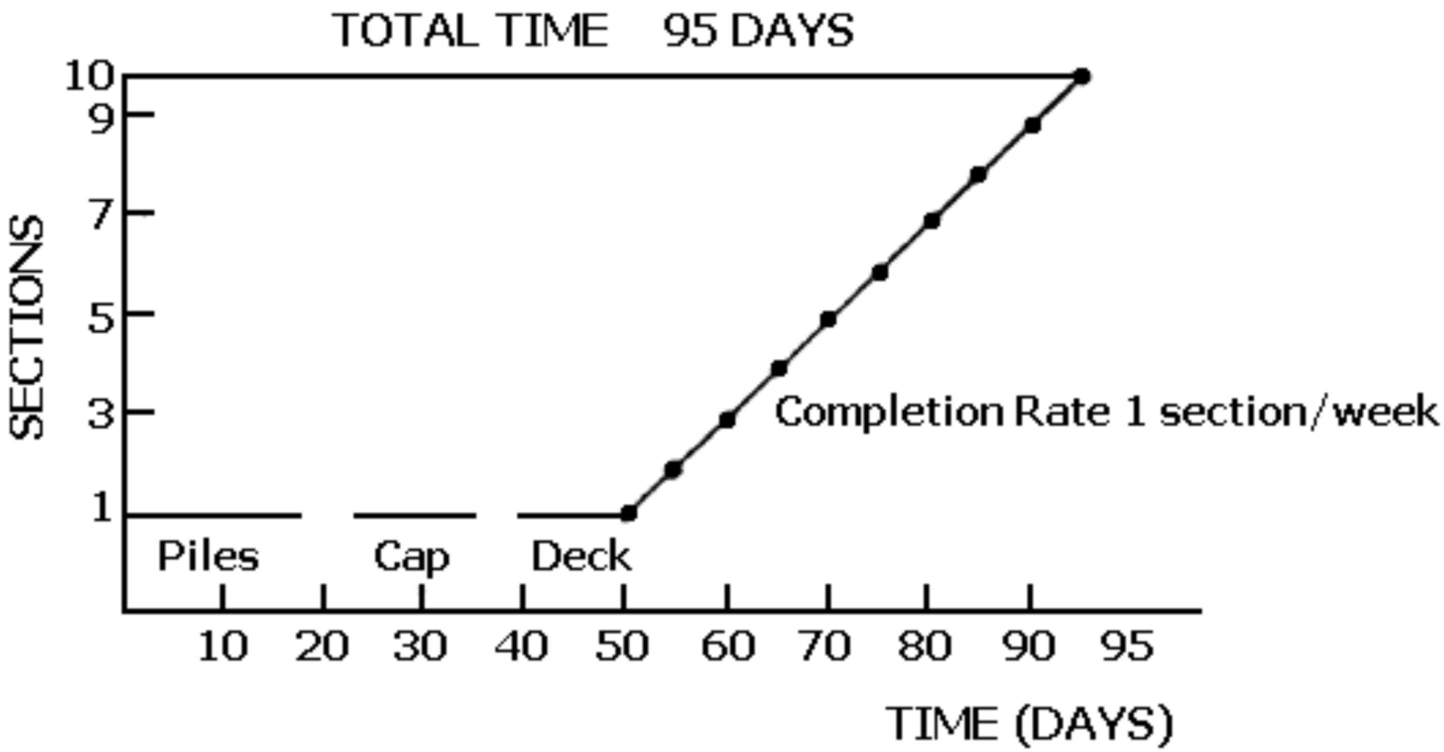


Figure 2.15 Time for completion of ten repetitive sequences at the rate of one per week

Example of Linear Schedule

- 50 days needed to complete 1 sequence of operations
- Target output expressed in terms of completion rate of sequences

Example:
If have target* of 1 section/week (5 working days) would complete project in 19 weeks (95 working days) (see Figure 2.15)

*Target completion rate imposed

∴ Use this output to identify number of crews needed to meet target output

Example of Linear Schedule

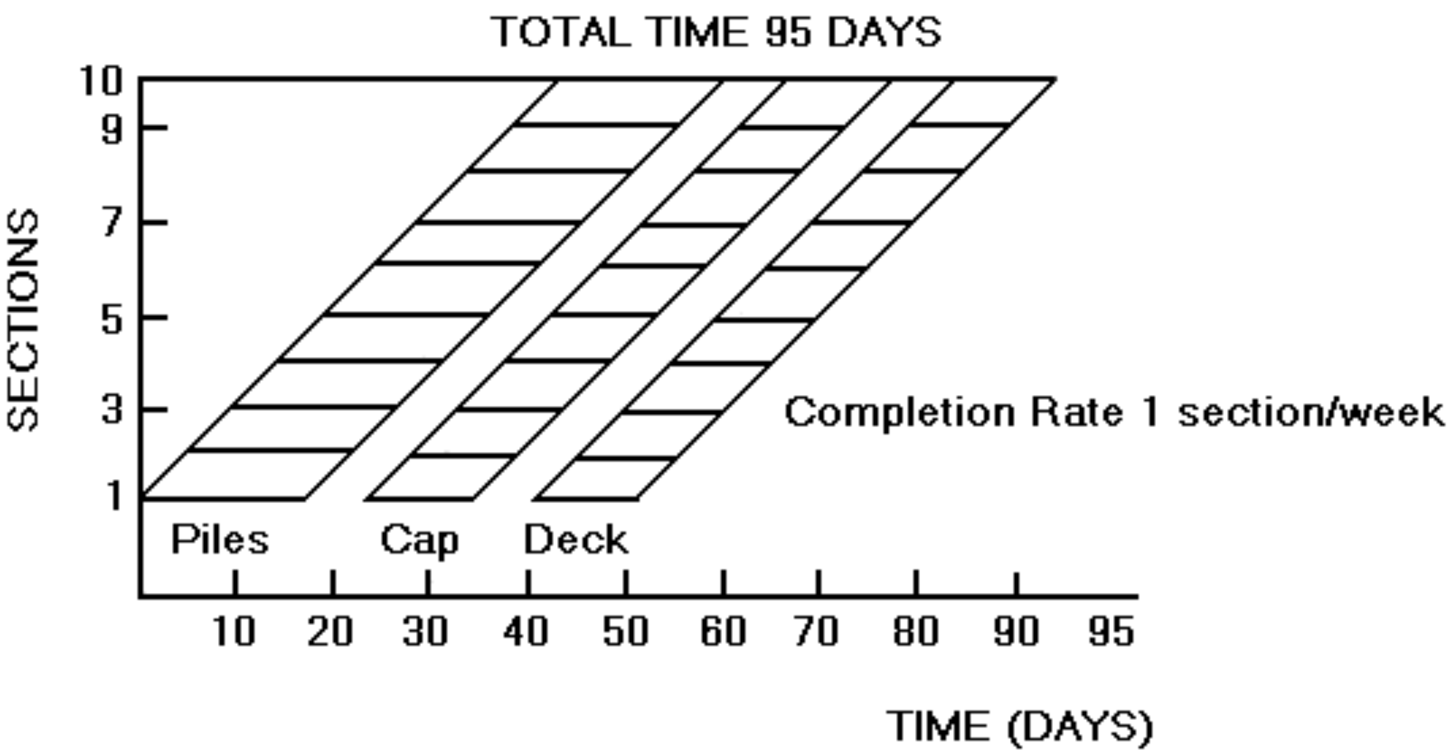


Figure 2.16 Logic diagram for each section added to the completion schedule

Example of Linear Schedule

- Can determine dates for each section
- Establishes LOB schedule, provided sufficient resources available to maintain production – crews must be available to start at scheduled start dates on each section $\longrightarrow$ velocity diagram (Figure 2.16)
- If have 3 crews starting at time zero on activity 1 (i.e. at sections 1, 2, and 3), need to balance this production rate by having 3 crews on activity 2 and 3 in sequence – experiment with different numbers of crews to keep all 3 activities in balance

