Time-Cost-Risk Optimization in Construction Work by using Ant Colony Algorithm

Vishnu Vijayan[1], Achu V[2], Riyana MS[3], Jayakrishnan R[4]

[1,2,3] Assistant Professor, Department of Civil Engineering, BMCE, Kerala, India
[4]Assistant Professor, Department of CSE, BMCE, Kerala, India

---***---

Abstract – Time and cost are the most important parameters considered in every construction project. Without the timely completion within the scheduled duration, the project may incur loss. Hence completing the project within the scheduled time frame is paramount importance.

Time, cost, risk of project delivery are among the crucial aspects of each project. The need to identify and manage risks in project delivery is crucial to establish ways and methods to deliver a project to meet end user's expectation and satisfaction. Construction planners face the challenge of optimizing resource utilization to compromise between different aspects, especially time and cost. It may be beneficial to consider the risk in performance of project in addition to time and cost.

Besides time and cost of activities, every resource utilization option will yield a specific performance quality according to the involved. The optimization of trade-off between these time, cost and risk parameters is done using Multi-Objective Ant Colony Optimisation technique. The optimization program was run for a number of giving weightage for the parameters. The total time, cost and risk for the project when executed in various combinations of alternatives were taken the trade-off between the parameters are analyzed. The method could be adopted for the time, cost, and risk optimization of any project with its quantified values. The risk values may vary with various factors and the choice of risk values depends entirely on the project.

Key Words: **Time cost, risk optimization, ant colony algorithm, resource utilization, project management, Multi-Objective Ant Colony Optimisation technique**.

1. INTRODUCTION

The prime objective in construction industry is to complete the planned activities of project in time. In order to maximize the return, both the client and contractor should strive to optimize the project duration and cost concurrently. Time and cost are the most important parameters considered in every construction project. Without the timely completion within the scheduled duration, the project may incur losses. Hence completing the project within the scheduled time frame is of paramount importance. Time, cost and risk of project delivery are among the crucial aspects of each project. Maximizing the quality of projects while minimizing its time and cost, require the development of innovative models considering risk. Each and every activity of the project may get affected by various factors and may adversely affect the cost and duration of the entire project. Great care should be taken to reduce or minimize these impacts. This requires an insight into the probable risks associated with each of the activities and the alternatives that can be adopted to reduce such risks. It is needed to quantify the associated potential impact of the identified risk and implementing measures to manage and mitigate the potential impact. This involves deciding on the relationship between the likelihood (frequency or probability) and the consequences (the impacts) of the risks that have been identified.

The need to identify and manage risks in project delivery is crucial to establish ways and methods to deliver a project to meet end user's expectation and satisfaction. In order to do so, the common problem in construction projects such as delays in completing the project, over budget, unsatisfactory product quality, unsafe working environment and so on needs to be eliminated as far as possible. Paying attention to the risk aspects in construction project will direct to profitable outcome. Risk arises out of uncertainty. It is measured in terms of the likelihood of it happening and the consequences if it does happen.

RISK= PROBABILTY *X* IMPACT

Construction planners face the challenge of optimizing resource utilization to compromise between different aspects of projects, especially time and cost. It may prove to be beneficial to consider the risk in performance of projects in addition to time and cost. These multi-objective natures impose an increasing pressure on decision makers in the construction industry to search for an optimal/near-optimal resource utilization plan that minimizes the construction cost and the time, while minimizing its risk. When the time interval of the activities is minimized we see the cost will increase due to more resources allocation in rapid accomplishment for the completion of work. Although lower project duration leads to higher direct costs, indirect costs are also decreased. In such situations it is important to study the trade-off between completion time, risk involved in each resource option and cost of the project. Crashing of activities results in increase in resource utilization which eventually leads to increased construction cost for the project and vice versa. In addition to time and cost of activities, each resource utilization option will yield specific risk. Trade-off between these conflicting aspects of project results in challenging job and as such planners are faced with numerous possible combinations for project delivery. If durations of the activities are crashed, the cost shows an increasing trend due to more resource being allocated for its rapid accomplishment. However by utilizing fewer resources results in extended duration of activities.

