# Flexible Scheduling for Construction Projects

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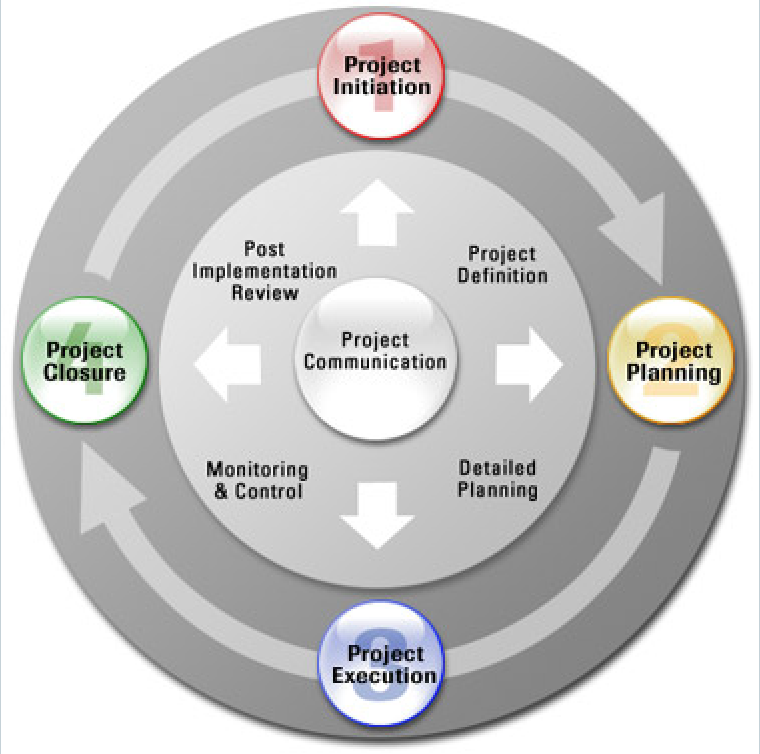
# OUTLINE

- Introduction and Background
- Statement of Problem
- Objective
- Methodology
- Modeling
- Results and Discussion
- Summary and Conclusions
- Recommendations

# INTRODUCTION
## Project Management

- Project Management
  - Process of delivering a product
- Different phases
- Planning and execution are interconnected
  - Performance measures
  - Day-to-day activities




http://trustsystems.co.uk

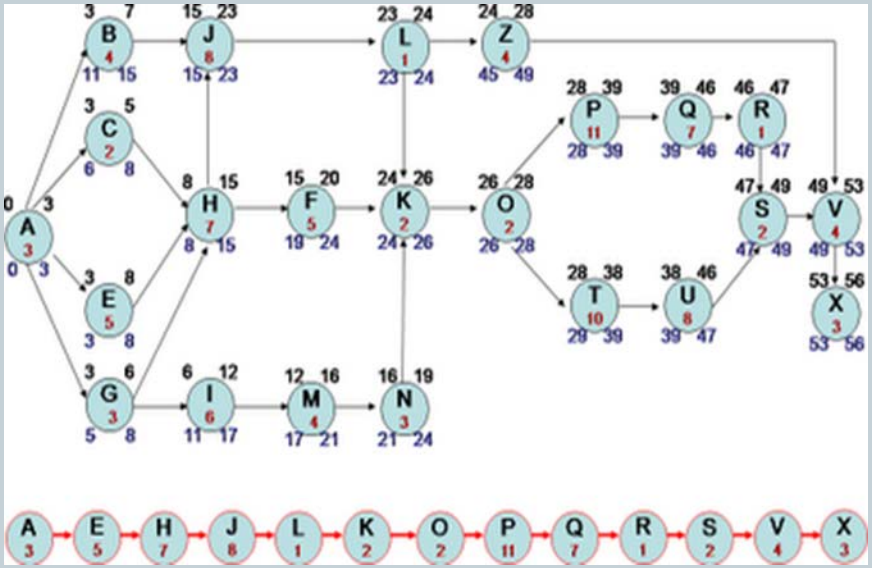
# INTRODUCTION
## Construction Projects

- Construction Projects
  - Multi-disciplinary
  - Complex
  - Constraints
    - Time
    - Cost
    - Quality
- Planning is essential for project success
  - Estimation
  - Scheduling


http://projectmanagement-software.info

# BACKGROUND
## Critical Path Method (CPM)

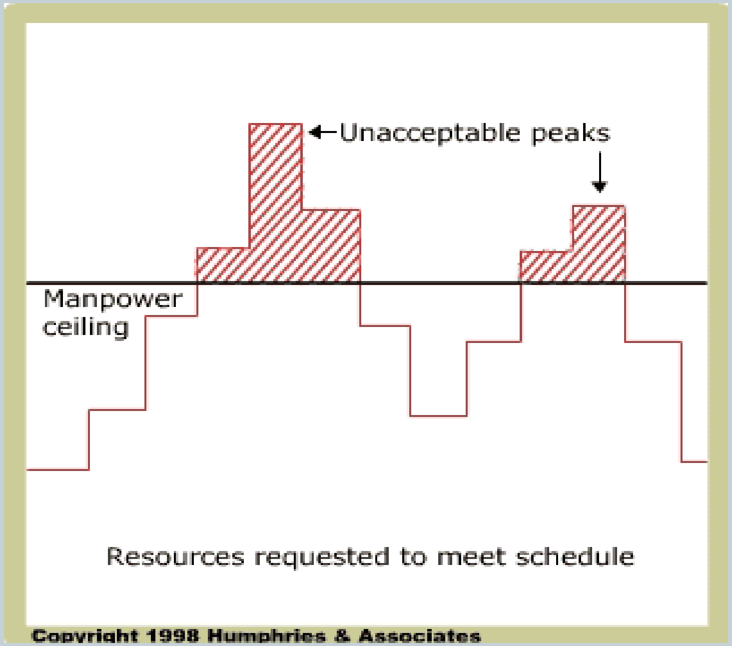
- Inputs: durations & relationships
- Forward pass: early start time
- Backward pass: late start time.
- CPM deals mainly with **Physical** & **Time** constraints.



http://www.leniel.net

# BACKGROUND
## Resource Allocation

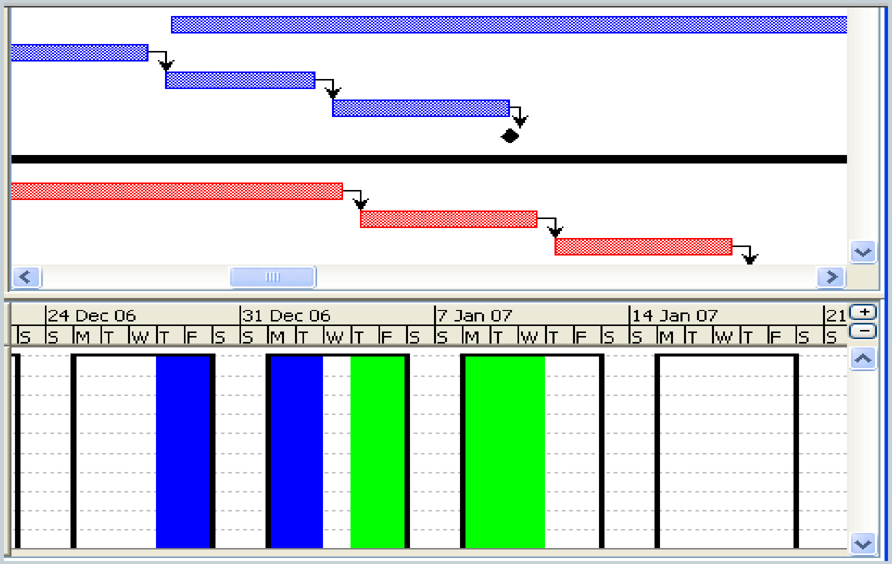
- CPM does <u>not</u> deal with resource constraints
- Resource allocation
- Resource histogram
- Ceiling on resource profile
- Schedule delays




http://learn.dau.mi

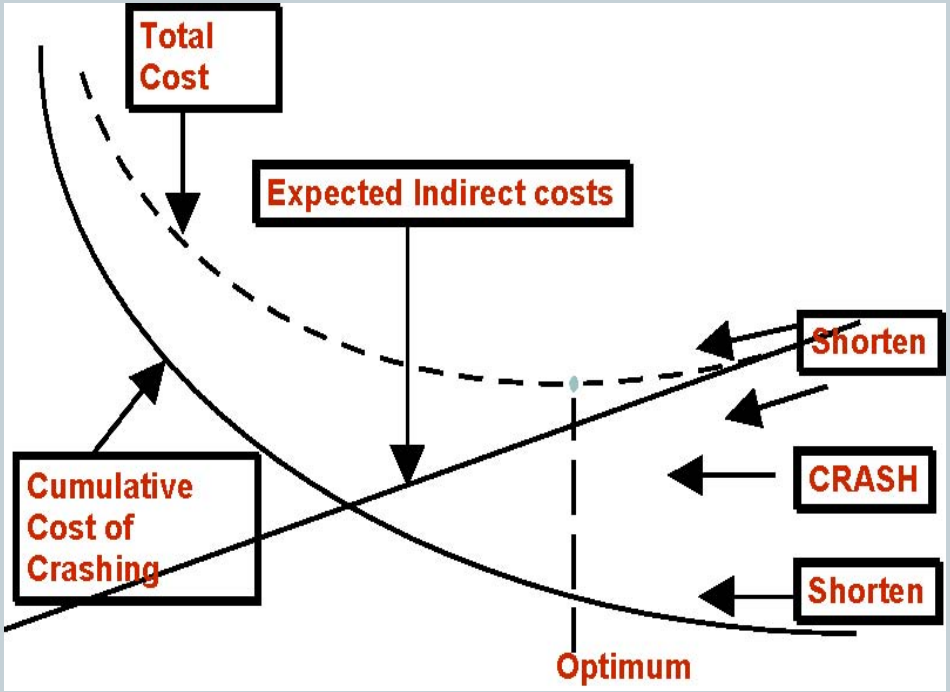
# BACKGROUND
## Resource Leveling

- Activity float is the only flexibility allowed by CPM
- Objective is to minimize variations in histogram & maintain schedule
- Cost reduction