Example of Linear Schedule

Pile Cap

Needs crew of 6 to construct each pile cap in 12 days

Use 2 crews of 6 each

∴ Output* is 0.83 sections/5 day week

∴ Does not meet target of 1 section/week

$$\text{*Production} = 2 \text{ crews} \times \frac{5 \text{ days/week}}{12 \text{ days/section}} = 0.83 \text{ sections/wk}$$

∴ Instead of completing 1 section/week, complete 0.83 sections/5 day week

↓

Rate assumed in Figure 2.16 based on 5 day week

Example of Linear Schedule

<u>Reason</u>

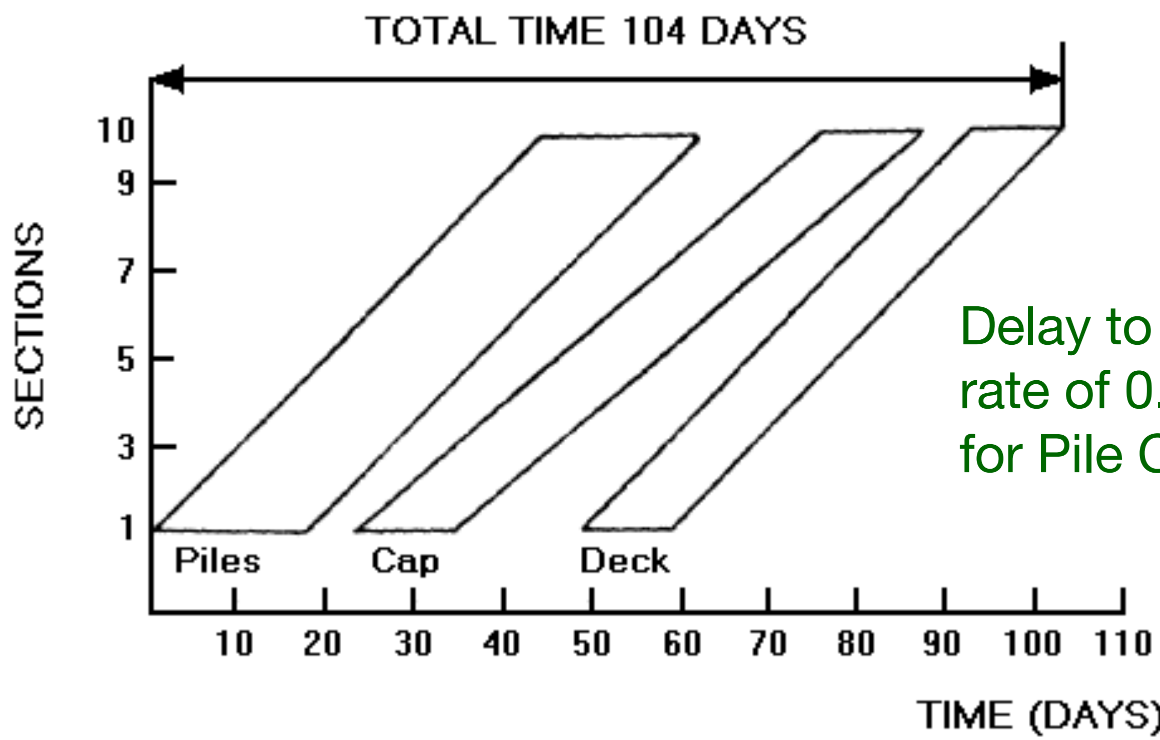
<u>Team 'a'</u> starts on section 1 of Pile Cap on day 23 and finishes on day 35 (12 days) (Figure 2.16).

<u>Team 'b'</u> starts on section 2 on day 28 (5 days after completion of piles) and finishes on day 40.

<u>Team 'a'</u> can not start on section 3 until finished section 1 (on day 35), but section 3 due to start on day 33 (after piles).

∴ Delayed 2 days ⟶ ∴ pushes all section start dates forward and delays project.

Example of Linear Schedule



Delay to project based on rate of 0.83 sections/week for Pile Cap

Figure 2.17 Effect of scheduling operation 'Pile cap' at a completion rate of 0.83 per week

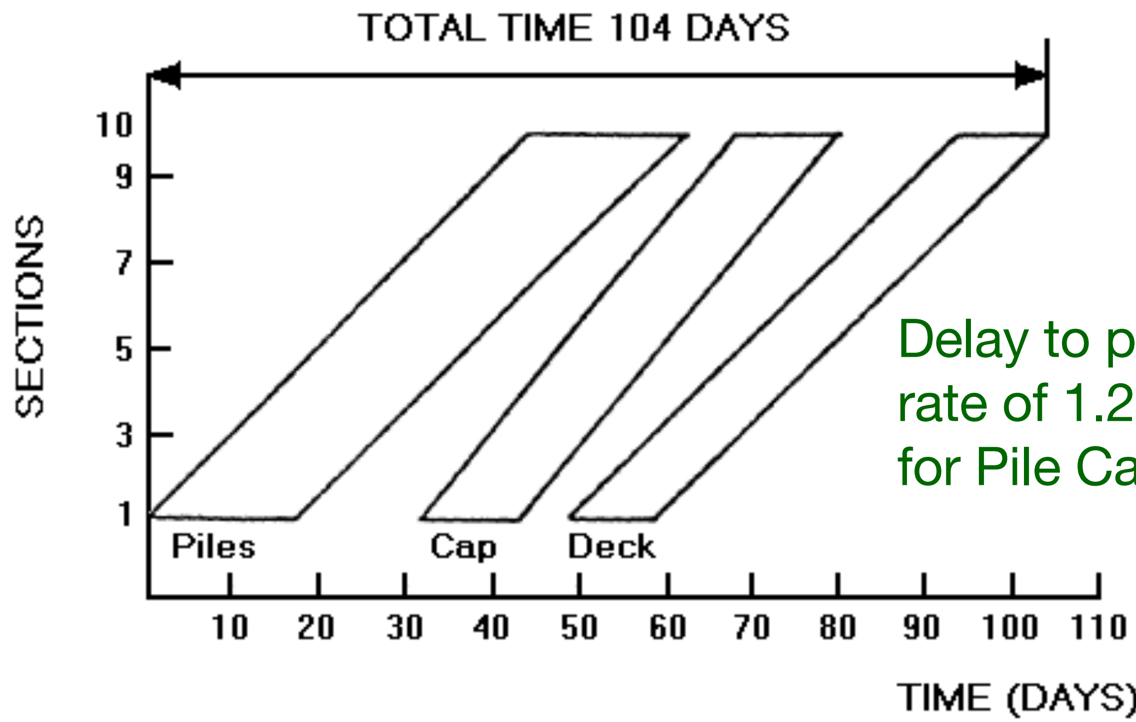
Example of Linear Schedule

Figure 2.18:

- If employ 3 teams (of 6 people each) on Pile Cap, output would be 1.25* sections/week (read off Fig. 2.18). Team ‘a’ completes first section on day 35 and moves to section 4, which can not start until day 38 (due to its other predecessor Piles for section 4)

$$\text{*Production} = 3 \text{ crews} \times \frac{5 \text{ days/week}}{12 \text{ days/section}} = 1.25\text{/week}$$

Example of Linear Schedule



Delay to project based on rate of 1.25 sections/week for Pile Cap

Figure 2.18 Effect of scheduling operation 'Pile cap' at a completion rate of 1.25 per week

Example of Linear Schedule

Figure 2.18:

Move production line for Cap forward so that crews have continuous work and required predecessors are complete. Cap operation is moved over on horizontal axis so does not clash (cross over) with Piles operation at higher locations. Location 1 of Cap does not start on day 23.