Besides time and cost of activities, every resource utilization option will yield a specific performance quality according to the risk involved. Trading between these conflicting aspects of project is a challenging job to construction planners. As an example, the number of possible combinations in a project with 18 activities and 4 possible resource utilization options for each activity will be more than 6 billion. An effective searching tool would then be worthwhile for comprehensive yet efficient time-cost- risk trade-off problem (El-Rayes et al 2005). In this paper, a new met heuristic approach is applied for optimization of three objective time-cost-risk problem based on multi-colony ant algorithm. In this thesis a sample project of 7 activities with time and duration of various resource options is taken. The risk for each resource option is calculated from the results of a questionnaire survey done on 35 different companies. The optimization of trade-off between these time, cost and risk parameters was done using Multi-Objective Ant Colony Optimisation technique. The optimization program was run for a number of times giving different weightage for the parameters. The total time, cost and risk for the project when executed in various combinations of alternatives were taken and the trade-off between the parameters are analyzed.

2. SCOPE

The report focuses on a 7 activity project with time and cost details of various activity options. The risk values are calculated from the data collected through a questionnaire survey done on 35 companies in the construction sector. The method could be used for any construction project, provided the quantified values of the three parameters are known. All the parameters, namely, time, cost and risk considered in this project are minimization in nature; however this could be used for objectives that are of maximization in nature by adopting minor changes. The time and cost of the activities could be easily estimated, but the quantification of risk values cannot be done easily. The risk of each activity may be calculated based on surveys or even from experience. The method could be adopted for the time, cost and risk Optimisation of any project with their quantified values. The risk values may vary with various factors and the choice of risk values depends entirely on the project.

3. ANT COLONY ALGORITHMS

In AS, solutions are constructed based on the transition probability,

$$P_{ij} = \frac{(\tau_{ij})^{\alpha}(\eta_{ij})^{\beta}}{\sum_{l \varepsilon u}(\tau_{il})^{\alpha}(\eta_{il})^{\beta}}$$

Where η*ij* is a local heuristic, α and β are two parameters that determine the relative influence of the pheromone trail (τ) and the heuristic, and U denotes the set of candidate solutions to be chosen. The pheromone trail can be updated as $\tau_{ij}^{new} = \rho\ \tau_{ij}^{old} + \tau_{ij}^{k}$

Where ρ is a parameter that controls the pheromone persistence, i.e., 1-ρ represents the proportion of the pheromone evaporated NA is number of ants, i.e., all ants can contribute to pheromone trail accumulation in the AS algorithm. Dorigo *et al*. (l99Ia, 1991b, 1996) propose three different approaches to find $\Delta\tau_{ij}$values for the TSP as follows:

- Ant Density: $\Delta\tau_{ij}^{k} = Q$,
- Ant Quantity: $\Delta\tau_{ij}^{k} = \frac{Q}{d_{ij}}$,
- Ant Cycle: $\Delta\tau_{ij}^{k} = \frac{Q}{L^{k}}$.

Where Q denotes a constant related the quantity of pheromone trail ants laid, *i j* represents the distance *d* between cities i and j, and is the total tour length of the ant. The ant density and ant quantity *L,k ,Kth* approaches deposit pheromone every time an ant goes from i to j, but the ant cycle deposits it only after a complete tour. Experiments indicate that ant cycle outperforms the other two approaches (Colomi *et al*. 1997, Dorigo *et al*. 1991a, 1991b, 1996).

Multi-objective optimization (or multi-objective programming or "pareto optimization") also known as multi-criteria or multi-attribute optimization, is the process of simultaneously optimizing two or more conflicting objectives subject to certain constraints.

A lot of work has been done on the multi- objective optimization in construction projects. Initial trials were to model multi-objective optimization tools for time cost trade-off problems. Later the efforts were extended for increased number of objectives. The technique has been in use for optimization of quality, resources, safety etc. in addition to time and cost.

4. MULTI-OBJECTIVE OPTIMIZATION IN CONSTRUCTION PROJECTS

Multi objective optimization methods are used in construction projects for a variety of parameters in addition to time and cost, such as, risk, quality, safety, environmental impact, resource leveling etc. Researchers have done the optimization of these conflicting parameters using various optimization methods. In the beginning the problem was solved taking two objectives at a time mainly time and cost and linear programming was generally used for this. Many researchers attempted to solve TCT by linear programming

(Babu and Suresh1996, Burns et al. 1996, Khang and Myint 1999, Wei and Wang 2003, Vanhoucke 2005, Bidhandi 2006).

