Flexible Scheduling for Construction Projects

Presented by
Mohammad F. Saleh

Committee Members
Dr. Sameh El-Sayegh
Dr. Saleh Abodabous
Dr. Hazim El-Baz
Dr. Salwa Beheiry

Dec 2011
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

- 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.

[Diagram of project network](http://www.leniel.net)
BACKGROUND
Resource Allocation

- CPM does **not** 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)]

![Graph showing efficiency with overtime](image)
### PROBLEM STATEMENT

#### Example:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Normal Duration</th>
<th>Total Man-hour</th>
<th>Precedence</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>200</td>
<td>Start</td>
<td>FS</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>168</td>
<td>A</td>
<td>SS+3</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>240</td>
<td>B</td>
<td>FS</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>112</td>
<td>A</td>
<td>FS</td>
</tr>
<tr>
<td>Finish</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\[
\text{No. of workers} = \frac{\text{Total Manhour}}{(\text{Duration}) \times (\text{Working hours})}
\]
• 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 Efficiency*=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 Efficiency*=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
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
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.
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”
METHODOLOGY

● Defining assumptions and input functions for the model:
  o It is assumed that relaxing activities has no effect on the productivity and that all activities are continuous and cannot split
  o Hinze Equations.

● What’sBest – Excel add-in
  o User-friendly interface
  o Simplicity
  o 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
  o *What’sBest* shortcoming (One Objective Cell)
  o Several combinations of scenarios
  o Fix found solution and minimize the cost

● Creation of hypothetical example
  o Includes all types of relationships
  o 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:
  - Acquire input data for each activity
  - Perform productivity calculations and extract scenarios
  - Manually select feasible scenarios
  - Apply selected scenarios to the model
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 = $115\% - 15\left(\frac{\text{Expanded Workforce}}{\text{Normal Workforce}}\right)$

Overtime Efficiency = $100\% - 5[(\text{days} - 5) + (\text{hours} - 8)]$

Overall Efficiency = Crowding Efficiency x Overtime Efficiency

New Duration = \(\frac{\text{Total Man-Hour Requirement}}{(\text{Ratio of workers}) \times (\text{Old Crew size}) \times (\text{Overall Efficiency}) \times T}\)
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)

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Crowding Efficiency</th>
<th>T</th>
<th>Overtime Efficiency</th>
<th>Over all Efficiency</th>
<th>Actual</th>
<th>Effective</th>
<th>New Duration</th>
<th>512</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.13</td>
<td>0.98125</td>
<td>8</td>
<td>1</td>
<td>98.125</td>
<td>9</td>
<td>8.83125</td>
<td>7.2</td>
<td>8</td>
<td>Labor</td>
</tr>
<tr>
<td>1.13</td>
<td>0.98125</td>
<td>9</td>
<td>0.95</td>
<td>93.21875</td>
<td>9</td>
<td>8.396875</td>
<td>6.8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>1.13</td>
<td>0.98125</td>
<td>10</td>
<td>0.9</td>
<td>88.3125</td>
<td>9</td>
<td>7.948125</td>
<td>6.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.13</td>
<td>0.98125</td>
<td>11</td>
<td>0.85</td>
<td>83.40625</td>
<td>9</td>
<td>7.5065625</td>
<td>6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.13</td>
<td>0.98125</td>
<td>12</td>
<td>0.8</td>
<td>78.5</td>
<td>9</td>
<td>7.065</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.25</td>
<td>0.9625</td>
<td>8</td>
<td>1</td>
<td>96.25</td>
<td>10</td>
<td>9.625</td>
<td>6.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.25</td>
<td>0.9625</td>
<td>9</td>
<td>0.95</td>
<td>91.4375</td>
<td>10</td>
<td>9.14375</td>
<td>6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.25</td>
<td>0.9625</td>
<td>10</td>
<td>0.9</td>
<td>86.625</td>
<td>10</td>
<td>8.6625</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.25</td>
<td>0.9625</td>
<td>11</td>
<td>0.85</td>
<td>81.8125</td>
<td>10</td>
<td>8.18125</td>
<td>5.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.25</td>
<td>0.9625</td>
<td>12</td>
<td>0.8</td>
<td>77</td>
<td>10</td>
<td>7.7</td>
<td>5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.375</td>
<td>0.94375</td>
<td>8</td>
<td>1</td>
<td>94.375</td>
<td>11</td>
<td>10.38125</td>
<td>6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.375</td>
<td>0.94375</td>
<td>9</td>
<td>0.95</td>
<td>89.65625</td>
<td>11</td>
<td>9.8621875</td>
<td>5.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.375</td>
<td>0.94375</td>
<td>10</td>
<td>0.9</td>
<td>84.9375</td>
<td>11</td>
<td>9.343125</td>
<td>5.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.375</td>
<td>0.94375</td>
<td>11</td>
<td>0.85</td>
<td>80.21875</td>
<td>11</td>
<td>8.8240625</td>
<td>5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.375</td>
<td>0.94375</td>
<td>12</td>
<td>0.8</td>
<td>75.5</td>
<td>11</td>
<td>8.305</td>
<td>5.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>0.925</td>
<td>8</td>
<td>1</td>
<td>92.5</td>
<td>12</td>
<td>11.1</td>
<td>5.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>0.925</td>
<td>9</td>
<td>0.95</td>
<td>87.875</td>
<td>12</td>
<td>10.545</td>
<td>5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>0.925</td>
<td>10</td>
<td>0.9</td>
<td>83.25</td>
<td>12</td>
<td>9.99</td>
<td>5.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>0.925</td>
<td>11</td>
<td>0.85</td>
<td>78.625</td>
<td>12</td>
<td>9.435</td>
<td>4.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Zero tolerance