Example of Linear Schedule

∴ Project completion date even later than original, despite speeding up Pile Cap ⟶ Pile Cap no longer in balance with its preceding and succeeding operations

∴ Need to (a) increase crew size to complete Pile Cap in 10 days or (b) increase days worked per week for pile cap to 6, so that

$$\text{Production} = 2 \text{ crews} \times \frac{5 \text{ days/week}}{10 \text{ days/section}} = 1 \text{ section/wk}$$

$$\text{or, Production} = 2 \text{ crews} \times \frac{6 \text{ days/week}}{12 \text{ days/section}} = 1 \text{ section/wk}$$

Use of LSM Schedules

- Objective is to keep all activity progress lines as close to parallel to each other as possible, considering economics of slower or faster production

∴ Project completion achieved as quickly as possible

- Progress lines that show wide variation among themselves may be indication of insufficient manpower for activities with low slopes or over manning on activities with high slopes
- Assign start and finish dates to horizontal axis
- Combine activities with similar craftspeople to develop labour histogram

Advantages of LSM Schedules

1. Easier to prepare and use than network schedules and present more information than bar chart.
2. Show rate of progress.
3. For repetitive work, help in identifying problems and solutions.
4. Can convey detailed, repetitive work in way easy to understand by management and field staff.

Advantages of LSM Schedules

5. Ease of preparation and flexibility make them suitable for comparing scheduling alternatives of progress rates, equipment combinations, sequences.
6. Help in determining time and space buffers.
7. Can yield activity start and finish dates and labour histogram $\longrightarrow$ resources can be balanced by adjusting progress.
8. Can yield earnings curve by comparing number of units forecasted to be complete on any given progress payment date.

Disadvantages of LSM Schedules

Less effective when activities do not need to follow each other in same order at every location, or when repetitive activities are regularly interrupted

e.g. road development in city with many interruptions (traffic, utilities)

Can still be used to evaluate best combination of individual progress rates for least-cost or least-time calculations

Characteristics of Repetitive Construction

1. Network schedules assume activities can be divided into number of relatively small, discrete activities – sequenced in order of their performance.
2. On some projects, same activities performed by same crew progress continuously for duration of project.

Last Planner®

Last Planner

- CPM are excellent for analyzing:
  - The logic of construction activities,
  - Identifying critical activities, and
  - Producing a model from which its is possible to undertake resource analysis and identify milestone/completion dates
  - Confirms production deadlines and contractual obligations
- However CPM fails
  - To direct production on site
  - Does not address short-term production planning as it will make the CPM schedule too detailed and difficult to update
- Last Planner® system of production control, first used in 1992, aims to address this gap.
  - Is now fully established as a Lean Production–based management system and is a corner- stone of the Lean Construction methodology.

Last Planner

- Last Planner® system comprises of
  - A philosophy: Pull based system
    - Rests on a belief that the world is inherently stochastic – all plans are forecasts and all forecasts are wrong as the further into the future or the more detail we attempt to forecast, the more wrong we will be.
    - Everyone has managerial responsibility for project success, especially the front-line supervisor (Last Planners)
    - Planning decisions of the front-line supervisor are qualitatively different from planning decisions made at higher organizational levels because they are not inputs to other planning processes, but directly drive action.
- Batch and Queue Production

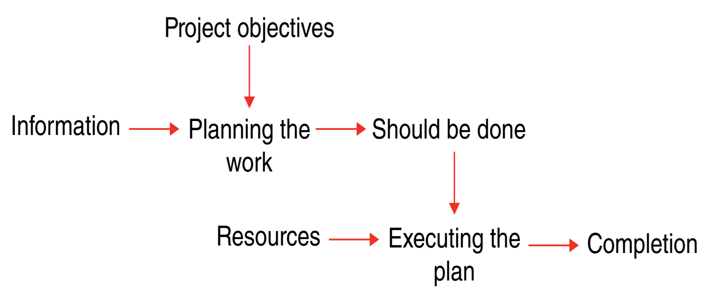


Figure 7.1 A traditional 'push' planning system.

- Continuous-Flow Production

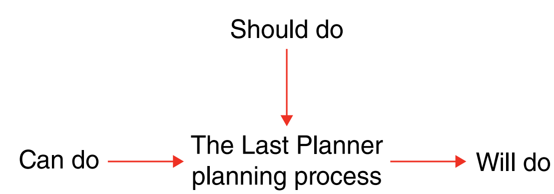


Figure 7.2 Last Planner® is a 'pull'-based system.

Last Planner

- Principles of Last Planner Systems
    1. Plan in greater detail as you get closer to doing the work
    2. Plan collaboratively with those who will do the work
    3. Undertake a constraints removal process on planned tasks publicly with those who can remove constraints
    4. Make reliable promises
    5. Learn from past failures; identify and act on root causes to prevent reoccurrence
- Implementing Last Planner Systems
    1. Initial programming
    2. Collaborative programming
    3. Programme compression
    4. Make ready, Look ahead
    5. Production planning
    6. Production

Last Planner

- Implementing Last Planner Systems

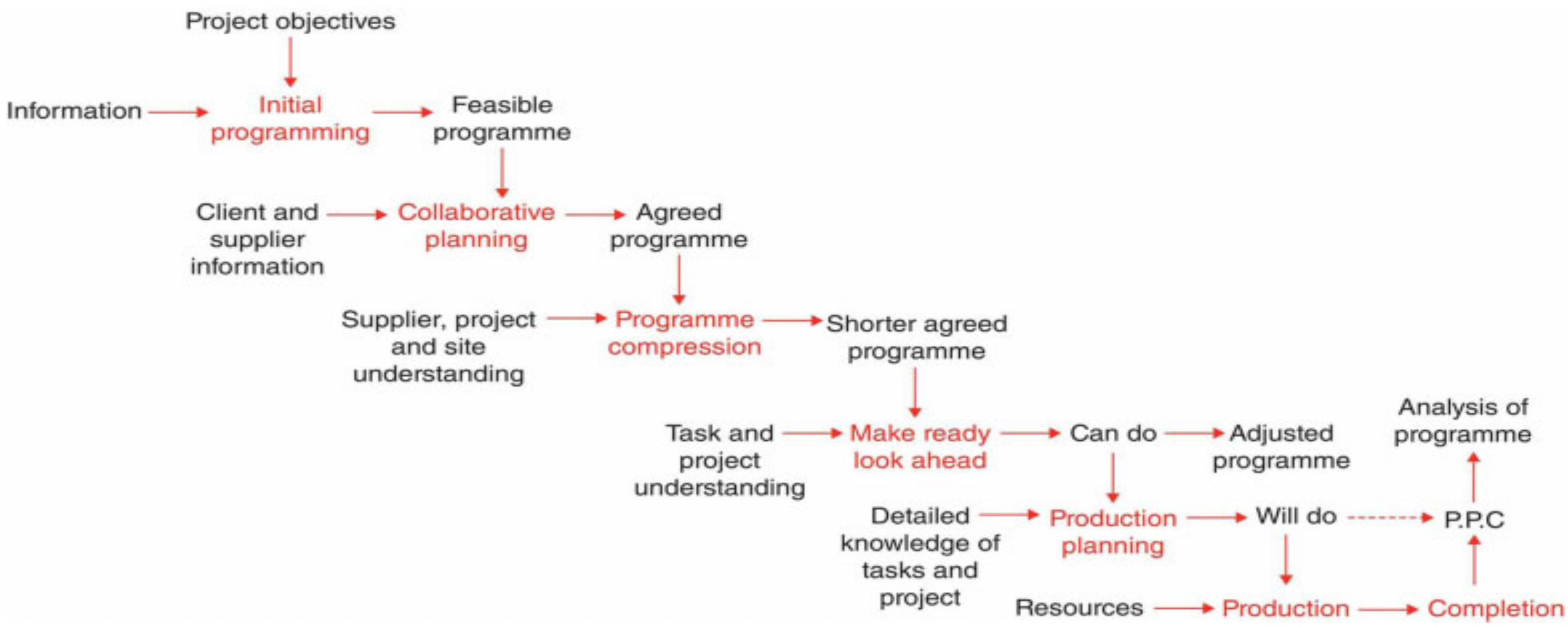


Figure 7.3 The LPS overview flow chart.