5. THE ANT COLONY OPTIMIZATION (ACO) ALGORITHM

The Ant colony optimization (ACO) algorithm was developed by Dorigo et al. ACO algorithms may be considered to be part of *swarm intelligence*, that is, the research field that studies algorithms inspired by the observation of the behavior of *swarms*. Swarm intelligence algorithms are made up of simple individuals that cooperate through self-organization. The Ant colony optimization (ACO) algorithm is a part of the swarm intelligence theory. The main idea behind the ACO algorithm is that the self-organizing principles that allow the highly coordinated behavior among ants in real life can be exploited to coordinate populations of artificial agents that collaborate to solve computational problems. Communication between ants relies on a chemical substance called pheromone. To search for food, ants follow pheromone paths made by other ants, and at the same time they themselves deposit pheromones along the path they take. Most ants will habitually take the path on which more pheromones are deposited. Consequently, the effect of this positive feedback will lead ants to take the path that has more pheromones deposited on it.

Marco Dorigo and colleagues introduced the first Any Colony Optimization (ACO) algorithms in the early 1990's which is inferred by the social behavior of ant colonies. Ants live in colonies and their behavior is governed by the goal of colony survival rather than being focused on the survival of individuals. When searching for food, ants randomly search through the possible paths between the food and their nests. Ants leave a chemical called *pheromone* which they can also smell. If an ant should make a decision about selecting a path to follow, it selects the one which contains highest amount of pheromone. The shortest path would have the highest pheromone concentration if all paths are initially preferred by same number of ants. This is because the ants would travel the shortest path in shorter duration and the path would be travelled by more ants when compared with the other paths. As this is the case, the pheromone concentration of the path would be increased by the ants and the probability of the shortest path would be higher than the other paths. During the return trip, the quantity of pheromone that an ant leaves on the ground may depend on the quantity and quality of the food. The pheromone trails will guide other ants to the food source. The indirect communication between ants via pheromone trails, known as *stigmergy*, enables them to find shortest paths between their nest and food sources.

In an experiment known as the "double bridge experiment"(Deneubourg *et al.)*, the nest of a colony of Argentine ants was connected to a food source by two bridges of equal lengths. In such a setting, ants start to explore the surroundings of the nest and eventually reach the food source. Along their path between food source and nest, Argentine ants deposit pheromone. Initially, each ant randomly chooses one of the two bridges. However, due to random fluctuations, after some time one of the two bridges presents a higher concentration of pheromone than the other and, therefore, attracts more ants. This brings a further amount of pheromone on that bridge making it more attractive with the result that after some time the whole colony converges toward the use of the same bridge. in another experiment conducted by Goss *et al.* When the nest is connected to the food source by a shorter path and a longer path the ants chooses the shorter path and all the ants gets converted to this path much earlier.

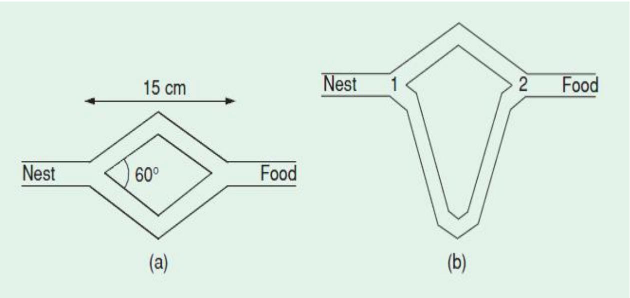

Fig 5.1 Double bridge experiment

Later various meta-heuristic methods which are more efficient and useful in solving multi-objective optimization problems were used ,such as, Genetic Algorithm (GA), Genetic Algorithm with Simulated Annealing(GASA),), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Electromagnetic Scatter Search (ESS) etc .These methods give more reliable results when multiple objectives are considered.

The multi-objective ant colony algorithm is very effective in solving multi-objective optimization in construction projects. Marco Dorigo and colleagues introduced the first Any Colony Optimization (ACO) algorithms in the early 1990's. Ant Colony Optimization (ACO) had been implemented by Kuang and Xiong(2005). They solved a small project with 7 activities and find the global optimum with ACO by searching only 6.63% of the possible search space.

6. THE THREE MAJOR PARAMETERS IN CONSTRUCTION

A construction project contains many uncertainties. It requires a number of resources and a large amount of investment. Time and cost are main management goals. Contractors want to get the highest profit so they must plan to complete the job in early time with a minimum cost. A project may be regarded as successful if it is completed within budget, on time, without any accidents, to the specified quality standards and overall client satisfaction.

