# *Object Oriented Scheduling using Nontraditional Optimization*

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# Outline

# Construction Scheduling

- Aim : arranging construction activities
- maintain proper time sequence : formidable task.
- network based and non network based techniques used.
- identify critical path
- decide start time of non critical activities
- use of non-traditional optimization techniques

# Objectives of present work

**Objective**

To develop methods for optimization of scheduling problems in construction utilizing the power of non traditional optimization techniques.

The aims of the present study are

- Formulation with multiple objectives of time cost trade off and resouce scheduling problems in construction.
- Solving the above formulation with multiobjective non traditional optimization techniques.
- Implementation of the above framework and demonstration on case studies.

# Work Plan

- Phase 1
  - Literature Review
  - Code for critical path method
  - Code for Ant Colony Optimization
- Phase 2
  - Constrained resource allocation using ACO
  - Time-cost trade-off using NSGA II

# Work Plan

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# Various floats for cosntruction activities

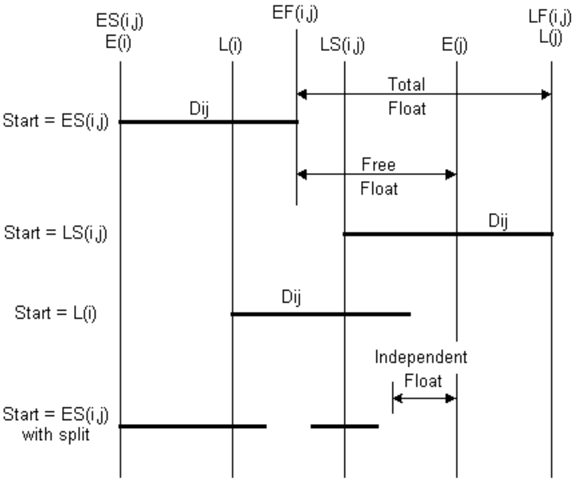



FIGURE: Illustration of Activity Float from [7]

# Non critical activities

Criteria for deciding start time:

- resource leveling
- meet resource constraints

# RESOURCE LEVELING

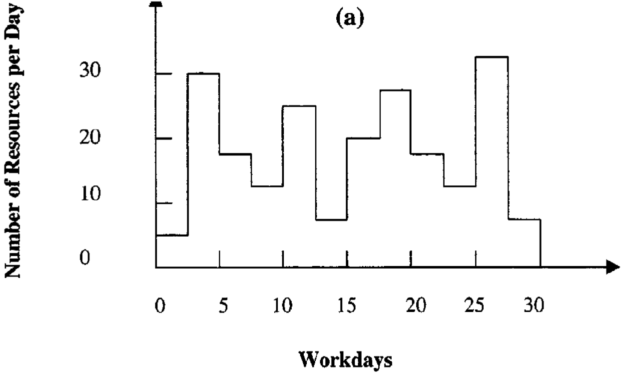



FIGURE: Resource usage example from [10]

# Constrained Resources

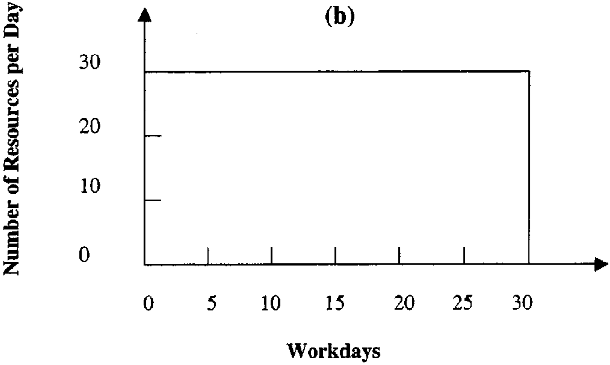



Figure: Resource usage example from [10]

# Time cost trade off

- sometimes different time estimates available
- project duration can vary
- direct and indirect cost
- direct cost inversely proportional to project duration
- indirect cost directly proportional to project duration
- obtain trade off surface and choose optimal solution