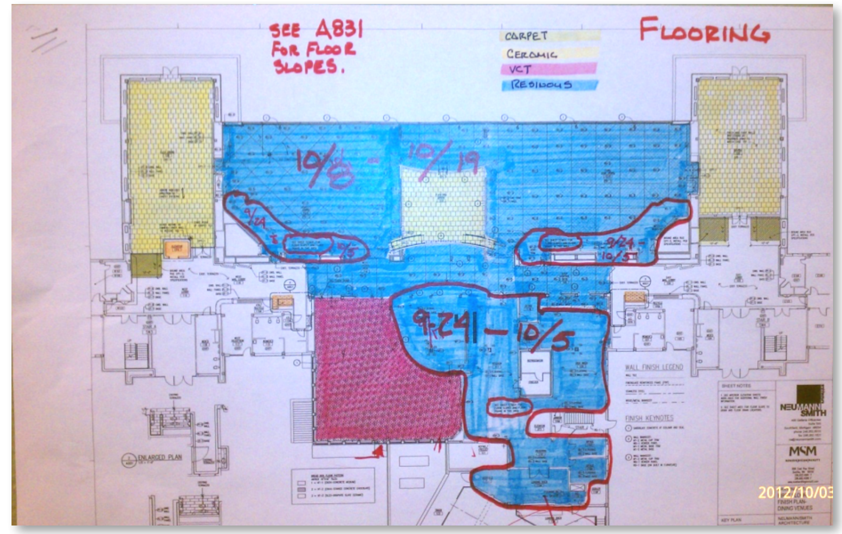
- Success of weekly work plan is measured against PPC (Planned Percentage Complete or Planned Promises Completed)

$$PPC = \frac{Completed\ Weekly\ Assignments}{Total\ Weekly\ Promised\ Assignments}$$

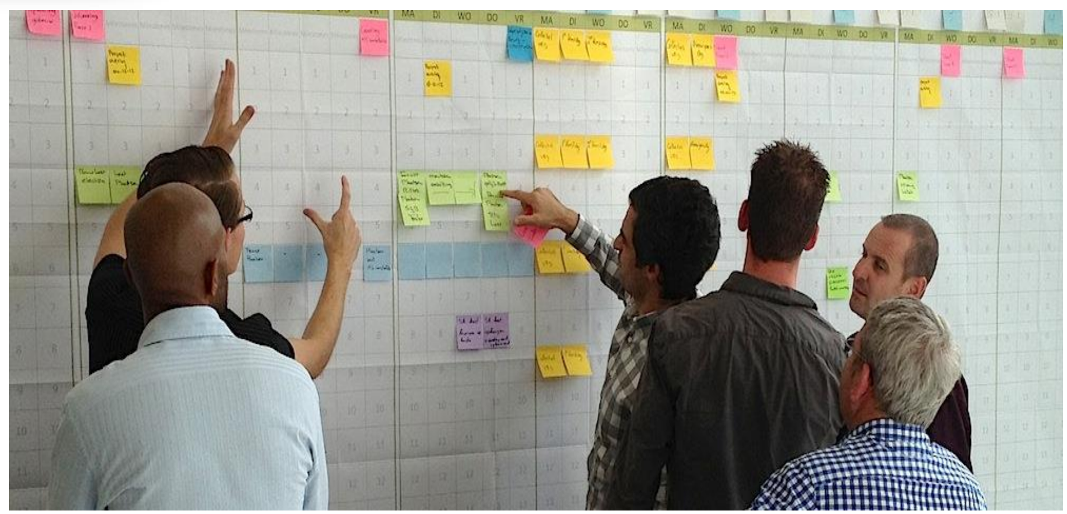
Last Planner

- Collaborative Planning

Big Room: Israel, Fab 28 Conversion Project

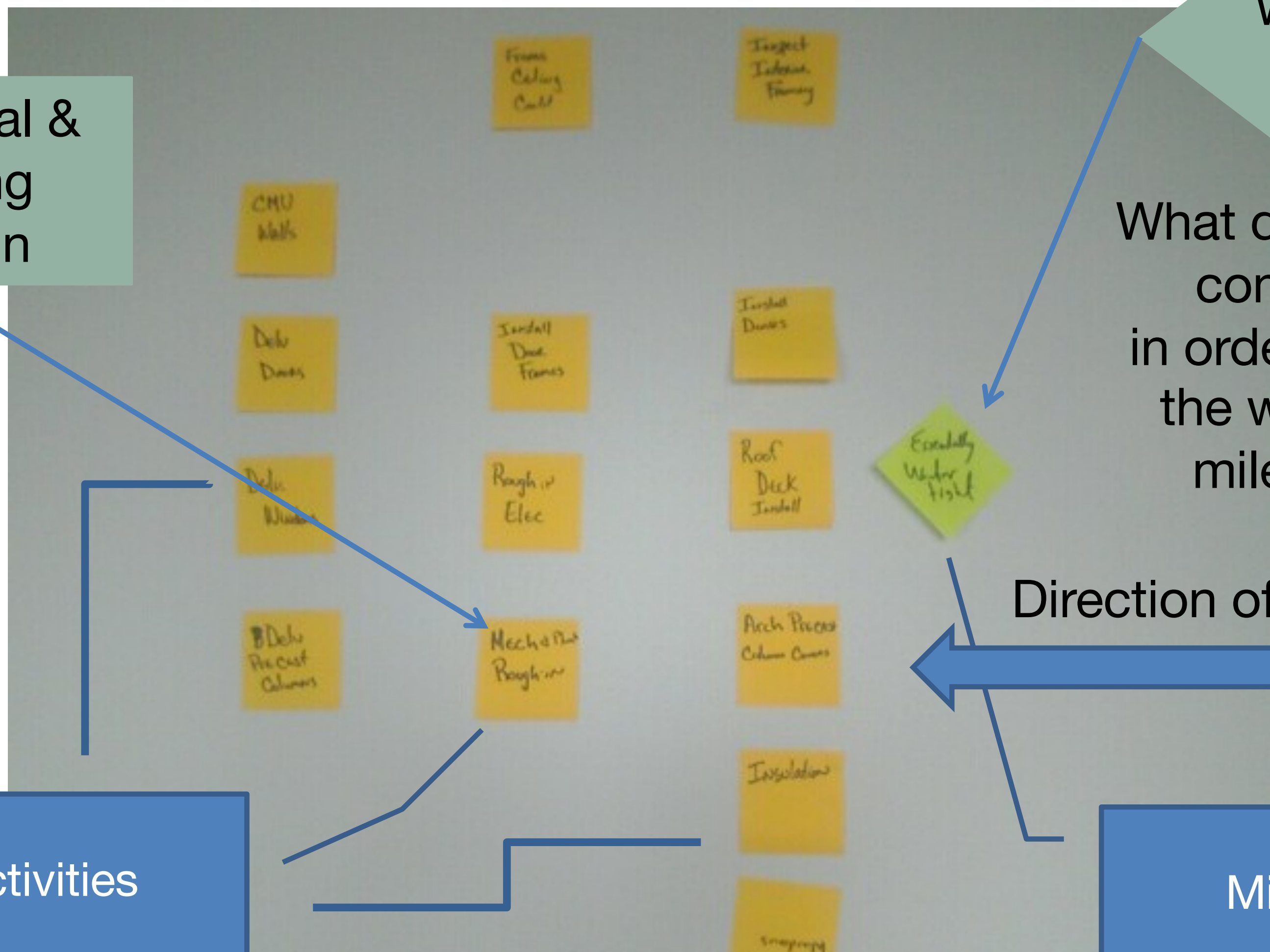


- Bring relevant experts to rehearse the actual project execution



Last Planner

- Pull Planning Process



Mechanical & Plumbing Rough-in

Water-tight

What do we need completed in order to reach the watertight milestone?