# BACKGROUND
## Time-Cost Tradeoff

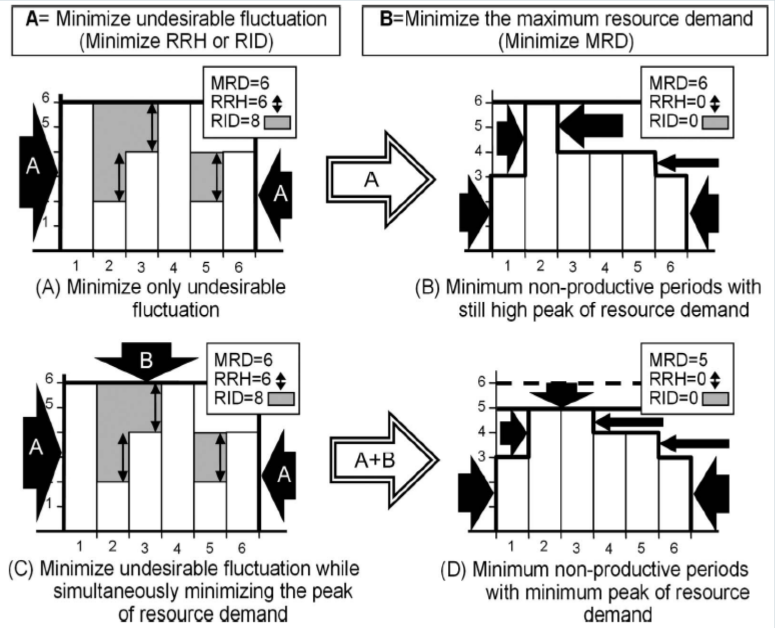
- Crashing durations of critical activities:
  - Over time
  - Increase crew size
  - Double shifts
  - Increase starting points
- Shortest Vs. Optimum
- Costly especially at later stages




http://free-books-online.org

# BACKGROUND
## Schedule Optimization

- Includes cost associated with CPM adjustments
  - Resource leveling
  - Resource allocation
  - Time-cost trade-off
- El-Rayes & Jun (2009):
  - New objectives & assumptions
  - Overall project cost optimization
- CHIU & TSAI (2002):
  - Project crashing & maximizing net present value

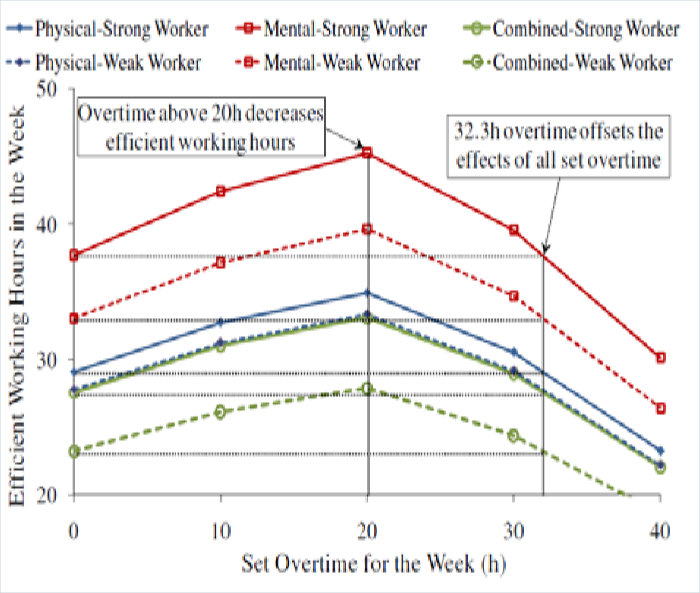



El-Rayes & Jun (2009)

# BACKGROUND
## Productivity

- Alvanchi, Lee & AbouRizk (2011)
  - Effects of overtime on long-run

- Hinze (2008) developed equations to estimate productivity losses:
  - Crowding Efficiency = 115% - 15( Expanded Workforce/Normal Workforce )
  - Overtime Efficiency = 100% - 5[(days-5) + (hours-8)]




Alvanchi, Lee & AbouRizk (2011).

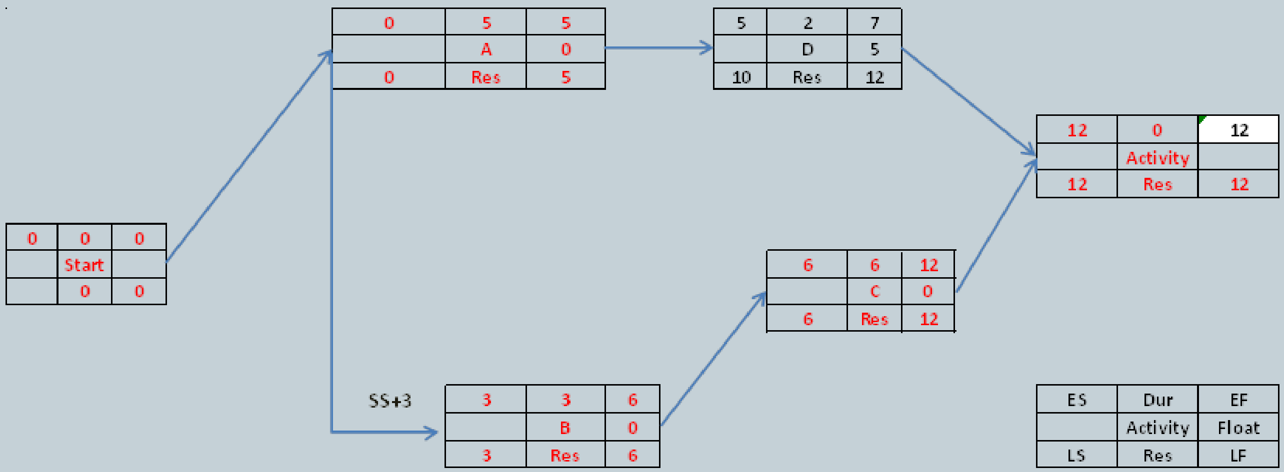
# PROBLEM STATEMENT

- Example:

| Activity | Normal Duration | Total Man-hour | Precedence | Relationship |
|---|---|---|---|---|
| Start | 0 | 0 | - | - |
| A | 5 | 200 | Start | FS |
| B | 3 | 168 | A | SS+3 |
| C | 6 | 240 | B | FS |
| D | 2 | 112 | A | FS |
| Finish | 0 | 0 | - | - |

$$No. of\ workers = \frac{Total\ Manhour}{(Duration)x(Working\ hours)}$$

# PROBLEM STATEMENT




- Activity B starts when 60% (3 days) of activity A is done

# PROBLEM STATEMENT

- Option 1- Crowding of Activity A:
  - If number of resources increased to 10 workers, duration will be:
  - $Crowding\ Effeciency = 115\% - 15 * (10/5) = 85\%$
  - $Duration = 200/(10*0.85*8) = 3\ Days.$
- Option 2- Overtime: (10 hours per day)
  - $Overtime\ Efficiency = 100\% - 5[(10-8)] = 90\%$
  - $Duration = 200/(5*10*0.9) = 4.44\ Days.$
- Option 3- Combination: (8 workers, 10 hours per day)
  - $Crowding\ Effeciency = 115\% - 15 * (8/5) = 91\%$
  - $Overtime\ Efficiency = 100\% - 5[(10-8)] = 90\%$
  - $Duration = 200/(8*10*0.91*0.9) = 3\ Days$

# PROBLEM STATEMENT

## Original Histogram

- Hiring = 9 workers
- Firing = 9 workers
- Maximum demand = 14 worker
- Duration = 12 days

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | | | | | | | | | | | | |
| 17 | | | | | | | | | | | | |
| 16 | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | |
| 14 | | | | | | D | | | | | | |
| 13 | | | | | | D | | | | | | |
| 12 | | | | B | B | D | D | | | | | |
| 11 | | | | B | B | D | D | | | | | |
| 10 | | | | B | B | D | D | | | | | |
| 9 | | | | B | B | D | D | | | | | |
| 8 | | | | B | B | D | D | | | | | |
| 7 | | | | B | B | B | D | | | | | |
| 6 | | | | B | B | B | D | | | | | |
| 5 | A | A | A | A | A | B | C | C | C | C | C | C |
| 4 | A | A | A | A | A | B | C | C | C | C | C | C |
| 3 | A | A | A | A | A | B | C | C | C | C | C | C |
| 2 | A | A | A | A | A | B | C | C | C | C | C | C |
| 1 | A | A | A | A | A | B | C | C | C | C | C | C |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

# PROBLEM STATEMENT

**Option 3 on Activity A - Relaxing Activity D - Changing Relation between A&B to FS**

- Hiring= 2 workers
- Firing= 5 workers
- Duration= 12 days
- Maximum demand= 9 workers