# TIME COST TRADE OFF

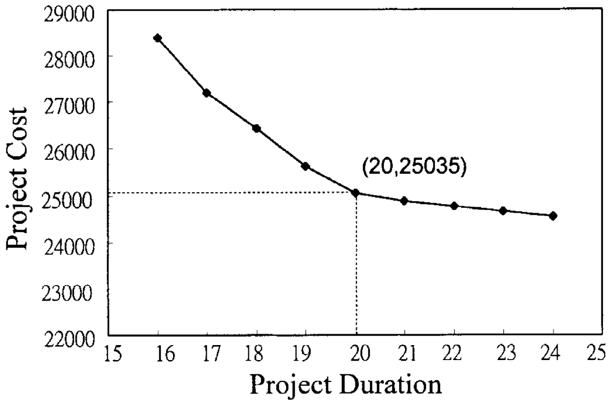



FIGURE: Time cost trade off from [13]

# Total cost

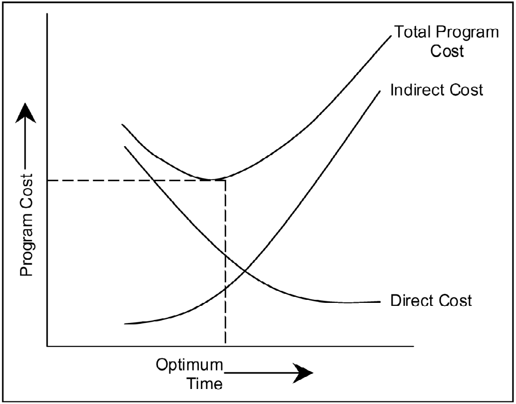
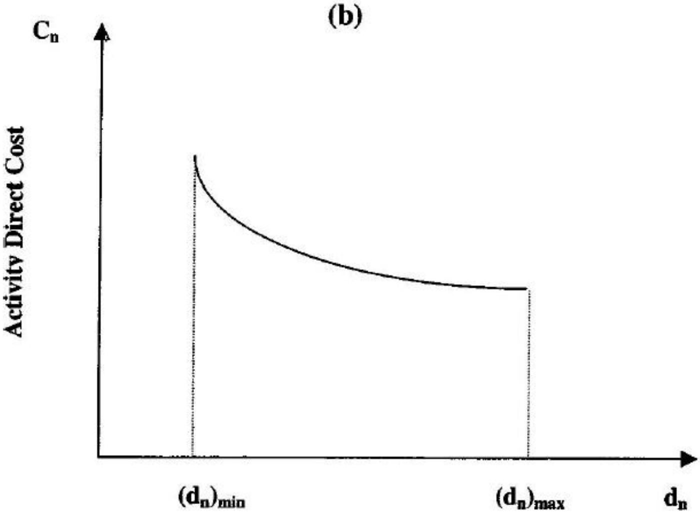



Figure: Time cost trade off

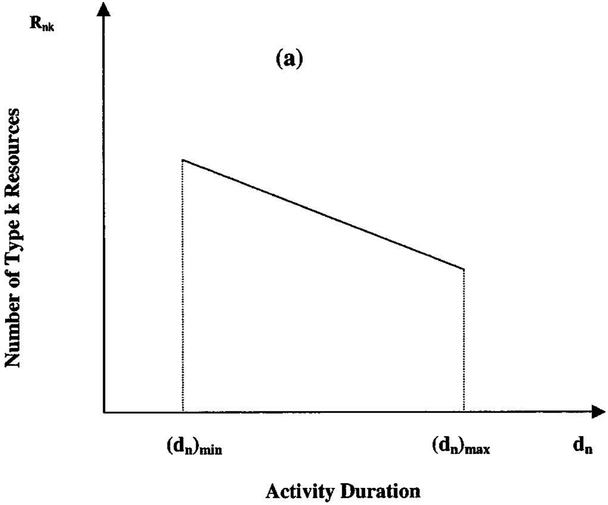
# Constrained resource allocation using ACO

- Aim : find a schedule with minimum total cost conforming to resource availability constraints and resource leveling
- Assume: Cost and resource distributions as functions of activity duration
- Find : start time and duration of each activity
- Any precedence relationship between the activities is permissible ( finish-finish, start-start, finish-start, start-finish).