Direction of planning

Pulled Activities

Milestone

Last Planner

- Levels of the Last Planner System

Master Scheduling
Milestones

- Are we confident we can deliver the project within the set limits?
- Who holds the promise to make this happen?

Phase Scheduling
Specify handoff

- Do we understand how we are going to do the work?
- Have we designed the network of commitments to make it happen?
- Are we confident we can deliver the milestones?

6-week Look-ahead/Make-ready Planning
Rolling look ahead & launch

- Is the network of commitments active?
- Are reliable promises in place to make work ready in the right sequence and amounts to deliver the milestone?
- Are we confident the work will begin and end as planned?

Weekly Work Planning
Measure PPC, act on reasons for failure to keep promises

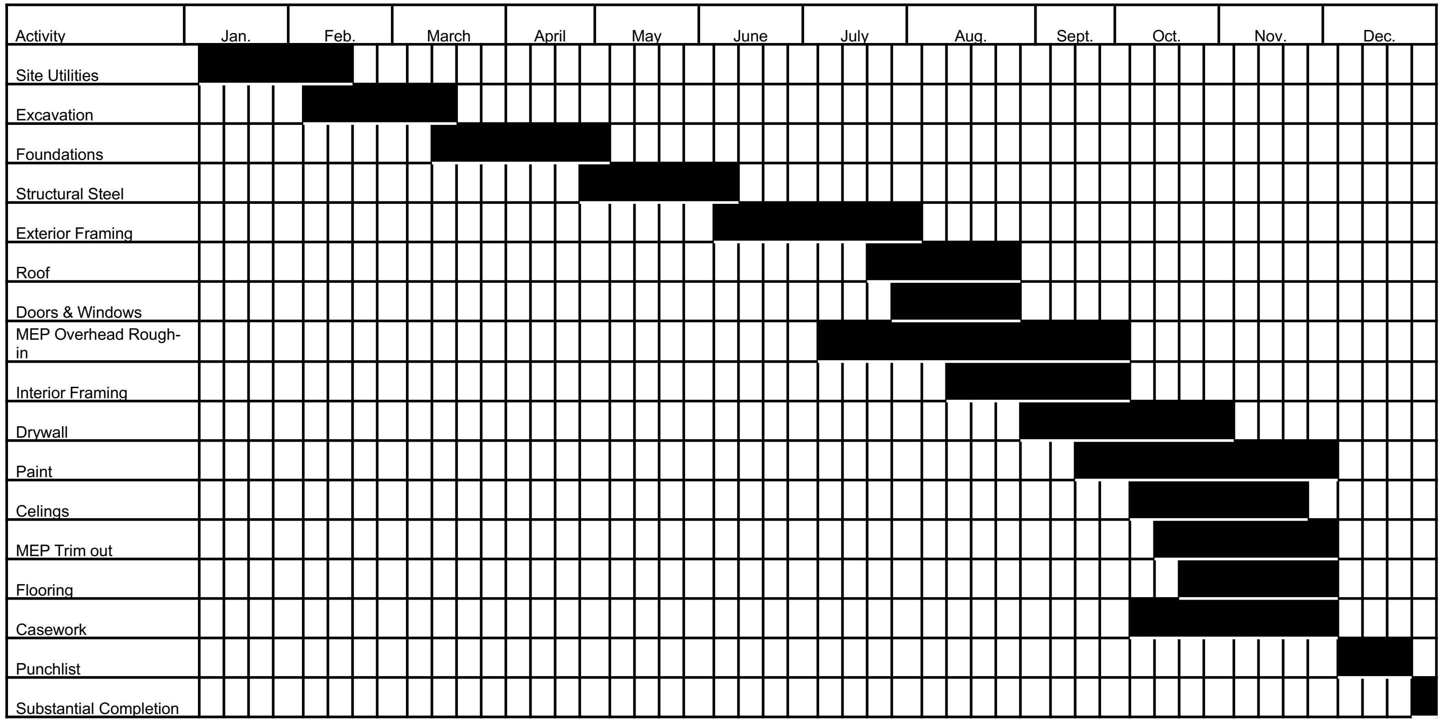
- How will we coordinate and adjust?
- Have we promised our tasks will be done as planned or said no?

Daily Huddles
Confirming your weekly plan and adjusting as required

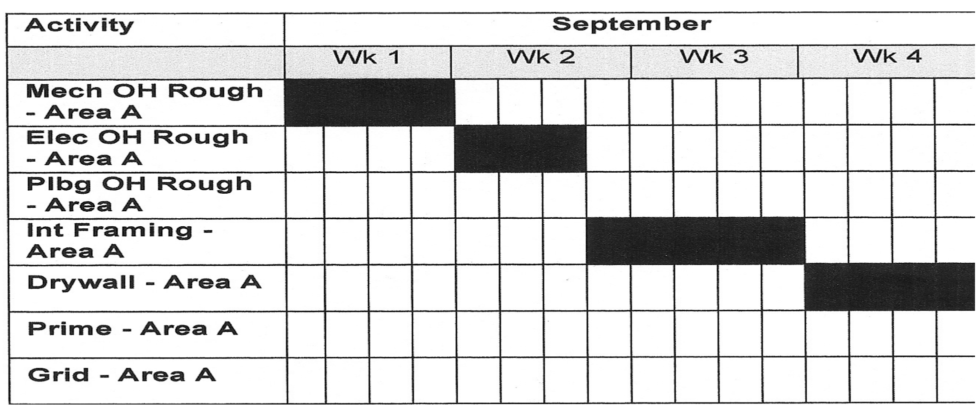
- What have we learned?
- What needs changing so we can improve our performance?