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | | | | | | | | | | | | |
| 17 | | | | | | | | | | | | |
| 16 | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | |
| 9 | | | | | D | D | | | | | | |
| 8 | A | A | A | | D | D | | | | | | |
| 7 | A | A | A | B | B | B | D | D | D | D | D | |
| 6 | A | A | A | B | B | B | D | D | D | D | D | |
| 5 | A | A | A | B | B | B | C | C | C | C | C | C |
| 4 | A | A | A | B | B | B | C | C | C | C | C | C |
| 3 | A | A | A | B | B | B | C | C | C | C | C | C |
| 2 | A | A | A | B | B | B | C | C | C | C | C | C |
| 1 | A | A | A | B | B | B | C | C | C | C | C | C |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

| | |
|---|---|
| | A |
| | B |
| | C |
| | D |

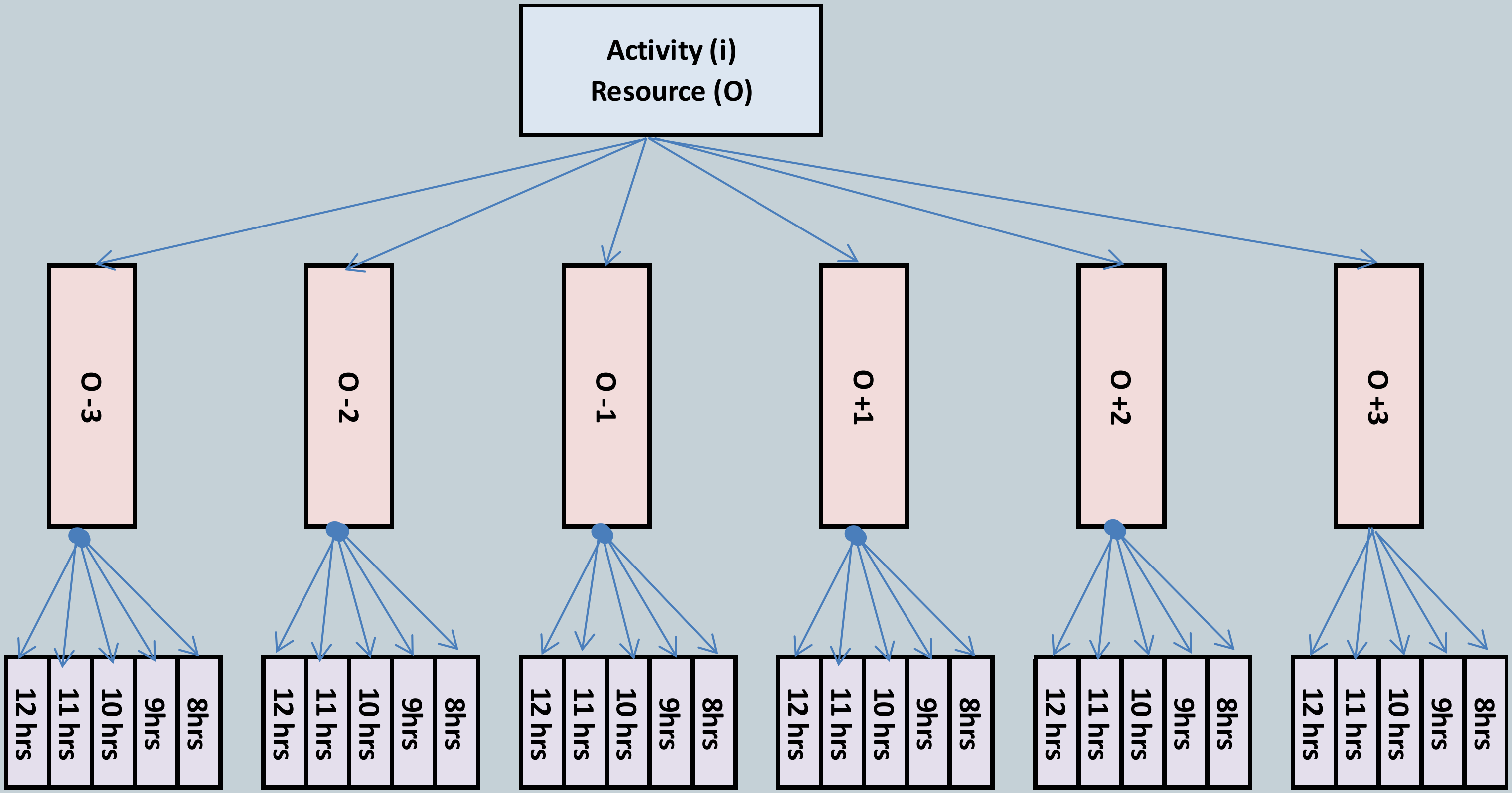
## PROBLEM STATEMENT

- CPM ignores resource constraints.
- Limited flexibility provided by CPM.
- Resource Allocation is time draining.
- Resource Leveling depends on the float.
- Potentially better solutions can be found if considering relaxing and crashing non-critical activities.

# OBJECTIVE

- The objective of this research is to develop a technique that explores better potential schedules than CPM's by taking into consideration resource assignment, working hours, and applicable relationships as variables. In addition, variations in resource assignment are subjected to productivity losses due to crowding/overtime. The developed approach examines all the possible combination of scenarios and finds the best one that serves different objectives. This technique is referred to as **"Flexible Scheduling"**

# OBJECTIVE



Activity (i)
Resource (O)
O -3
O -2
O -1
O +1
O +2
O +3
12 hrs
11 hrs
10 hrs
9hrs
8hrs

# METHODOLOGY

- Defining assumptions and input functions for the model:
  - It is assumed that relaxing activities has no effect on the productivity and that all activities are continuous and cannot split
  - Hinze Equations.
- *What'sBest* – Excel add-in
  - User-friendly interface
  - Simplicity
  - High capabilities

# METHODOLOGY

- Defining problem's parameters:
  - Nonlinear problem:
    - Presence of logical non-smooth function (IF, AND, OR...etc.)
    - Variables are bounded by functions (non-constants)
  - Variables:
    - Actual Start, resources, lags, and working hours.
  - Objectives:
    - Resource leveling, allocation, and cost optimization.
  - Constraints:
    - Depending on the objective (duration, max resource demand, minimum lag...etc)

# METHODOLOGY

- Finding the economically best Solution
  - *What'sBest* shortcoming (One Objective Cell)
  - Several combinations of scenarios
  - Fix found solution and minimize the cost
- Creation of hypothetical example
  - Includes all types of relationships
  - Objectives:
    - Resource leveling
    - Resource allocation
    - Cost optimization
- Validation of the model

# MODELING

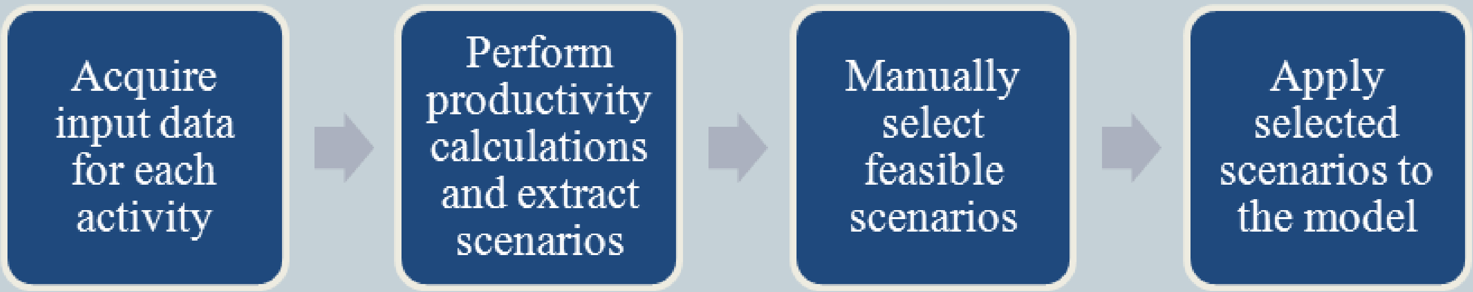
- Model assumptions:
  - Activity resources are uniformly distributed throughout the activity duration
  - Losses associated with reducing number of workers will be neglected
  - Activities are continuous and cannot be split
  - Fixed cost is expected to remain constant
  - Costs will be assumed as follows unless noted otherwise:
    - Hiring/firing cost = 150 $/unit
    - Overtime pay rate = 1.5 x regular pay rate
    - Overtime can extend up to 4 hours (total of 12 working hours daily)

# MODELING

- Process was divided to two sub-processes:
  - Pre-modeling:
    - Extract all possible scenarios for every activity
    - Manual selection of feasible solution
    - Implementation of selected scenarios in the model
  - Modeling:
    - CPM network is interconnected with resource histogram
    - Implementation of scenarios and other flexibilities (moving within available float
    - Solving for different objectives

# MODELING

- Pre-Modeling:

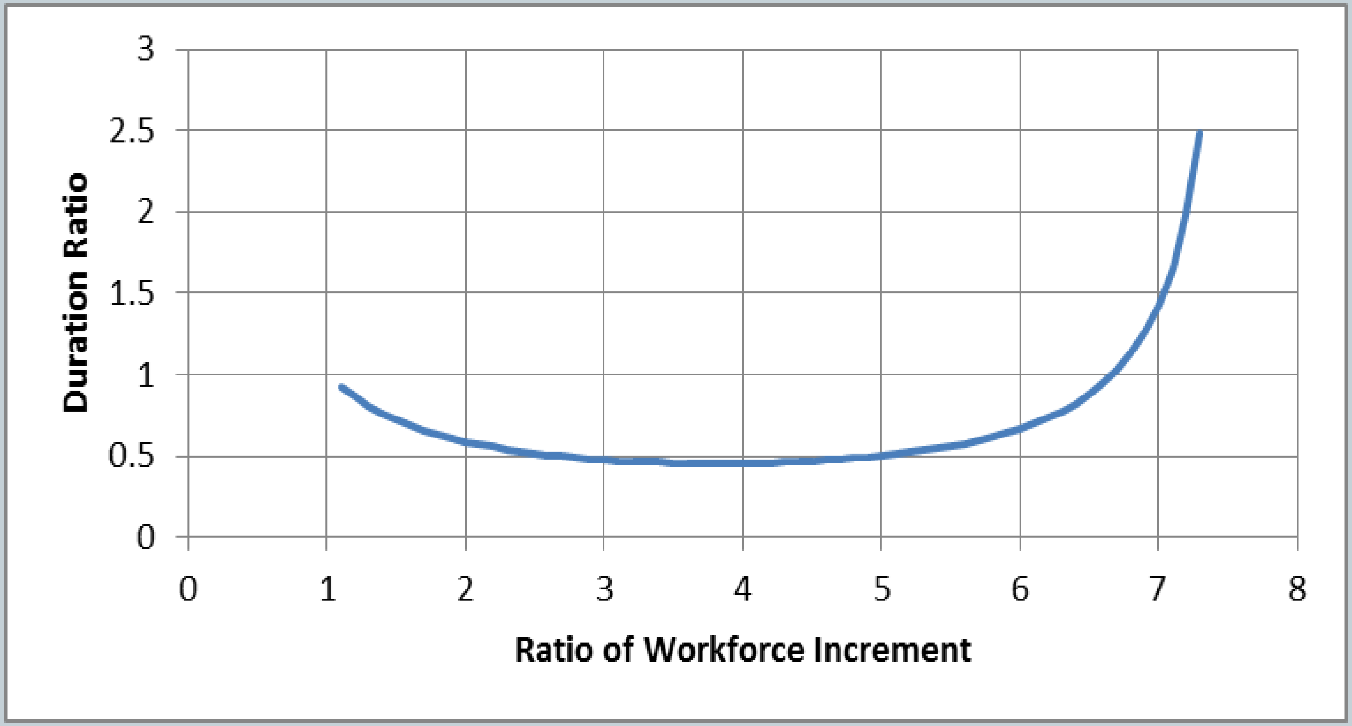


# MODELING

- Flexible Scheduling scenarios are based on:
  - Increasing/decreasing number of workers (Crowding).
  - Increasing number of working hours (Overtime)
  - Combination of crowding and overtime.
- Crowding Efficiency = 115% – 15( $\frac{\text{Expanded Workforce}}{\text{Normal Workforce}}$ )
- Overtime Efficiency = 100% – 5[(days – 5) +(hours – 8)]
- Overall Efficiency = Crowding Efficiency x Overtime Efficiency
- New Duration = $\frac{\text{Total Man–Hour Requirement}}{(\text{Ratio of workers})\text{x}(\text{Old Crew size})(\text{Overall Efficiency})\text{x}(\text{T})}$