The closest to 6 (-0.2 tol)
MODELING

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

1. Construct a network diagram and a histogram
2. Conduct forward and backward passes
3. Implement scenarios & flexibilities
4. Run the simulation
5. Define problem parameters (objective, variable and constraints)
6. Replace ES by AS and constrain them by ES and/or LS
7. Fix the first objective to the found solution
8. Run the second objective (minimum cost) if needed
9. Extract results
Construct a Network Diagram:

Forward Pass:
- Find early start and finishing times (ES\textsubscript{i} & EF\textsubscript{j}):
  \[ ES\textsubscript{i} = \max \left( \sum_{i=1}^{j} (EF\textsubscript{ij} + L\textsubscript{ij}) \right) \]

  \[ SS\rightarrow \max \left( [ES\textsubscript{ij} + L\textsubscript{ij}], [ES\textsubscript{2j} + L\textsubscript{2j}], \ldots, [ES\textsubscript{nj} + L\textsubscript{nj}] \right) \]

  \[ FF\rightarrow \max \left( [EF\textsubscript{ij} + L\textsubscript{ij}], [EF\textsubscript{2j} + L\textsubscript{2j}], \ldots, [EF\textsubscript{nj} + L\textsubscript{nj}] \right) - D\textsubscript{mi} \]

- \( EF\textsubscript{j} = ES\textsubscript{i} + D\textsubscript{mi} \)

Backward Pass:

- \( FS\rightarrow \min \left( [LS\textsubscript{1k} - L\textsubscript{1k}], [LS\textsubscript{2k} - L\textsubscript{2k}], \ldots, [LS\textsubscript{nki} - L\textsubscript{nki}] \right) \]

  \[ LF\textsubscript{i} = \min \left( [LS\textsubscript{1ki} - L\textsubscript{1ki}], [LS\textsubscript{2ki} - L\textsubscript{2ki}], \ldots, [LS\textsubscript{nki} - L\textsubscript{nki}] + D\textsubscript{mi} \right) \]

- \( LS\textsubscript{i} = LF\textsubscript{i} - D\textsubscript{mi} \)

- \( L_{ji} \geq (%\text{comp constraint}) \times D_{jmi} \) (Lag constraint)
MODELING

- Implementation of Scenarios:

\[ D_{mi} = Z_{1i} * D_{1i} + Z_{2i} * D_{2i} + Z_{3i} * D_{3i} + \ldots + Z_{mi} * D_{mi} \]

\[ O_{mi} = Z_{1i} * O_{1i} + Z_{2i} * O_{2i} + Z_{3i} * O_{3i} + \ldots + Z_{mi} * O_{mi} \]

\[ C_{mi} = Z_{1i} * C_{1i} + Z_{2i} * C_{2i} + Z_{3i} * C_{3i} + \ldots + Z_{mi} * C_{mi} \]

- \( Z_{mi} \) 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 \((ES_i \text{ and } LS_i)\) 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:**
      - \(ES_i \leq AS_i \leq LS_i\)
      - \(L_{jin} \geq (%\text{comp constraint}) \times D_{jini}\)
      - \(\sum_{1}^{m} Z_{mi} = 1\)
      - \(T=\) 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:
  - \( \text{Max}(R_t) \leq RC \)
  - \( AS_i \geq ES_i \)
  - \( L_{jin} \geq (%\text{comp constraint}) \times D_{jni} \)
  - \( \sum_{1}^{m} Z_{mi} = 1 \)
- Minimize the cost on the second run.

http://learn.dau.mi
**MODELING**

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

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

- 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
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

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Duration</th>
<th>Peak demand</th>
<th>Hiring-firing</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPM</td>
<td>22</td>
<td>28</td>
<td>78</td>
<td>159340</td>
</tr>
<tr>
<td>Classical Allocation</td>
<td>42</td>
<td>12</td>
<td>18</td>
<td>211390</td>
</tr>
<tr>
<td>Flexible Scheduling Allocation</td>
<td>28</td>
<td>12</td>
<td>0</td>
<td>189700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Duration</th>
<th>Peak demand</th>
<th>Hiring-firing</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPM</td>
<td>22</td>
<td>28</td>
<td>78</td>
<td>159340</td>
</tr>
<tr>
<td>Classical Leveling</td>
<td>22</td>
<td>23</td>
<td>40</td>
<td>153640</td>
</tr>
<tr>
<td>Flexible Scheduling Leveling</td>
<td>22</td>
<td>15</td>
<td>3</td>
<td>183685</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Duration</th>
<th>Peak demand</th>
<th>Hiring-firing</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPM</td>
<td>22</td>
<td>28</td>
<td>78</td>
<td>159340</td>
</tr>
<tr>
<td>Cost Optimization</td>
<td>17</td>
<td>30</td>
<td>42</td>
<td>143700</td>
</tr>
<tr>
<td>Cost Optimization + Allocation</td>
<td>20</td>
<td>20</td>
<td>17</td>
<td>150315</td>
</tr>
</tbody>
</table>
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