Last Planner

- Master Schedule

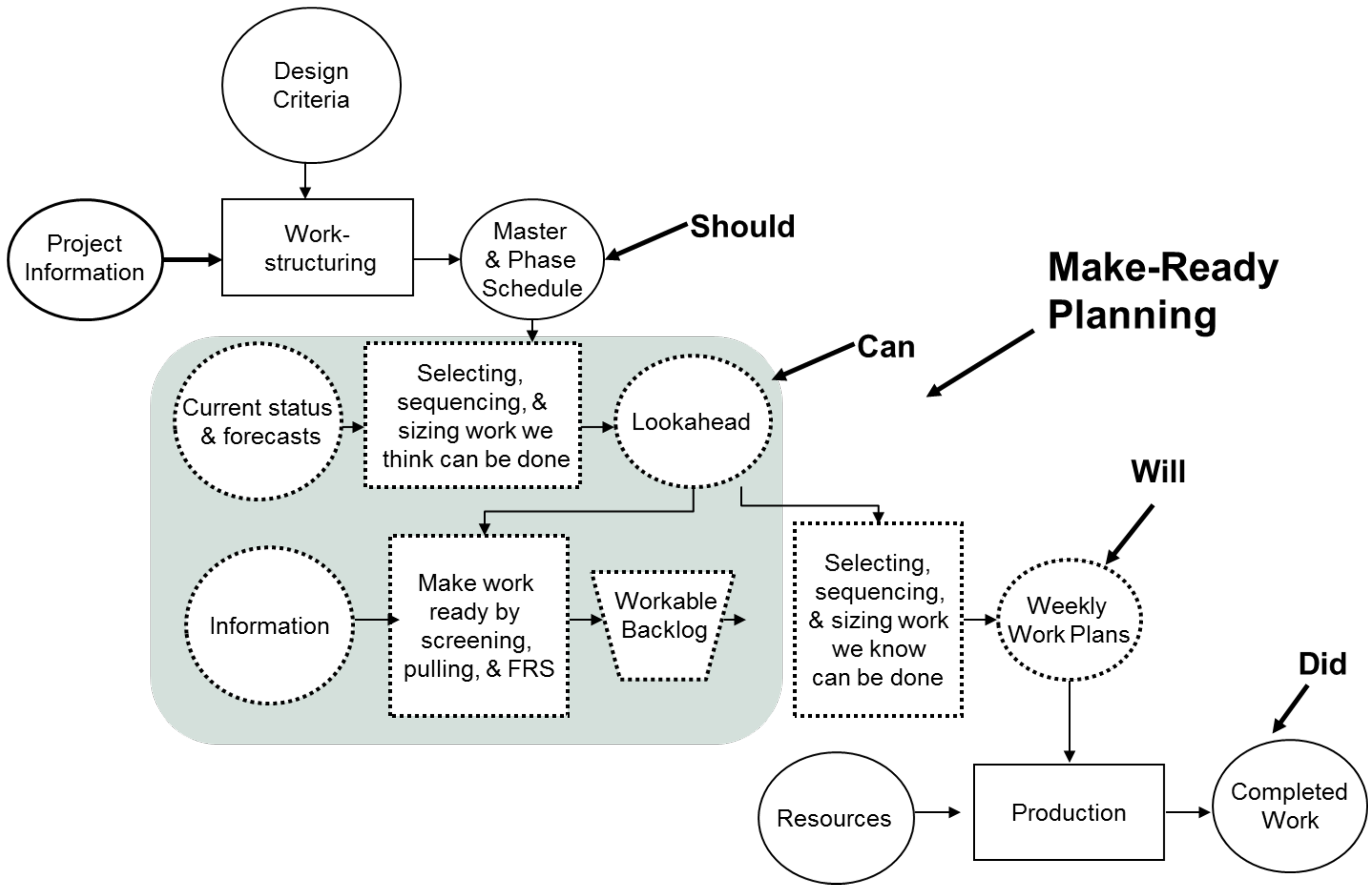


- Phase Schedule



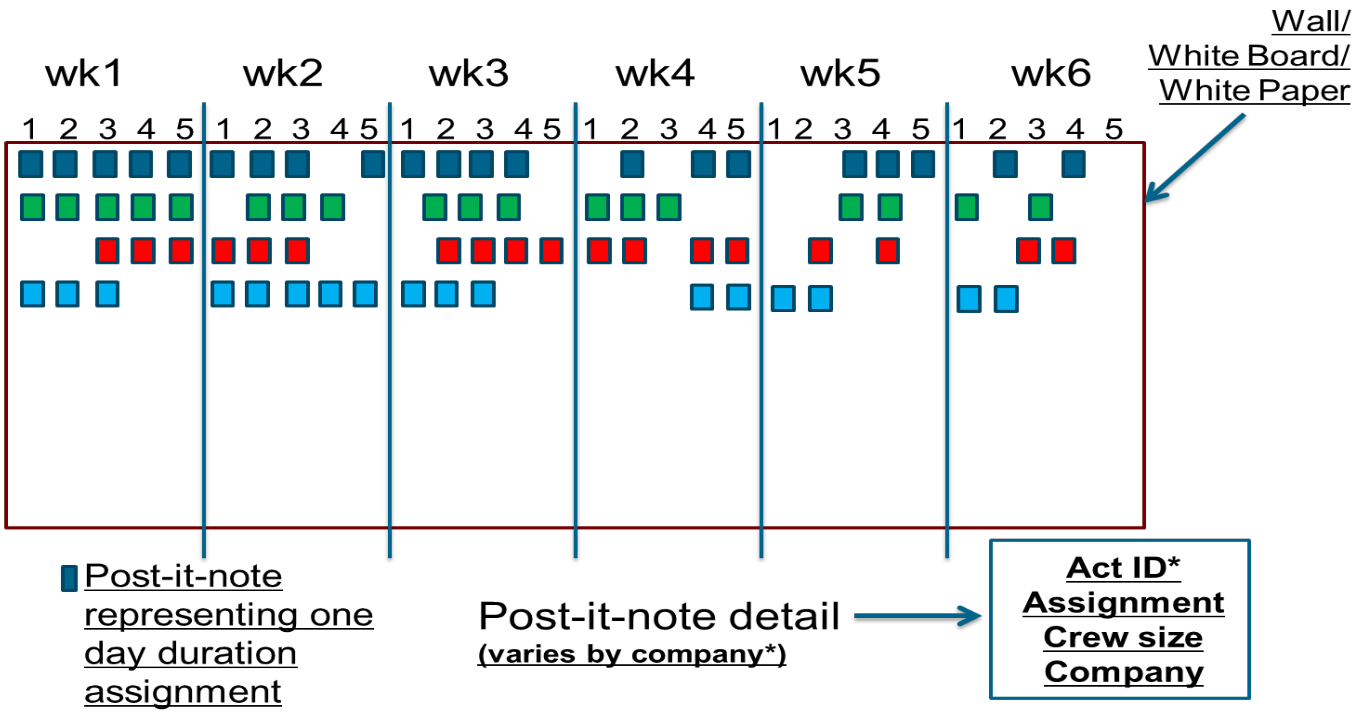
Last Planner

- 6 week Look-ahead/Make-ready Planning



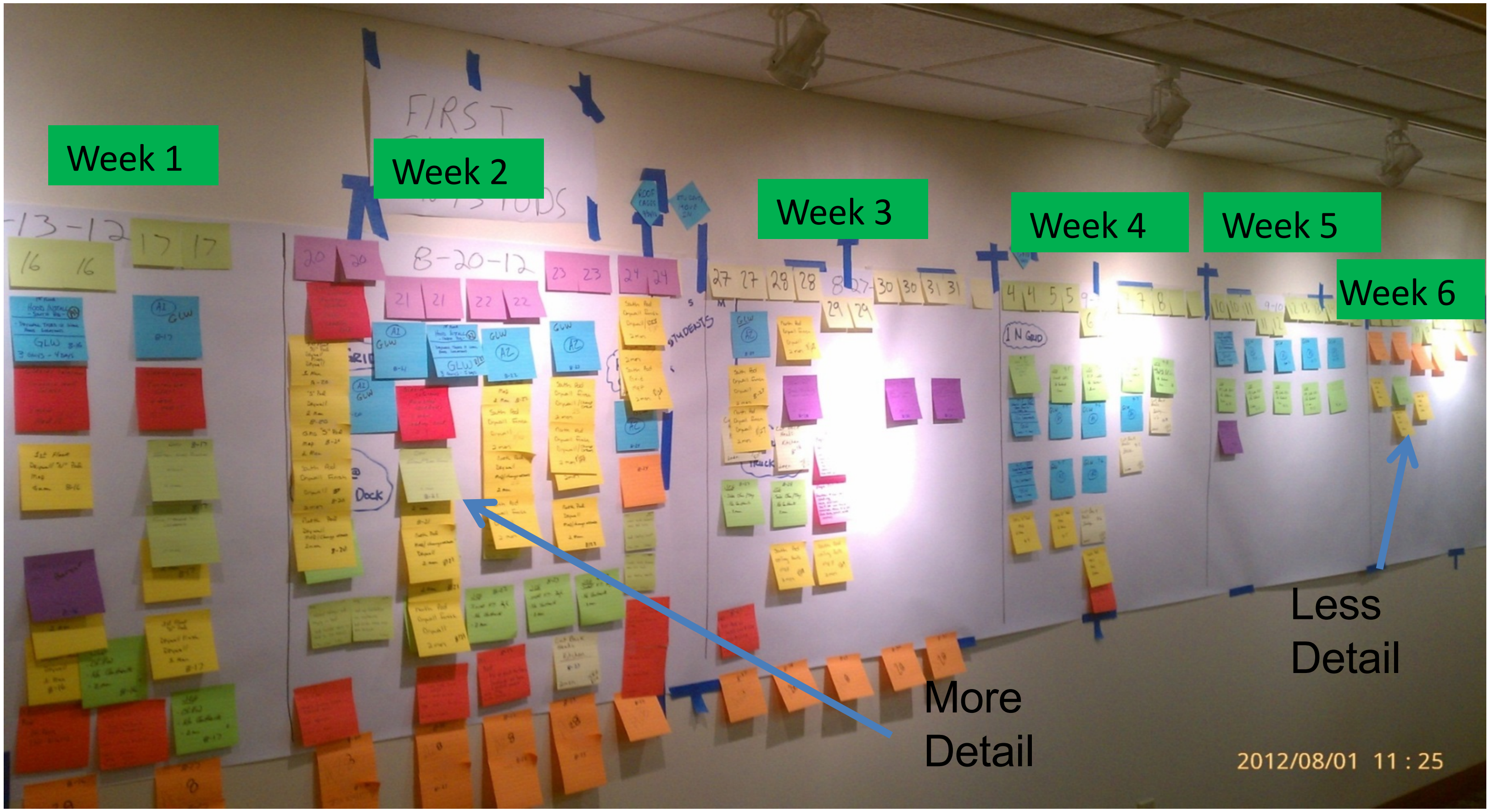
Last Planner

- 6 week Look-ahead/Make-ready Planning



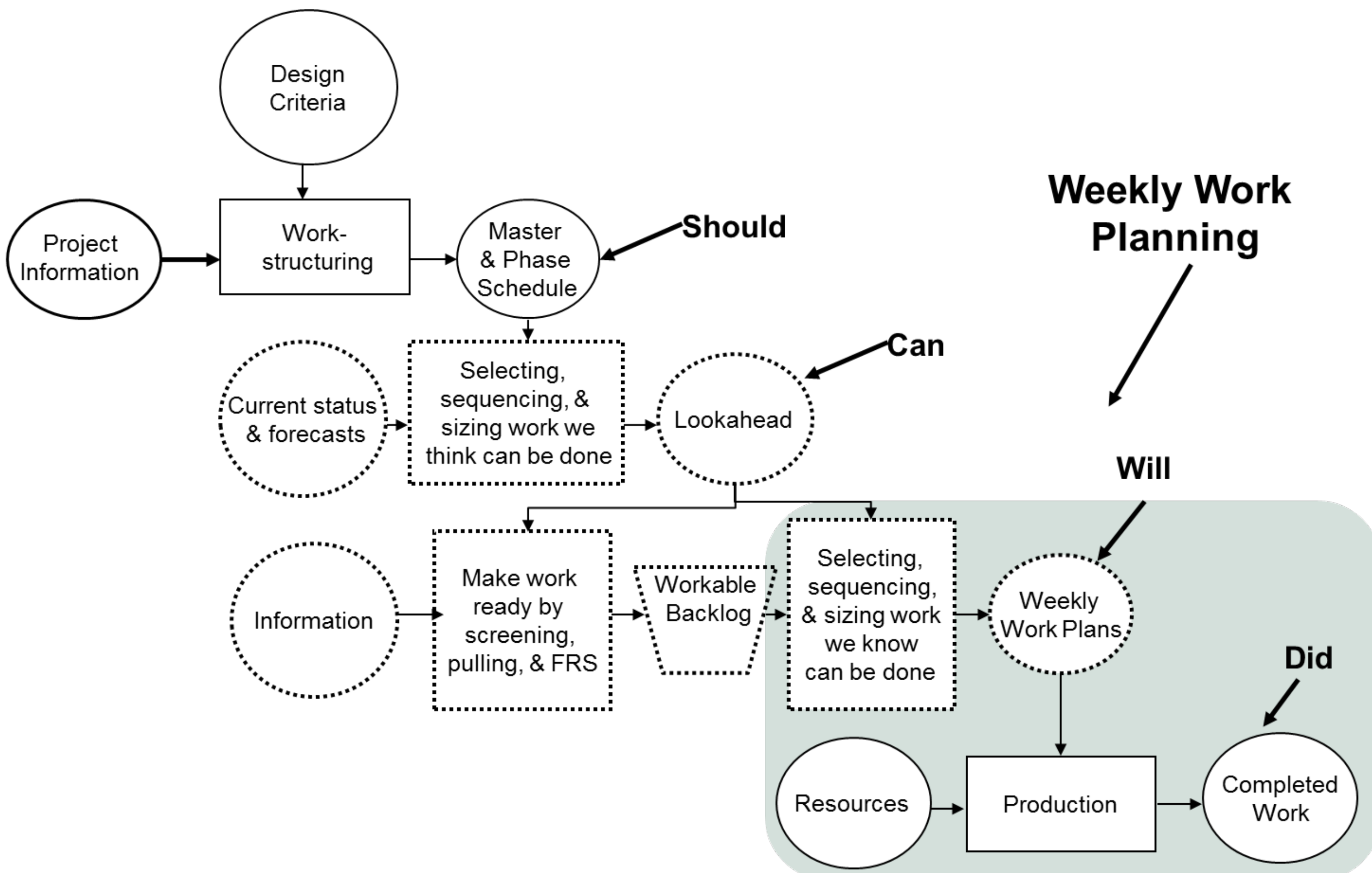
Last Planner

- 6 week Look-ahead/Make-ready Planning



Last Planner

- Weekly Work Planning



Last Planner

- Weekly Work Planning