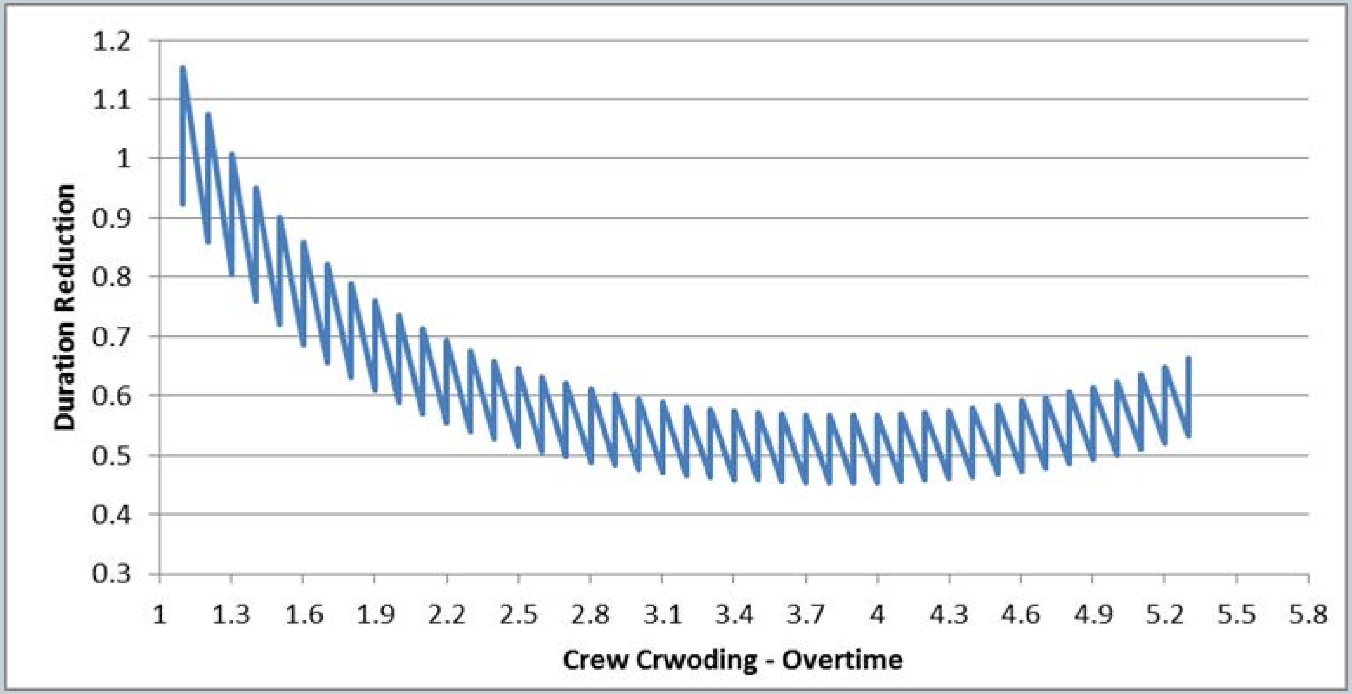
# MODELING

- $$\text{Crowding Efficiency} = 115\% - 15\left(\frac{\text{Expanded Workforce}}{\text{Normal Workforce}}\right)$$



# MODELING

- Overtime Efficiency = 100% – 5[(days – 5) +(hours – 8)]
- Overall Efficiency = Crowding Efficiency x Overtime Efficiency



# MODELING

- Calculate all possible scenarios based on step increments/decrements.
- Manual selection of feasible scenarios (-0.2 days tolerance)

| Ratio | Crowding Effciency | T | Overtime Effeciency | Over all Effeciency | Actual | Effective | New Duration | 512 | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1.13 | 0.98125 | 8 | 1 | 98.125 | 9 | 8.83125 | 7.2 | 8 | Labor |
| 1.13 | 0.98125 | 9 | 0.95 | 93.21875 | 9 | 8.3896875 | 6.8 | 8 | Duration |
| 1.13 | 0.98125 | 10 | 0.9 | 88.3125 | 9 | 7.948125 | 6.4 | | |
| 1.13 | 0.98125 | 11 | 0.85 | 83.40625 | 9 | 7.5065625 | 6.2 | | |
| 1.13 | 0.98125 | 12 | 0.8 | 78.5 | 9 | 7.065 | 6.0 | | |
| 1.25 | 0.9625 | 8 | 1 | 96.25 | 10 | 9.625 | 6.6 | | |
| 1.25 | 0.9625 | 9 | 0.95 | 91.4375 | 10 | 9.14375 | 6.2 | | |
| 1.25 | 0.9625 | 10 | 0.9 | 86.625 | 10 | 8.6625 | 5.9 | | |
| 1.25 | 0.9625 | 11 | 0.85 | 81.8125 | 10 | 8.18125 | 5.7 | | |
| 1.25 | 0.9625 | 12 | 0.8 | 77 | 10 | 7.7 | 5.5 | | |
| 1.375 | 0.94375 | 8 | 1 | 94.375 | 11 | 10.38125 | 6.2 | | |
| 1.375 | 0.94375 | 9 | 0.95 | 89.65625 | 11 | 9.8621875 | 5.8 | | |
| 1.375 | 0.94375 | 10 | 0.9 | 84.9375 | 11 | 9.343125 | 5.5 | | |
| 1.375 | 0.94375 | 11 | 0.85 | 80.21875 | 11 | 8.8240625 | 5.3 | | |
| 1.375 | 0.94375 | 12 | 0.8 | 75.5 | 11 | 8.305 | 5.1 | | |
| 1.5 | 0.925 | 8 | 1 | 92.5 | 12 | 11.1 | 5.8 | | |
| 1.5 | 0.925 | 9 | 0.95 | 87.875 | 12 | 10.545 | 5.4 | | |
| 1.5 | 0.925 | 10 | 0.9 | 83.25 | 12 | 9.99 | 5.1 | | |
| 1.5 | 0.925 | 11 | 0.85 | 78.625 | 12 | 9.435 | 4.9 | | |

Zero tolerance

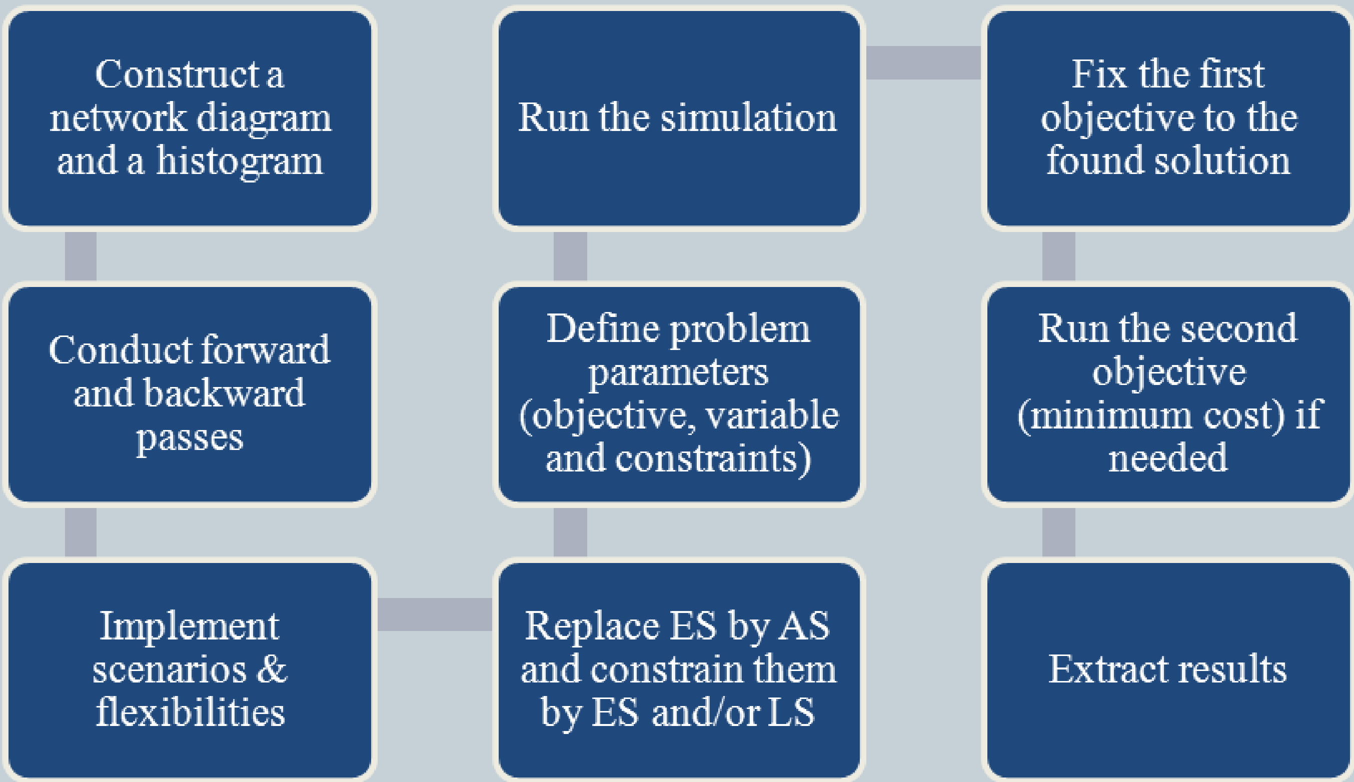
The closest to 6 (-0.2 tol)