6.1 TIME

There are many reasons why time management is important in construction. One of these is the fact that workers are often paid by the hour, so time management will help control salary costs. Another reason time management in construction is important is that having work delayed or behind schedule can hinder the overall project, especially when one group or company must wait for another company to finish a certain type of work before beginning the next step in the project. Time management in construction also is vital because, if projects are not finished in a timely manner, or at least as quickly as promised, then this can cause the construction company to lose payment for breach of contract or monetary penalty according to the contract.

6.2 COST

The most important factor considered in most of the construction projects is cost. The costs of a construction project include both the initial capital cost and the subsequent operation and maintenance costs. Each of these major cost categories consists of a number of cost sub components. The capital cost for any construction project includes the expenses related to the initial establishment of the facilities such as land acquisition, planning and feasibility studies, architectural and engineering design, inspection and testing etc. The operation and maintenance cost in subsequent years over the project life cycle includes land rent(if applicable),operating staff, labour and material for maintenance and repairs etc.

The magnitude of each of these cost components depends on the nature, size and location of the project as well as the organization. The owner is interested in achieving the lowest possible overall project cost that is possible within its investment .It is important to realize that while the construction cost may be the single largest component of the capital cost, other cost components are not insignificant. For example, land acquisition costs are a major expenditure for building construction in high-density urban areas.

The total project cost consists of two parts, direct costs and indirect costs. Direct costs are the activity based costs which are the labor, material, equipment and machinery costs of the project. As the activity's normal duration is crashed, it is expected that the direct costs are increased. This is because in order to finish a certain activity, larger crews are assigned or the crew is over-timed. Larger crew size or over-timing decreases the productivity. As a result of this, unit cost per unit output increases. Indirect costs are the overhead costs and possible delay penalties of the projects. Overhead cost includes any costs of the project which cannot be associated with the activities of the project. Salaries of the cook, security staff and office staff can be counted as overhead costs. Heating or cooling, illuminating of the site and other buildings are also included in overhead costs of the project. Overhead costs fluctuate during the project as it affected by the climate and the number of the workers in the site. In order to simplify the cost computations, overhead cost is usually assumed constant during the project. Consequently, indirect cost decreases when the project duration decreases.

6.3 RISK

Risks are unavoidable in almost every construction project whether if it is building projects, civil works, or any other type of construction projects. Risk is inherent in all human endeavors, including construction activities, and the risk factors involved are diverse and varied. Risks are uncertainties, liabilities, or vulnerabilities, which may cause a project to deviate from its defined plan. While risk in a project environment cannot be totally eliminated or transferred, it can be monitored and minimized or mitigated wherever possible. To succeed, organizations must commit to addressing risk management throughout the project lifecycle.

Risk is defined as "the chance of something happening that will have an impact on objectives". Risks and uncertainties appear in various stages and types. Risk is an inevitable aspect of most projects, but even the most proficient managers have difficulty handling it. To avoid the projects ending up with an overrun schedule, overflowing budget and compromised specifications, the common problem in construction projects such as delays in completing the project, over budget, unsatisfactory product quality, unsafe working environment and so on needs to be eliminated as far as possible . Risk analysis and management in construction depend mainly on intuition, judgment and experience. In projects the objectives are most often related to time, cost, quality etc.

The risks in construction projects could be broadly classified as:

- Cost related risks:
- Time related risks:
- Quality related risks:
- Environment related risks:
- Safety related risks:

This project mainly concentrates on selecting appropriate resource options for every activity to obtain the objective of time, cost and risk of a project. Quantifying the risk involved in performing different activity as a function of different resource utilizations is a challenging task because of the difficulty in measuring impact of these strategies of performing activities. Moreover, it is a complicated work to evaluate the contribution of individual activities' risk on performance of the project. The objective of risk may be evaluated with following function:

$$\text{Mean Risk} = \Sigma\,(r \times w)/\Sigma w$$

Where *r* is the risk of the optimized resource option for each activity w is the activity weight for each activity. A common approach is to define risk as the combination of the probability (or likelihood) and impact of an event (or outcome or result of exposure). This gives rise to the widely used concept of risk:

Severity (risk) =Probability x Impact

6.4 TIME COST TRADE-OFF(TCT) PROBLEM

The objectives of the TCT analysis are to compress the project to the optimum duration which minimizes the total project cost. TCT analysis is performed by evaluating the possible crashing alternatives of the activities. Possible crashing durations can be obtained in three ways: by over sizing the crew, by over timing or by executing another construction technique which is faster but more expensive. Crashing of activities increases the activity's cost, thus increasing the direct project cost. However, crashing of activities reduces the project duration and decreases the indirect project costs. Summation of direct and indirect project costs is aimed to be minimized in TCT problem.