# ACTIVITY COST DURATION CURVES



# Activity resource usage distribution curves



# Problem formulation

Notation

- $\mathfrak{d}_i$ : duration of activity $i$; $\mathfrak{d}_i^{min} \leq \mathfrak{d}_i \leq \mathfrak{d}_i^{min}$, $\forall i = 1, 2, \ldots, n_a$.
- $\mathfrak{s}_i$ : start time of activity $i$;
- $\mathfrak{c}_i$ : direct cost of of activity $i$ for duration $\mathfrak{d}_i$; $i = 1, 2, \ldots, n_a$.
- $\mathfrak{l}_{ij}$ : lag/ lead time between activities $i$ and $j$.
- $\mathcal{S}_i$: set of activities succeding activity $i$
- $\mathcal{C}_d$: direct project cost; $\mathcal{C}_d = \sum_i^{n_a} \mathfrak{c}_i(\mathfrak{d}_i)$
- $\mathcal{C}_i$: indirect project cost
  $\mathcal{C}_i = \mathcal{C}_0 + b\mathcal{D}$

# Problem formulation

Notation

- $\mathcal{C}_t$: total project cost; $\mathcal{C}_t = \mathcal{C}_d + \mathcal{C}_i$
- $\mathcal{S}_t$: set of activities in progress at time $t$
- $r_{ki}$: daily requirement of $k$th resource for activity $i$.
- $R_{kt}$: maximum availability of $k$th resource at time $t$.
- vector of decision variables :
  $X = \{\mathfrak{s}_1, \mathfrak{s}_2, \ldots, \mathfrak{s}_{n_a}, \mathfrak{d}_1, \mathfrak{d}_2, \ldots, \mathfrak{d}_{n_a}, \}$

# Resource constrained scheduling problem

$$\text{minimize} \qquad \mathcal{C}_t(X) \tag{1}$$

subject to:

Precedence constraints

- Finish to start (FS)

$$\mathfrak{s}_i + \mathfrak{d}_i + \mathfrak{l}_{ij} \leq \mathfrak{s}_j \qquad \forall j \in \mathcal{S}_i \tag{2}$$

- Start to start (SS)

$$\mathfrak{s}_i + \mathfrak{l}_{ij} \leq \mathfrak{s}_j \qquad \forall j \in \mathcal{S}_i \tag{3}$$

- Start to Finish (SF)

$$\mathfrak{s}_i + \mathfrak{l}_{ij} \leq \mathfrak{s}_j + \mathfrak{d}_j \qquad \forall j \in \mathcal{S}_i \tag{4}$$

- Finish to Finish (FF)

$$\mathfrak{s}_i + \mathfrak{d}_i + \mathfrak{l}_{ij} \leq \mathfrak{s}_j + \mathfrak{d}_j \qquad \forall j \in \mathcal{S}_i \tag{5}$$

# PROBLEM FORMULATION

Maximum Resource Constraint

$$\sum_{i \in \mathcal{S}_t} r_{ki} \leq R_{kt} \tag{6}$$

Peak resource usage deviation constraint

$$\left| \sum_{i \in \mathcal{S}_t} r_{ki} - \sum_{i \in \mathcal{S}_{t+1}} \right| \leq RL \tag{7}$$

where *RL* is the desired resource leveling limit.
Variable bounds

$$\mathfrak{d}_i^{min} \leq \mathfrak{d}_i :\leq \mathfrak{d}_i^{min} \tag{8}$$

# Computer implementation

- ACO algorithm : computer program developed in C on Linux operating system
- solution component: each combination of duration and start time for an activity and the corresponding resource utilization for executing an activity
- solution construction routine: ants decide upon a solution component using the available pheromone information.
- objective function evaluation starts with reading of the activity precedence relationships and assignment of the time duration and start time for each activity.

- constraint violation: start time and duration of each activity – checked for precedence relationship constraints
- constraint handling: weighted normalized penalty is applied for each violation
- Finally the complete project cost with the penalty for constraint violation is returned to the apply pheromone update routine.

# CASE STUDY

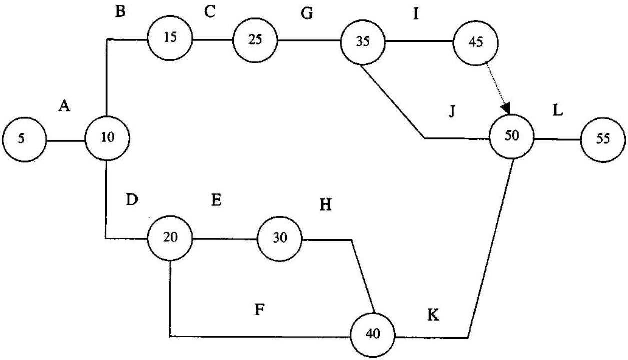



FIGURE: Network for test problem (from [13])