# MODELING

- Calculating associated cost for each scenario and plugging into the model.
- $C_{Li}$=[Resource x Duration x 8 x (Cost / hour)+(Overtime x 1.5 x (Cost / hour)]

| | | Scenario 1 | | | | Scenario 2 | | | | Scenario 3 | | | | Scenario 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Res | Dur | OT | Cost | Res | Dur | OT | Cost | Res | Dur | OT | Cost | Res | Dur | OT | Cost |
| A | 200 | 5 | 5 | 0 | 20000 | 6 | 4 | 1 | 22800 | 8 | 3 | 3 | 30000 | 9 | 3 | 1 | 25650 |
| B | 240 | 5 | 6 | 0 | 24000 | 6 | 5 | 1 | 28500 | 7 | 5 | 0 | 28000 | 7 | 4 | 3 | 35000 |
| C | 512 | 8 | 8 | 0 | 51200 | 9 | 7 | 2 | 69300 | 9 | 6 | 4 | 75600 | 10 | 6 | 2 | 66000 |
| D | 160 | 5 | 4 | 0 | 16000 | 6 | 3 | 3 | 22500 | 7 | 3 | 0 | 16800 | 10 | 2 | 3 | 25000 |
| E | 280 | 5 | 7 | 0 | 28000 | 6 | 6 | 0 | 28800 | 6 | 5 | 4 | 42000 | 7 | 5 | 1 | 33250 |
| F | 256 | 8 | 4 | 0 | 25600 | 9 | 3 | 4 | 37800 | 10 | 3 | 2 | 33000 | 11 | 3 | 1 | 31350 |
| G | 384 | 8 | 6 | 0 | 38400 | 9 | 5 | 2 | 49500 | 10 | 5 | 0 | 40000 | 11 | 4 | 3 | 55000 |
| H | 448 | 7 | 8 | 0 | 44800 | 8 | 6 | 4 | 67200 | 9 | 6 | 2 | 59400 | 10 | 6 | 0 | 48000 |
| R | 256 | 8 | 4 | 0 | 25600 | 9 | 3 | 4 | 37800 | 10 | 3 | 2 | 33000 | 11 | 3 | 1 | 31350 |
| P | 168 | 7 | 3 | 0 | 16800 | 9 | 2 | 4 | 25200 | 10 | 2 | 2 | 22000 | 11 | 2 | 1 | 20900 |

# MODELING


Construct a network diagram and a histogram
Conduct forward and backward passes
Implement scenarios & flexibilities
Replace ES by AS and constrain them by ES and/or LS
Define problem parameters (objective, variable and constraints)
Run the simulation
Fix the first objective to the found solution
Run the second objective (minimum cost) if needed
Extract results

# MODELING

- Construct a Network Diagram:
  - Forward Pass:
    - Find early start and finishing times ($ES_i$ & $EF_i$).

$$ES_i = MAX\begin{cases} FS \rightarrow MAX([EF_{1ji} + L_{1ji}], [EF_{2ji} + L_{2ji}], \ldots, [EF_{nji} + L_{nji}]) \\ SS \rightarrow MAX([ES_{1ji} + L_{1ji}], [ES_{2ji} + L_{2ji}], \ldots, [ES_{nji} + L_{nji}]) \\ FF \rightarrow MAX([EF_{1ji} + L_{1ji}], [EF_{2ji} + L_{2ji}], \ldots, [EF_{nji} + L_{nji}]) - D_{mi} \end{cases}$$

    - $EF_i = ES_i + D_{mi}$
  - Backward Pass:

$$LF_i = Min\begin{cases} FS \rightarrow MIN([LS_{1ki} - L_{1ki}], [LS_{2ki} - L_{2ki}], \ldots, [LS_{nki} - L_{nki}]) \\ SS \rightarrow MIN([LS_{1ki} - L_{1ki}], [LS_{2ki} - L_{2ki}], \ldots, [LS_{nki} - L_{nki}]) + D_{mi} \\ FF \rightarrow MIN([LF_{1ki} - L_{1ki}], [LF_{2ki} - L_{2ki}], \ldots, [LF_{nki} - L_{nki}]) \end{cases}$$

    - $LS_i = LF_i - D_{mi}$
  - $L_{jin} \geq$ (%comp constraint) x $D_{jni}$ (Lag constraint)

# MODELING

- Implementation of Scenarios:

$$D_{mi} = Z_{1i} * D_{1i} + Z_{2i} * D_{2i} + Z_{3i} * D_{3i} + \cdots + Z_{mi} * D_{mi}$$

$$O_{mi} = Z_{1i} * O_{1i} + Z_{2i} * O_{2i} + Z_{3i} * O_{3i} + \cdots + Z_{mi} * O_{mi}$$

$$C_{mi} = Z_{1i} * C_{1i} + Z_{2i} * C_{2i} + Z_{3i} * C_{3i} + \cdots + Z_{mi} * C_{mi}$$

- $Z_{mi}$ is a binary coefficient (1,0)

$$\sum_{1}^{m} Z_{mi} = 1$$

- Only one scenario is selected at a time.

# MODELING

- Replace early start by a variable (Actual start):
  - This step is to implement movement of activities within their available float.
  - Duration, resources, and applicable lags are variables.
  - Constrain ($AS_i$)to fall within early and late start timing ($ES_i$ and $LS_i$) depending on the objective.

$$ES_i \leq AS_i \leq LS_i$$

- Construct the histogram:

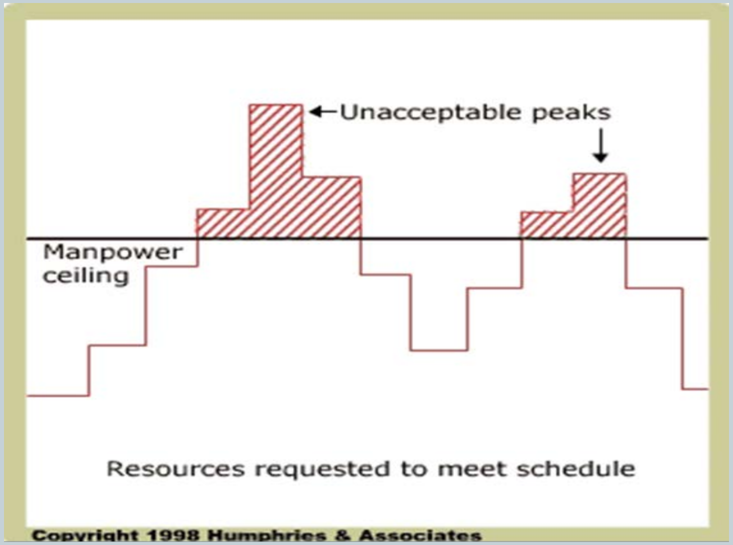
$$R_t = \sum_{i=1}^{n} (O_{mi} \times X_{ti})$$

# MODELING

- Define problem parameters:
  - Resource Leveling:
    - Objective: $\text{MIN}\ (\sum_{t=1}^{T} HF_t)$ ; Where $HF_t = |R_t - R_{(t-1)}|$
    - Variables: $AS_i$ (Integer); $Z_{mi}$ (Binary); $L_{jin}$ (Integer)
    - Constraints:
      - $ES_i \leq AS_i \leq LS_i$ ;
      - $L_{jin} \geq (\%comp\ constraint)\ x\ D_{jni}$
      - $\sum_1^m Z_{mi} = 1$
      - T= Fixed (cannot change from CPM)
    - Minimize the cost on the second run.

# MODELING

- Define problem parameters:
  - Resource Allocation:
    - Objective: MIN (T)
    - Variables: $AS_i$ (Integer); $Z_{mi}$ (Binary); $L_{jin}$ (Integer)
    - Constraints:
      - $Max(R_t) \leq RC$
      - $AS_i \geq ES_i$
      - $L_{jin} \geq (\%comp\ constraint)\ x\ D_{jni}$
      - $\sum_1^m Z_{mi} = 1$
- Minimize the cost on the second run.

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# MODELING

- Define problem parameters:
  - Cost Optimization:
    - Objective: MIN ($C_T$) ( $C_T = C_{HF} + C_{OH} + C_{LD} + (\sum_{i=1}^{n} C_{Li}) - I_n$ )
    - Variables: $AS_i$ (Integer); $Z_{mi}$ (Binary); $L_{jin}$ (Integer)
    - Constraints:
      - $ES_i \leq AS_i$
      - $L_{jin} \geq$(%comp constraint) x $D_{jni}$
      - $\sum_1^m Z_{mi} = 1$
    - Actual start is only constrained by early start.