TCT is one of the major interests of the construction management, since the optimum solution of TCT problems directly increases the productivity and thus the profit of the project. It is expected that the cost slope of activities increase as the activities are further crashed. This is mainly caused by the reduced productivity of labour and machinery as the crew size or amount of overtime is increased. A relationship exists between the duration of a construction activity and its cost. Similarly, construction cost and time for undertaking a construction project are interrelated. Generally, the total project cost includes both the direct and indirect costs of performing construction work. The higher curve in Figure 1 illustrates the relationship between cost and time for a construction project.

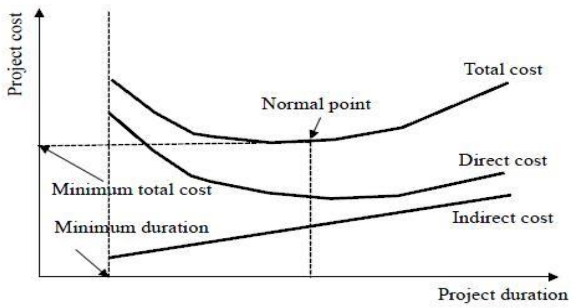

Fig 6.1 time cost relationship of construction project

At the normal point, the construction costs are minimized. Construction costs may increase if any variation in time occurs from this point. If the construction time from the point is reduced, the direct costs will increase while the indirect costs decrease (and vice versa). The TCT analysis is helpful in providing monetary benefits and such cost reductions add up to the increase the profits.

6.5 TIME-COST- RISK OPTIMISATION

It is important to study the trade-off between completion time, risk involved in each resource option and cost of the project. Crashing of activities results in increase in resource utilization which eventually leads to increased construction cost for the project and vice versa. In addition to time and cost of activities, each resource utilization option will yield specific risk. Trade-off between these conflicting aspects of project results in challenging job and as such planners are faced with numerous possible combinations for project delivery. If durations of the activities are crashed, the cost shows an increasing trend due to more resource being allocated for its rapid accomplishment. However by utilizing fewer resources results in extended duration of activities. Moreover time and cost of activities, every resource utilization option will yield a specific performance quality according to the risk involved.

Time Cost Risk Trade off analysis is the compression of the project schedule to achieve a more favorable outcome in terms of project duration, cost, and risk. The time-cost trade-off problem (TCTP) is the most important content in the project management. Although a lot of research has been done on time cost trade-off problems , the TCTP considering the risk elements has not been solved to such extend effectively. Each activity has certain options for resource utilization with varying cost, time and risk factors. The goal is to find the optimal or near optimal solution with optimal trade-off. Quantifying the risk involved in performing different activity as a function of different resource utilizations is a challenging task because of the difficulty in measuring impact of these strategies of performing activities. Moreover, it is a complicated work to evaluate proportion of individual activities' risk on performance of the project. The trade off analysis between time cost and risk is more advantageous and helps in selecting a project delivery with less risk. The parameters used for the quantification may be purely subjective. The risk factor may be quantified on various grounds such as safety, quality, cost overrun, schedule overrun, availability of skilled laborers, availability of machineries etc. The time cost risk trade off analysis helps not only in the comparison between time and cost, but also help in comparing various alternatives with respect to the risk associated with the alternative and helps in better decision making.

7. MODEL DEVELOPMENT

7.1 description of the algorithm

This thesis aims to develop an optimization tool for the time-cost-risk trade-off based project planning and optimization problems. The problems in concern have a common point in which all have the objective function as minimization of an objective value. Project duration can often be shortened by accelerating some of its activities at an additional expense. Obtaining optimum or near-optimum solution for the project planning problems considering time, cost and risk is the main objective of this project. Optimization procedure is performed by software generated during the thesis study. Time-Cost-Risk Trade-off analysis is the compression of the project schedule to achieve a more favorable outcome in terms of project duration, cost, and risk.