# CASE STUDY

TABLE: Relationship between activity duration and cost, resouce usage

| Activity | Minimum duration | Maximum duration | Number of resources | Direct cost ($) |
|---|---|---|---|---|
| A | 1 | 2 | 3-$d$ | 3000- 100$d$- 50$d^2$ |
| B | 4 | 5 | 9-$d$ | 7000- 300$d$- 75$d^2$ |
| C | 1 | 3 | 8-$d$ | 6000- 500$d$- 25$d^2$ |
| D | 1 | 2 | 3-$d$ | 8000- 600$d$- 50$d^2$ |
| E | 2 | 4 | 5-$d$ | 11000- 400$d$- 20$d^2$ |
| F | 2 | 3 | 5-$d$ | 11000- 400$d$- 75$d^2$ |
| G | 1 | 2 | 6-$d$ | 7000- 500$d$- 10$d^2$ |
| H | 1 | 2 | 4 -$d$ | 3500- 300$d$- 75$d^2$ |
| I | 2 | 4 | 9-$d$ | 3500- 300$d$- 50$d^2$ |
| J | 7 | 8 | 9-$d$ | 2500- 100$d$- 15$d^2$ |
| K | 4 | 6 | 7-$d$ | 5000- 200$d$- 25$d^2$ |
| L | 2 | 3 | 4-$d$ | 2000- 200$d$- 30$d^2$ |

# Case study

TABLE: Activity precedence relationships.

| Activity | Succeeding activity | relationship type | lag time (days) |
|---|---|---|---|
| A | B | SS | 2 |
| A | D | SS | 2 |
| B | C | FF | 3 |
| C | G | FS | 0 |
| D | E | SF | 2 |
| D | F | FF | 4 |
| E | H | SS | 1 |
| F | K | FS | 0 |
| G | I | FF | 4 |
| G | J | FF | 2 |
| H | K | FS | 2 |
| I | L | FS | 1 |
| J | L | FS | 0 |
| K | L | FS | 0 |

# CASE STUDY

- initial cost :$6,000
- daily cost of $2,500

TABLE: Algorithm details for test problem

| | |
|---|---|
| Algorithm used: | Rank Based Ant System |
| Ranks Used | 5 |
| Elitist Ants | 1 |
| No of variables | 23, |
| No of ants | 50 |
| Max no of cycles | 50 |
| Max no of runs | 3 |
| Evaporation (rho) | 0.200000 |
| Initial trail | 1.000000 |
| Local update | used |
| $\alpha$ | 1.000000, |
| Local update evap( $\gamma$) | 0.200000 |
| Local search used with | Global Best Ant |

# RESULTS

direct cost :$ 49775, while indirect cost :$ 46000
Total cost of the project :$ 95775.

TABLE: Schedule with maximum resource usage 7.

| Activity | $\mathfrak{d}_i$ | # resources | $\mathfrak{s}_i$ | $\mathfrak{c}_i$ |
|---|---|---|---|---|
| A | 2 | 1 | 0 | 2600 |
| B | 5 | 4 | 2 | 3625 |
| C | 3 | 5 | 7 | 4275 |
| D | 2 | 1 | 3 | 6600 |
| E | 4 | 1 | 0 | 9080 |
| F | 3 | 2 | 4 | 9125 |
| G | 2 | 4 | 10 | 5600 |
| H | 2 | 2 | 1 | 2600 |
| I | 4 | 5 | 12 | 1500 |
| J | 8 | 1 | 8 | 740 |
| K | 6 | 1 | 6 | 2900 |
| L | 3 | 1 | 12 | 1130 |