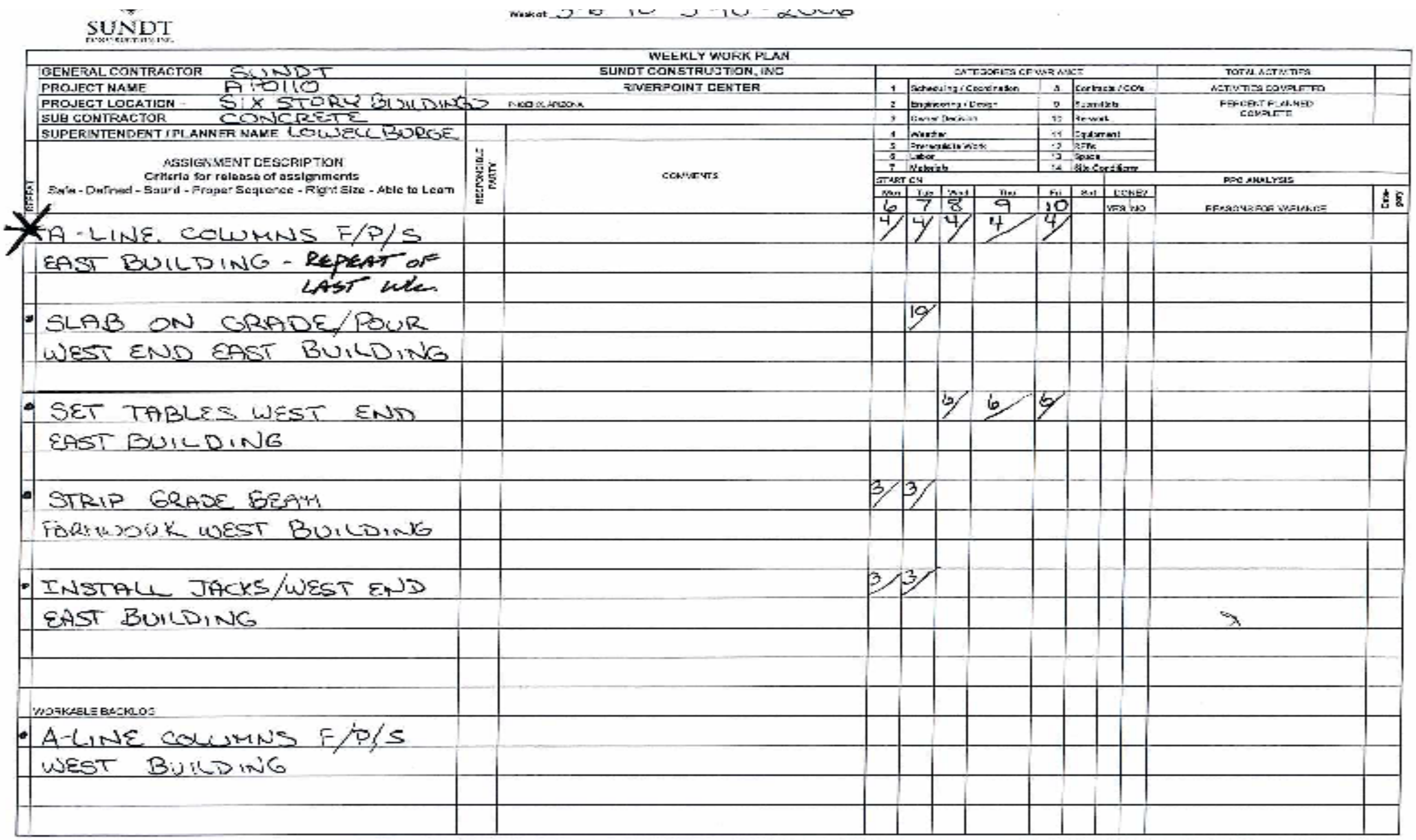
		October - Week 3							
Activity	**Sub.**	**M**	**T**	**W**	**Th**	**F**	**Complete**	**Reason**	**Notes**
Area A									
Mech Trim	Mech	■							
Elec Trim	Elec			■	■				
Area B									
Elec Trim	Elec					■			
Plbg Trim	Plbg	■	■		■				
Area C									
Mech Trim	Mech		■	■					
Elec Trim	Elec	■							
Paint - Start	Painter				■	■			
Area D									
Mech Trim - Start	Mech				■	■			
Elec Trim	Elec	■	■						
Plbg Trim				■					