The ant colony optimization is used commonly for various multi-objective optimization problems. In this report multi-objective ant colony optimization methodology is used to find optimal or near optimal solutions for time-cost-risk trade off for a sample project consisting of 7 activities with different resource option alternatives. The ant colony algorithm used in the optimization process is explained in detail.

In the ant colony optimization adopted in this study, each activity is considered to be a path for the ants. A colony of ants is assumed to visit the nodes and an objective is assigned to the colony of ants. This colony of ants checks the solution and updates the pheromone by considering this objective alone. The start and end of each activity is considered to be a node (similar to the cities in travelling sales man problem). But unlike in travelling salesman problem the ants do not take all the paths randomly; the ants can travel from one node to the next node by taking one of the path connecting those nodes (using a resource option).The ants takes up the paths randomly in the first visit as no pheromone trail is present in any of the paths and all the paths are equally attractive to the ants. Once the ant takes up a path the ant moves to the next activity. The ending node of the first activity serves as the starting node for the next activity.

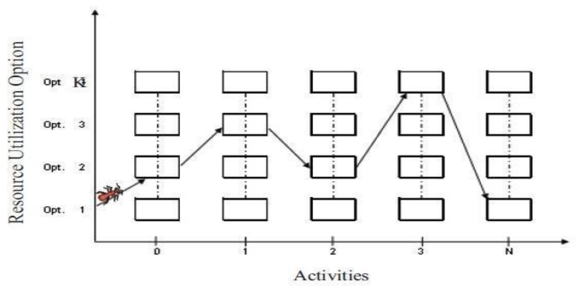

Fig 7.1 Graphical representation of problem R. Shrivastava etal(2011)

Once all the ants have visited all the nodes (all the activities are done by every ant by taking one resource option for each activity), an iteration is completed and all the paths is deposited with different amounts of pheromone depending on the goodness of that path. Then a new colony of ants is assigned a different objective and is allowed to visit the nodes. This colony of ants checks the solutions based on this objective alone. The new colony of ants chooses the paths based on the pheromone content (deposited by the ants of the preceding colony) in the paths.

Since the second colony of ants makes their visit only after all the ants in the first colony completes the iteration, there is a time lag between the visits of the two ant colonies at every node. The pheromone is a volatile substance and it evaporates with the passage of time. In order to simulate the pheromone evaporation, the pheromone evaporation coefficient (ρ) is defined which enables greater exploration of the search space and minimizes the chance of premature convergence to suboptimal solutions. The pheromone evaporation also helps in eliminating the localization of search, by evaporating the pheromone content of all the paths by a factor, the difference in pheromone content of all the paths are reduced. This makes even the worst solution to be considerably more favorable for ants to be visited in the subsequent iterations and hence helps in conducting a wider search and avoids localization and early convergence of solution. The probability of ants choosing a path from one node the next node depends on the pheromone content in the paths. The path with higher amount of pheromone attracts more number of ants and vice versa.

The number of colony of ants made to visit the node in one cycle is equal to the number of objectives considered. Once all the colonies visits the nodes an optimal or near optimal solution is obtained which has been evaluated on the grounds of all the objectives. The quality of the solution increases as the number of cycles increases. After a number of cycles the solution converges to a single solution which gives a near optimal solution with respect to all the objectives considered. The weightage of each objective could be varied and this gives a different solution depending on the assigned weightages.

At the end of each cycle a number of optimal/near optimal solutions are obtained. After running the optimization program for a number of cycles all the optimal /near optimal solutions obtained are analyzed and the pareto-optimal solutions are grouped. Then the constraints are imposed on the set of pareto-optimal solutions by providing upper limits for the objectives. If the value of at least one of the objectives exceeds the upper limit of the corresponding objective, it is eliminated. This provides refined set pareto-optimal solutions representing the solutions with all the parameters of objectives within in the acceptable limits. The solutions thus obtained are compared to obtain the results.

7.2 THE MAIN PHASES OF ACO ALGORITHM

- Initialisation of parameters
- Selection of paths by the ants.
- the pheromone update and the pheromone evaporation
- finding the optimal path(solution)

7.2.1 INITIALISATION OF PARAMETERS

Various parameters are used in the ant colony optimization algorithms. Most of them are used to simulate the real life ant colony behavior, which they use to find the shortest path from nest to the food source. The parameters use in this algorithm and the values used are.