# RESULTS

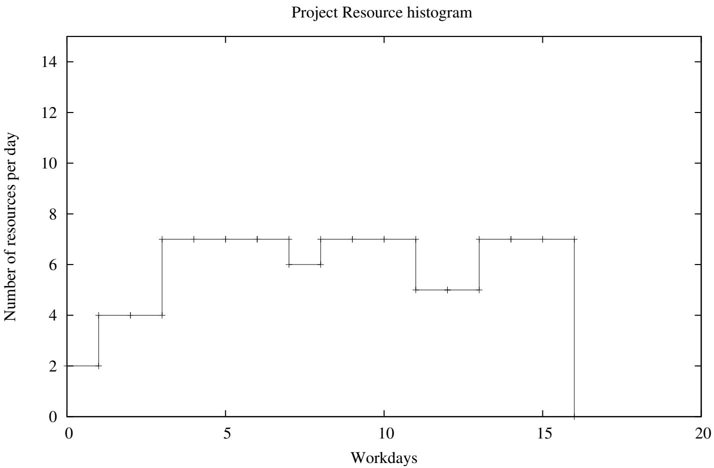



FIGURE: Project resource histogram for case study

# RESULTS

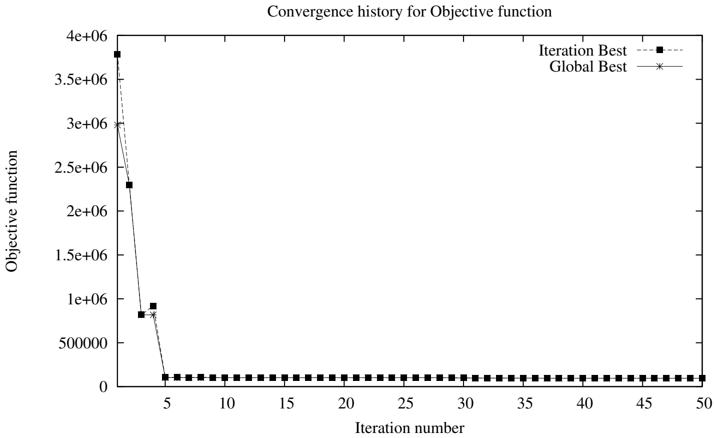



FIGURE: Convergence of algorithm for case study

# Results

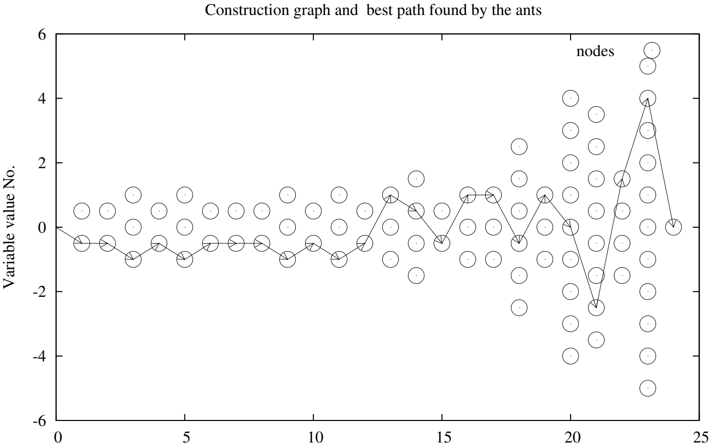



FIGURE: Construction Graph for case

# Time-Cost Trade-Off using Genetic Algorithms

- set of options for carrying out each activity available
- Aim : To choose an option for each activity so as to simulataneously
  - minimize the cost of carrying out activities (direct cost)
  - minimize the project duration.
- higher project duration –> higher indirect cost
- optimum solution balances direct and indirect cost to obtain a minimum project cost

# Time-Cost Trade-Off using Genetic Algorithms

- calculation of totalcost: exact mathematical relationship b/w the project duration and indirect cost.
- Such information is not always known in advance,

AIM Find the time-cost trade-off curve

- The TCTO curve is obtained using a multiobjective genetic algorithm called NSGA-II [2].

# NOTATION

- $n_a$ number of activities in the network
- Each activity $i$ can be performed with $\theta_i$ combinations of methods, resources and equipment with a corresponding
- cost $\mathfrak{c}_i$ of option $i$
- time duration $\mathfrak{t}_i$of option $i$
- $x_i$ is the options chosen for activity $i$
- vector of decision variables $X = \{x_1, x_2, \ldots, x_{n_a}\}$.
- $EST_i$ earliest start time of the $i$ th activity

# Multi-objective TCTO problem formulation

$$\text{minimize} \qquad \mathfrak{C}(X) = \sum_{i=1}^{n_a} \mathfrak{c}_i(x_i) \tag{9}$$

$$\text{minimize} \qquad \mathcal{T} = max\{EST_i + \mathfrak{t}_i(x_i) \quad | \quad i = 1, 2, \ldots, n_a\} \tag{10}$$

subject to

$$1 \leq x_i \leq \theta_i \tag{11}$$

# Computer implementation

Problem formualtion solved using the Non dominated sorting Genetic Algorithm - II ( NSGA II) [2] in following three phases:

1. Initialization phase that generates an initial set of S possible solutions for the problem;
2. fitness evaluation phase that calculates the cost, and time of each generated solution;
3. population generation phase that seeks to improve the fitness of solutions over successive generations.