# MODELING

- Example:

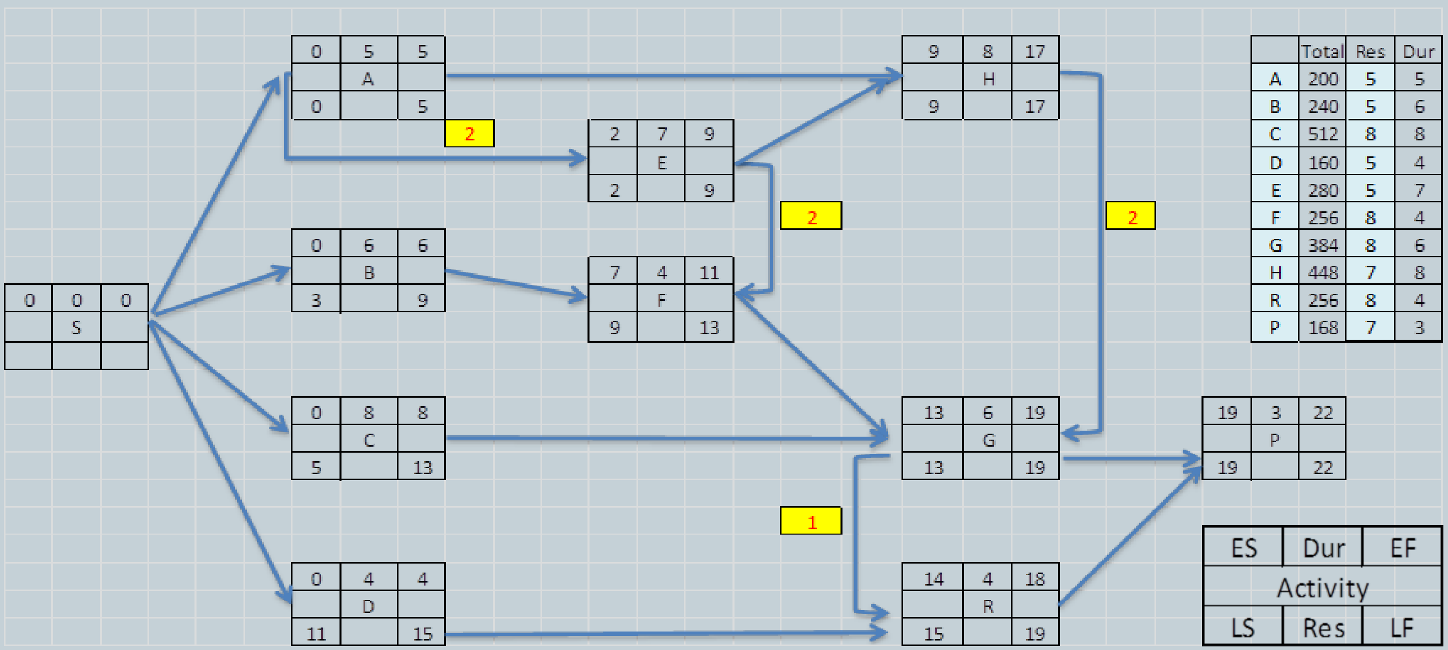
| Activity | Total man-hour | Resource assignment | Normal duration | Logic act: logic + lag |
|---|---|---|---|---|
| A | 200 | 5 | 5 | - |
| B | 240 | 5 | 6 | - |
| C | 512 | 8 | 8 | - |
| D | 160 | 5 | 4 | - |
| E | 280 | 5 | 7 | A: SS+2 |
| F | 256 | 8 | 4 | B: FS+0<br>E: FF+2 |
| G | 384 | 8 | 6 | F,C : FS+0<br>H: FF+2 |
| H | 448 | 7 | 8 | A,E: FS+0 |
| R | 256 | 8 | 4 | G: SS+1<br>D: FS+0 |
| P | 168 | 7 | 3 | G,R: FS+0 |

# MODELING

- Project Information:
  - The client wants the project to finish in 20 days
  - Liquidated damages are $1000/day
  - Incentives for early finish $1000/day
  - Regular man-hour pay rate = $35
  - Hiring/Firing unit cost = $150
  - Lags are performance-based lags and represent the minimum allowable lag

# MODELING

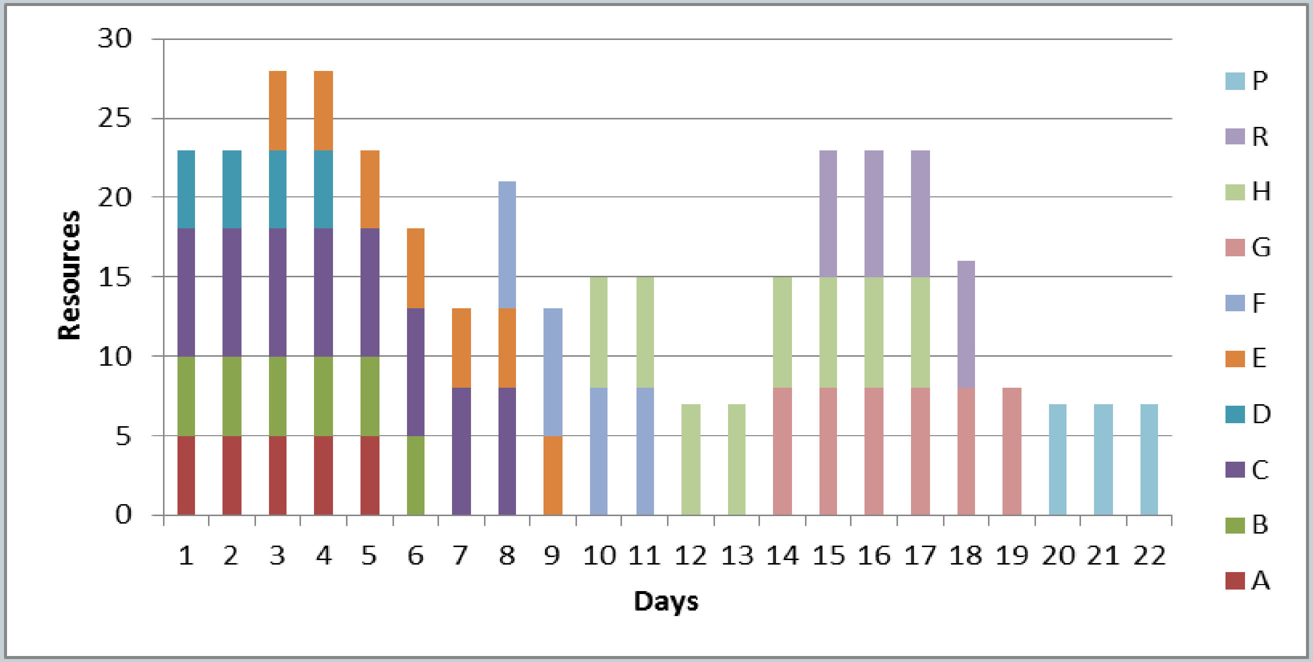
- Network Diagram




| | Total | Res | Dur |
|---|---|---|---|
| A | 200 | 5 | 5 |
| B | 240 | 5 | 6 |
| C | 512 | 8 | 8 |
| D | 160 | 5 | 4 |
| E | 280 | 5 | 7 |
| F | 256 | 8 | 4 |
| G | 384 | 8 | 6 |
| H | 448 | 7 | 8 |
| R | 256 | 8 | 4 |
| P | 168 | 7 | 3 |

- CPM duration is 22 days

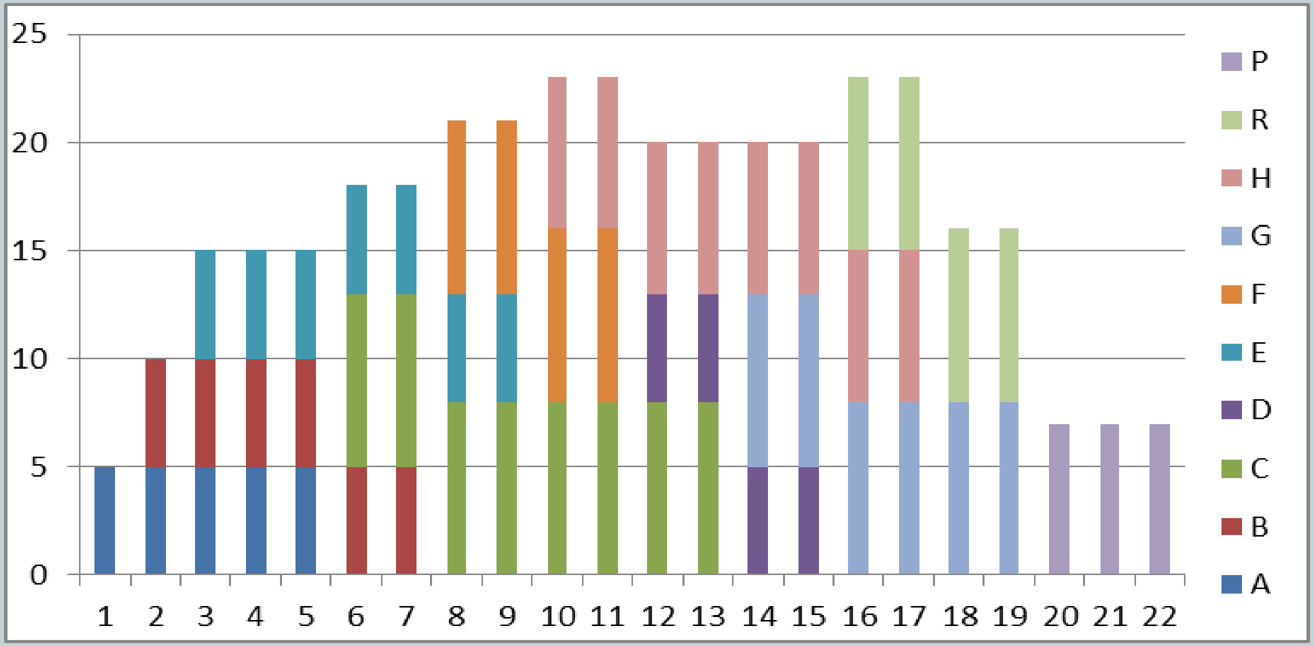
# MODELING




- Peak demand of 28 workers
- Hiring-Firing of 78 practices
- Total cost = $159340