Last Planner

- Weekly Work Planning

Last Planner

- Weekly Work Planning



SUNDT

Week of 3-6 to 3-10-2006

WEEKLY WORK PLAN

GENERAL CONTRACTOR	SUNDT	SUNDT CONSTRUCTION, INC	
PROJECT NAME	APOLLO	RIVERPOINT CENTER	
PROJECT LOCATION	SIX STORY BUILDINGS	PHOENIX, ARIZONA	
SUB CONTRACTOR	CONCRETE		
SUPERINTENDENT / PLANNER NAME	LOWELL BORGE		

CATEGORIES OF VARIANCE

1	Scheduling / Coordination	8	Contracts / CO's
2	Engineering / Design	9	Submittals
3	Owner Decision	10	Rework
4	Weather	11	Equipment
5	Prerequisite Work	12	RFIs
6	Labor	13	Space
7	Materials	14	Site Conditions

TOTAL ACTIVITIES	
ACTIVITIES COMPLETED	
PERCENT PLANNED COMPLETE	

REPEAT	ASSIGNMENT DESCRIPTION Criteria for release of assignments Safe - Defined - Sound - Proper Sequence - Right Size - Able to Learn	RESPONSIBLE PARTY	COMMENTS	Mon 6	Tue 7	Wed 8	Thu 9	Fri 10	Sat	DONE? YES	NO	REASONS FOR VARIANCE	Category
X	A-LINE COLUMNS F/P/S EAST BUILDING - REPEAT OF LAST wk			4	4	4	4	4					
	SLAB ON GRADE/POUR WEST END EAST BUILDING				19								
	SET TABLES WEST END EAST BUILDING					6	6	6					
	STRIP GRADE BEAM FORMWORK WEST BUILDING			3	3								
	INSTALL JACKS/WEST END EAST BUILDING			3	3								

WORKABLE BACKLOG

- A-LINE COLUMNS F/P/S WEST BUILDING

Last Planner

- Daily Huddles:

Last Planner

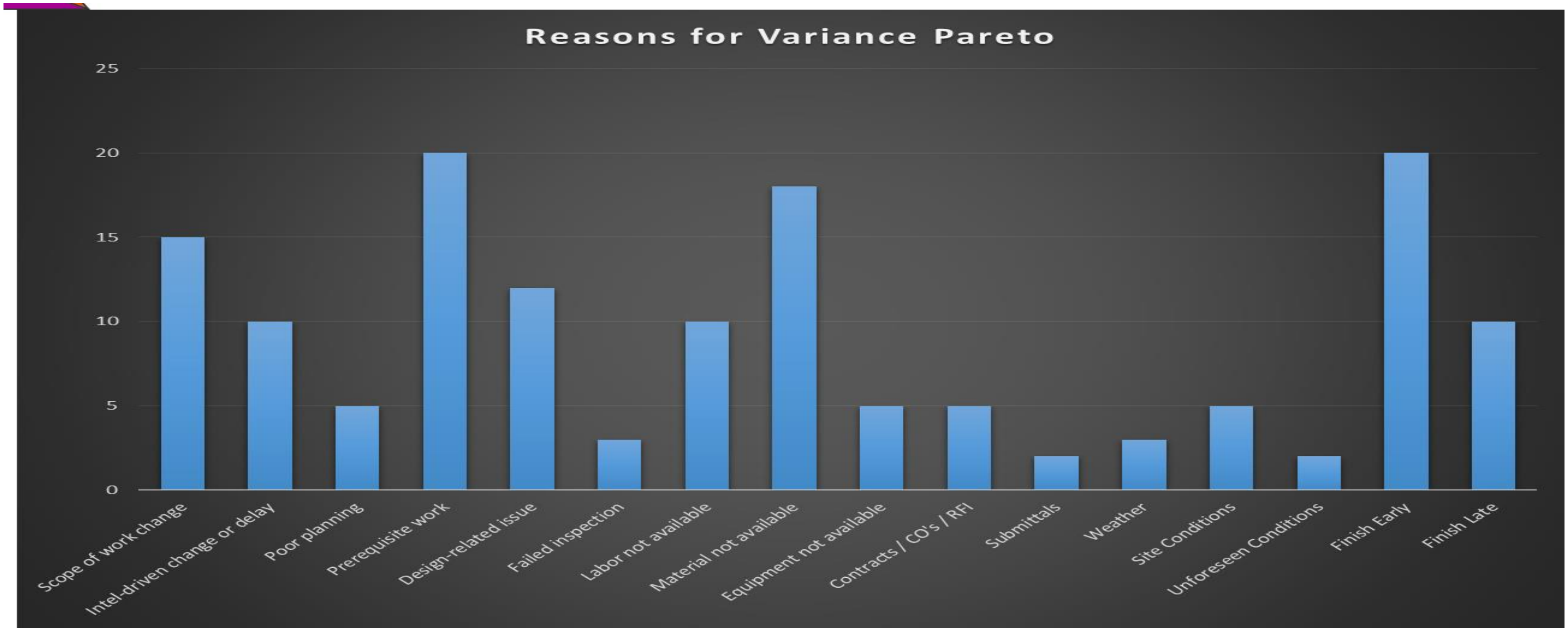
- Weekly Work Planning: Control

		October - Week 2							
Activity	**Sub.**	**M**	**T**	**W**	**Th**	**F**	**Complete**	**Reason**	**Notes**
Area A									
Mech Trim - Start	Mech						No	Manpower	Journeyman called in sick
Area B									
Grid	Ceiling						Yes		
Mech Trim	Mech						Yes		
Plumbing Trim	Plbg						Yes		
Area C									
Elec Trim	Elec						Yes		
Plumbing Trim	Plbg						No	Material	Late on W.; pushed activity completion to Th.
Area D									
Prime	Painter						Yes		
Grid	Ceiling						Yes		

Last Planner

- PPC Trend

- Reasons for Variance Pareto



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- Baldwin, A. and Bordoli, D. (2014). *A Handbook for Construction Planning and Scheduling*, John Wiley and Sons.
- Lean Construction Education Program: Project Team Course, Presentation, Associated General Contractors of America.
- Lean Construction Institute. Last Planner® System: Business Process Standard and Guidelines.