- Source code for NSGA II was obtained from KanGAL, IIT Kanpur ( `www.iitk.ac.in/kangal/soft.htm`).
- The NSGA II software from KanGAL – requires the user to change only the objective function

### Objective Function

- project duration $\mathcal{T}$ calculated using the CPM routine, which takes actvitiy precedence and duration as input.
- direct cost ( $\mathfrak{C}(X)$ )sum up the costs of the individual activities

# Case Study

18-activity network of [5]

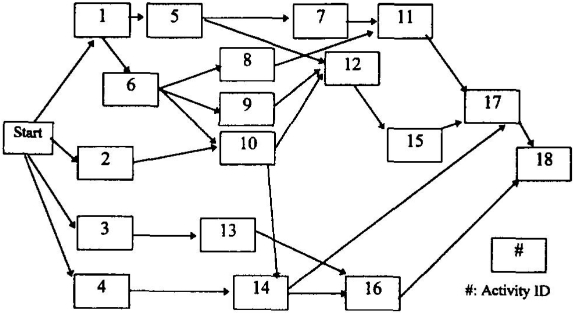
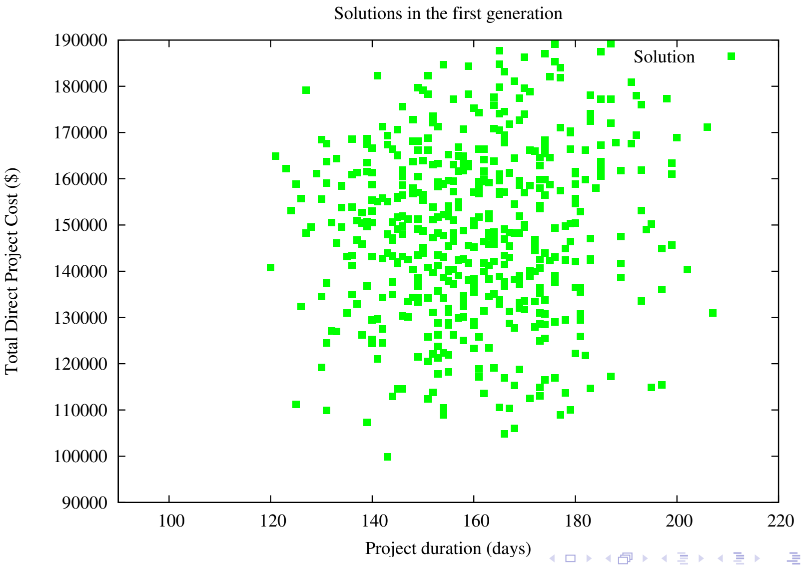



FIGURE: Network for test problem (from [5])

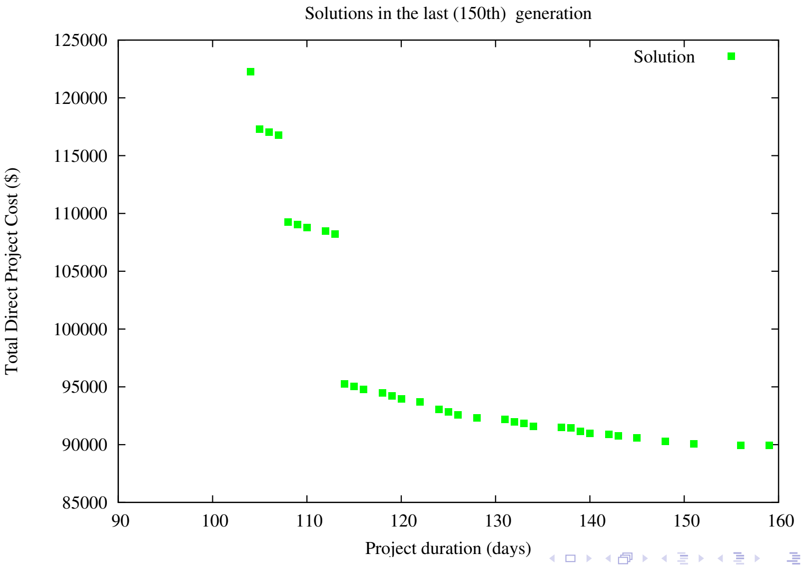
# Parameters and data

- Various resource utilization options assumed for all the activities
- Binary solution encoding is used for every activity option variable
- Population size = 500
- Number of generations = 150
- Number of objective functions = 2
- Number of binary variables = 18
- Probability of crossover of binary variable = 0.8
- Probability of mutation of binary variable = 0.02