# MODELING

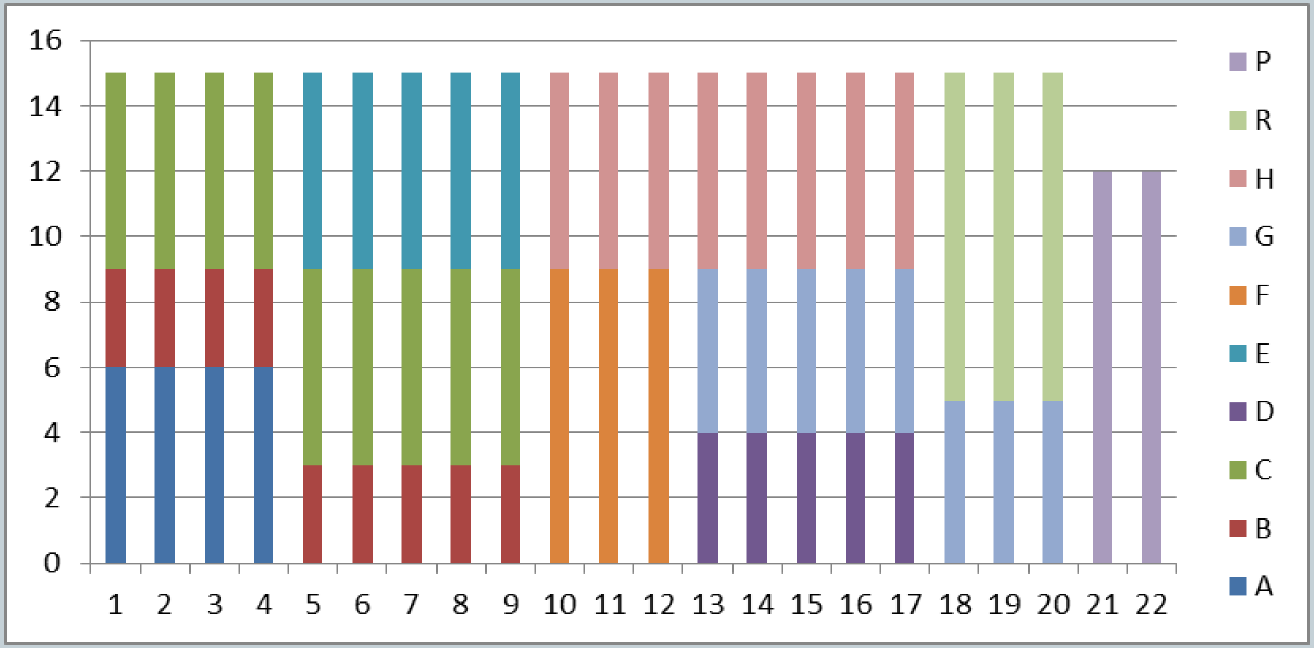
- Classical Leveling:




- Peak 23 workers
- Hiring-Firing = 40

# MODELING

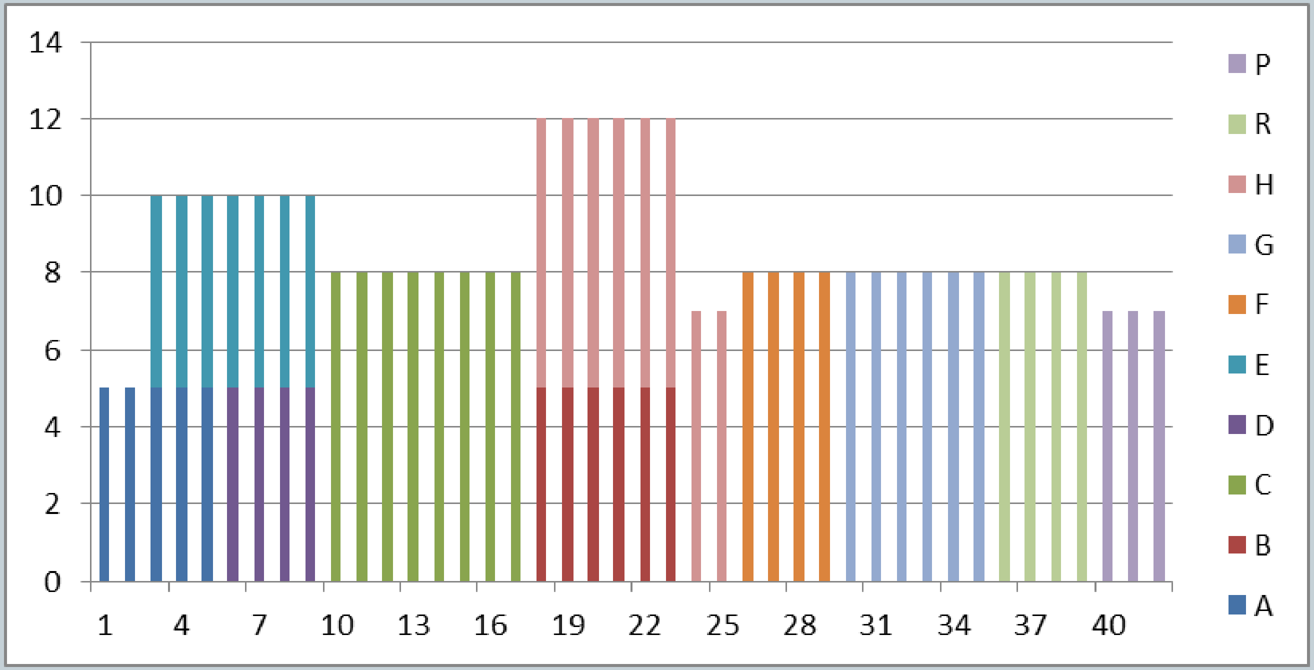
- Flexible Scheduling – Resource Leveling:




- Peak demand = 15 workers
- Hiring-firing= 3 workers

# MODELING

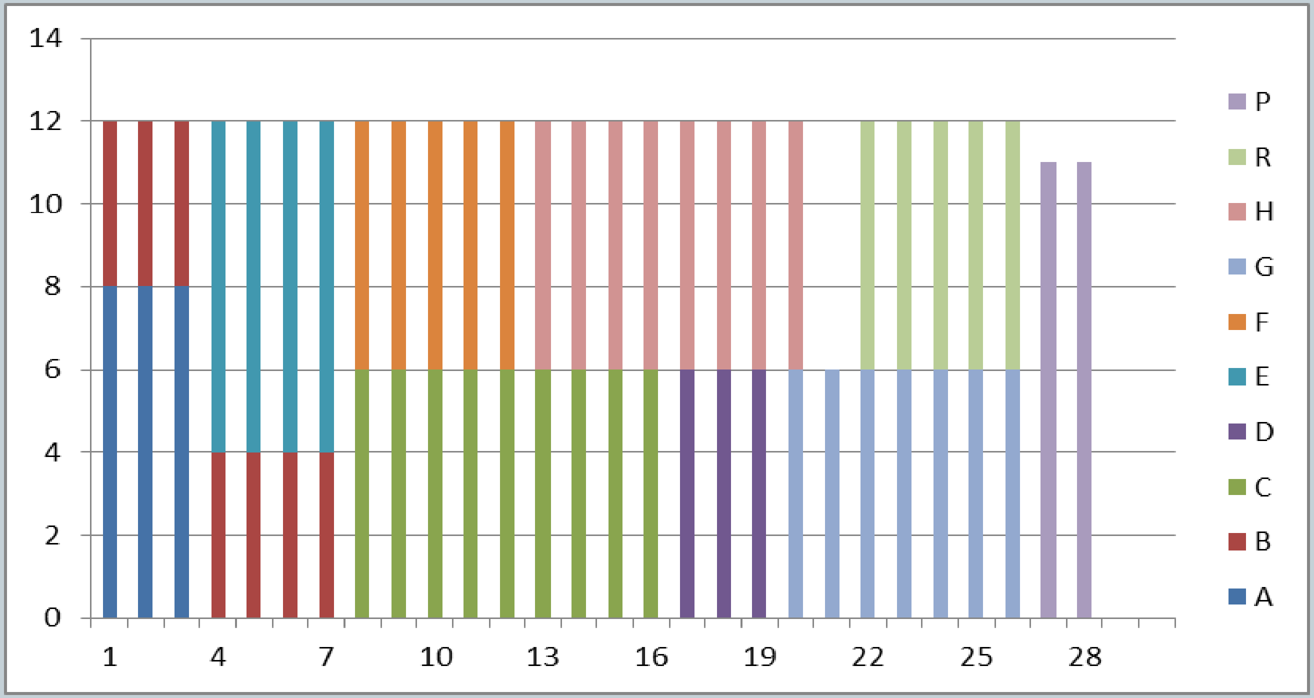
- Classical Allocation:




- Duration = 42 days

# MODELING

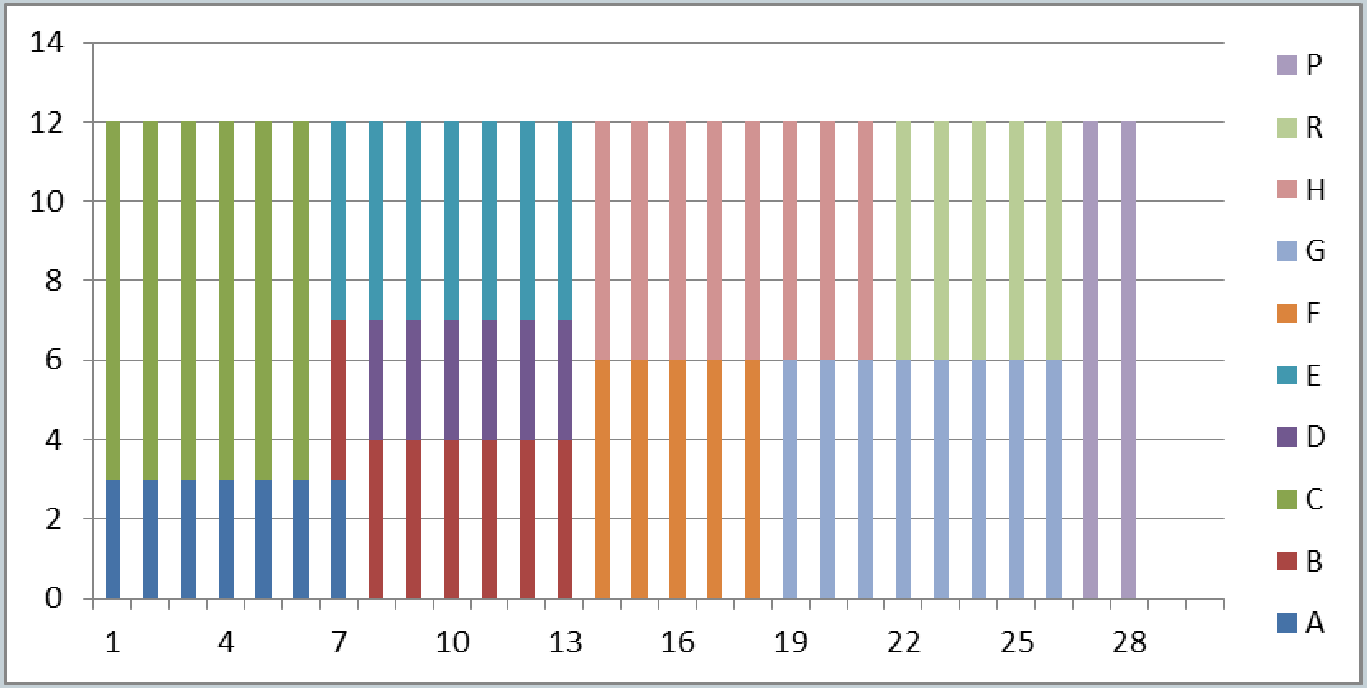
- Flexible Scheduling – Resource Allocation:




- Duration: 28 days

# MODELING

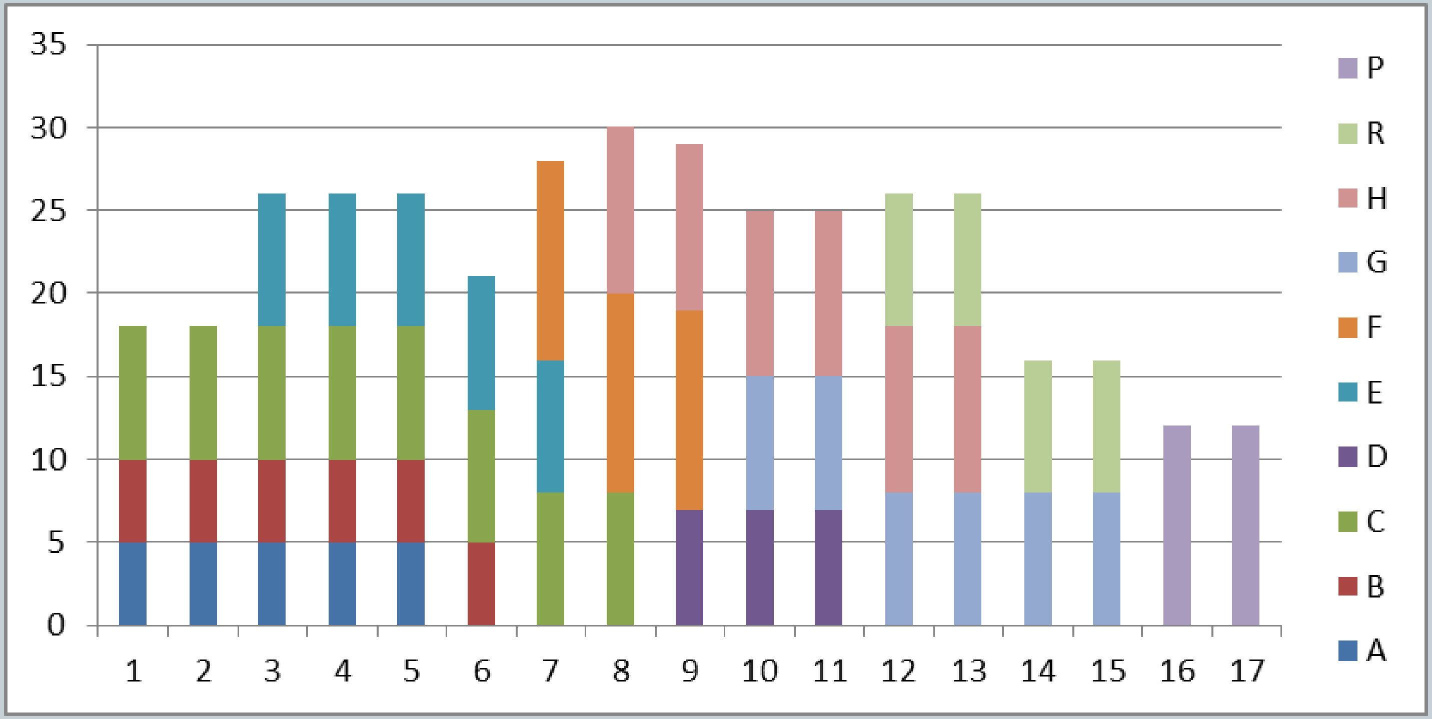
- Second run (Flexible Scheduling- Minimize cost):




- Leveled histogram

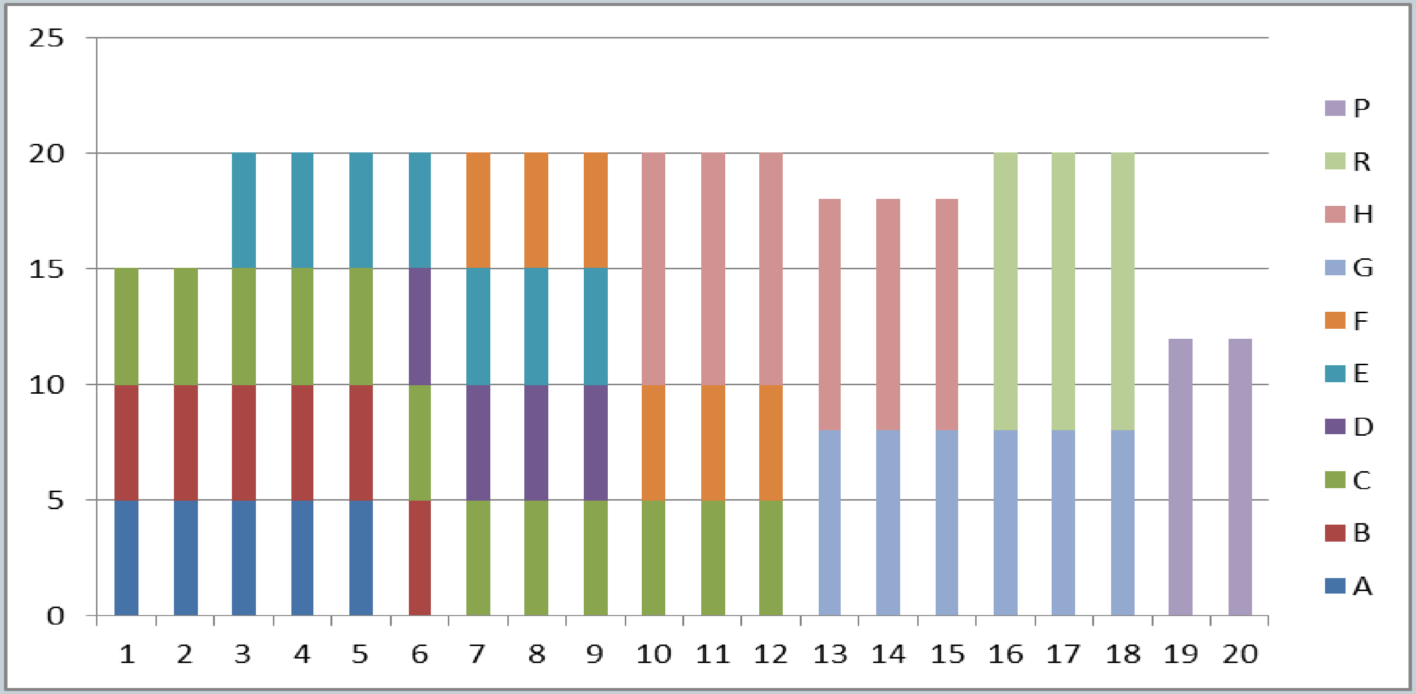
# MODELING

- Flexible Scheduling - Cost Optimization:



# MODELING

- Flexible Scheduling (Cost optimization with resource constraint):



# RESULTS AND DISCUSSION

| Attributes | Duration | Peak demand | Hiring-firing | Cost |
|---|---|---|---|---|
| CPM | 22 | 28 | 78 | 159340 |
| Classical Allocation | 42 | 12 | 18 | 211390 |
| Flexible Scheduling Allocation | 28 | 12 | 0 | 189700 |

| Attributes | Duration | Peak demand | Hiring-firing | Cost |
|---|---|---|---|---|
| CPM | 22 | 28 | 78 | 159340 |
| Classical Leveling | 22 | 23 | 40 | 153640 |
| Flexible Scheduling Leveling | 22 | 15 | 3 | 183685 |

| Attributes | Duration | Peak demand | Hiring-firing | Cost |
|---|---|---|---|---|
| CPM | 22 | 28 | 78 | 159340 |
| Cost Optimization | 17 | 30 | 42 | 143700 |
| Cost Optimization + Allocation | 20 | 20 | 17 | 150315 |

# RESULTS AND DISCUSSION

- Flexible Scheduling is successfully implemented
  - Variable resource assignment
  - Variable working hours
  - Variable lags when applicable
  - Variable duration
  - Productivity losses
- New cost of resource leveling
- More adequate results that current techniques
  - Resource Leveling
  - Resource Allocation
  - Cost Optimization

# SUMMARY AND CONCLUSIONS

- Potential solutions were found when implementing Flexible Scheduling
- Introduction new trade-off between efficiency, time and cost
- Introduction of cost of leveling
- Flexible Scheduling results outperformed current scheduling techniques
- Flexible Schedules are detailed and specific

# RECOMMENDATIONS

- Productivity losses are calculated through empirical equations
  - Differ depending on the work environment.
  - Pre-modeling is an independent process.
- Run-time is consuming
  - Use other software/ heuristics.
- Incorporate more approaches to manipulate duration:
  - Starting points.
  - Working Days.
- Flexible Scheduling assumes one dominant resource and hence it's suggested to consider multi-resources for future research.

# Questions