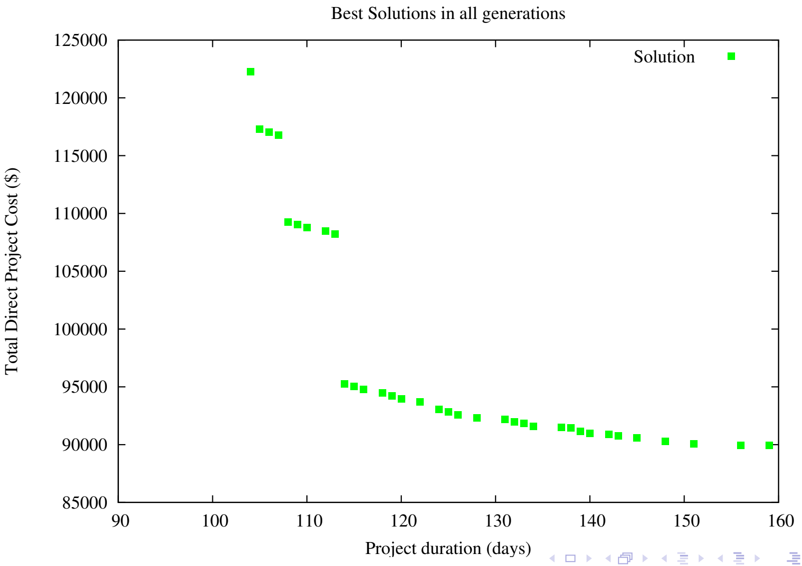
# Population in first generation



# Last generation

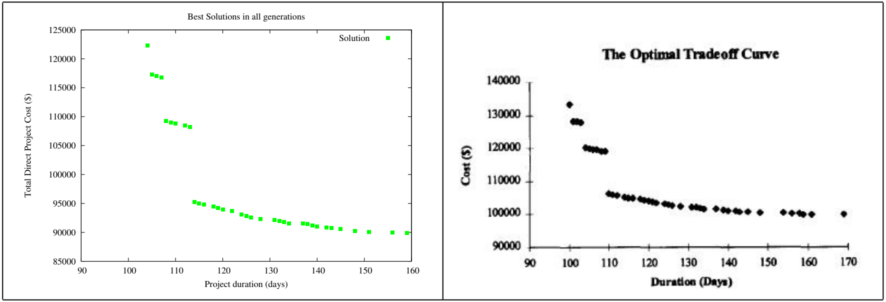


# BEST SOLUTIONS OF ALL GENERATIONS



# VALIDATION OF MODEL

FIGURE: Comparison of best solutions obtained with that of Feng et al ( 1996).



# SUMMARY

From literature review, one can conclude that

- time cost trade off and resource scheduling are problems of equal interest to project managers
- but separate treatment in literature
- some have attempted a solution in integrated way
- Multiple objectives not considered
- all kinds of precedence relationships between activities not considered

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- In time-cost trade-off problem, aim is to find the duration of each activity.
- In resource leveling and allocation, aim is to find the starting time of each activity.
- Duration of each activity decides the critical path and the activity floats.
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# MAIN CONTRIBUTIONS

Following softwares developed in C on Linux operating system

- Critical path method software for activity-on-node and activity-on-edge networks
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The above two softwares were used to solve the multiobjective time-cost trade-off problem and the constrained resource scheduling problem.

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# FUTURE WORK

Many interesting possibilities arise out of the present work.

- study the effect of parameter settings of the ACO and NSGA II algorithm on the performance
- quality aspect of construction can be incorporated into the time-cost trade-off problem [8, 4].
- problem formulation which takes into account the project time, cost and quality along with the resource constraints
- the effect of converting the resource leveling constraint into an objective and studying this effect on the quality of solutions obtained.

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