1. The number of ants in each ant colony, antcol= 50
2. The maximum number of activities that can be evaluated= 50
3. Pheromone updation amount, $\Delta\tau_{ij}$
4. The coefficient controlling the influence of pheromone ,α=1
5. Heuristic function is not considered in the algorithm, therefore the parameter controlling its influence β=0.
6. The maximum number of resource options that can be assigned to each activity=15
7. Initial pheromone in each path, τ_o=1/ number of resource option for the activity
8. The pheromone evaporation coefficient ,ρ=5%
9. The number of iteration in each cycle=3
10. The number of cycles=1000
11. Total number of iterations=3000

7.2.2 Selection of Paths by Ants:

When the ants come to a node and has to select one among the ants chooses the paths based on probability which in turn is governed by the pheromone content present in the path. The probability of an ant choosing a path is;

Prob (path) = $(\tau_{path})^{\alpha}/(\sum\tau_{paths})^{\alpha}$

Where τ_{path} is the pheromone content in the desired path and $\sum\tau_{paths}$ is the sum of pheromone content of all the paths for that activity.

7.2.3 Pheromone Updation:

After each iteration, the pheromone values are updated by the *m* ants that have chosen the same path. The pheromone τ_{ij} for path *ij* is updated as

$$\tau_{ij} \leftarrow (1-\rho)\cdot\tau_{ij} + \sum_{k=1}^{m}\Delta\tau_{ij}^{k},$$

Where i is the activity number j is the resource option chosen ρ is pheromone evaparation coefficient ([0,1])

Δ τij is the amount of pheromone updated by each ant. m is the number of ants using the path *ij k* is the ant taking the path *ij*. Once the ants completes the travel it updates the pheromone on the path depending on the goodness of the parameter considered. The amount of pheromone updated by each ant Δ τij is calculated.

7.2.4 Finding Optimal Solution or Path:

In first iteration the colony of ants evaluates the paths and updates pheromone considering the time. In the second iteration the ants evaluates the paths and updates pheromone considering cost and risk in the third. At the end of each cycle (3 iterations) the ants provides a solution considering all the objectives. The paths containing the highest amount of pheromone at the end of each path becomes the solution of that cycle. The solutions changes as the program evaluates the alternates, and finally they tend to converge to the near optimal solution based on the weights assigned to the objectives.

7.2 ASSUMPTIONS MADE

The main assumptions made in this project are

1. All the activities have finish start relationship

2. Only one activity is done at a time and all the activities have the preceding activity as its predecessor.

3. Indirect cost for each activity is Rs 5000/day.

8. CASE STUDY

The time and cost data is taken as that for a 7 activity project with different resource options for each activity. The cost consists of direct cost and indirect cost. Indirect cost of Rs 5000/day is assumed. The activities are assumed to occur one after the other on a finish to star condition (finish of a preceding activity is a condition for the start of the succeeding activity.

Sl No	Activity description	Option	Duration (day)	Cost (Rs)
1	Site Preparation	1crew+equipment 1	14	990000
		2 crew +equipment 2	20	820000
		3crew+equipment 3	24	600000
2	Forms and Rebar	method 1	15	195000
		method 2	18	186000
		method 3	20	172000
		method 4	23	175000
		method 5	25	165000
3	Excavation	equipment 1	15	255000
		equipment 2	22	270000
4	Precast Concrete Girder	method 1	12	1875000
		method 2	16	1480000
5	Foundations and Piers	method 1	22	910000
		method 2	24	820000
		method 3	28	740000

		method 4	30	550000
6	Deliver PC girders	Railroad	14	1670000
		Truck	18	1370000
7		1 crew+ crane 1	9	1245000
		2 crew+crane 2	15	1035000
	Erect girders	3crew+crane3	18	870000

Table 8.1: Initial Data (R. Shrivastava et al.(2011))

9. RESULTS AND DISCUSSIONS

SOLUTIONS USING THE MULTI OBJECTIVE ANT COLONY OPTIMISATION

The program was used to get the solution for the time cost risk trade-off for the sample project. Running the project for a number of times gives a number of solutions with different combination of resource option for each activities. From these solutions the pareto-optimal solutions are selected to obtain the optimal/near optimal solutions. A total of 70 solutions were obtained using the ant colony.

9.1 REPRESENTATION FEASIBLE SOLUTIONS

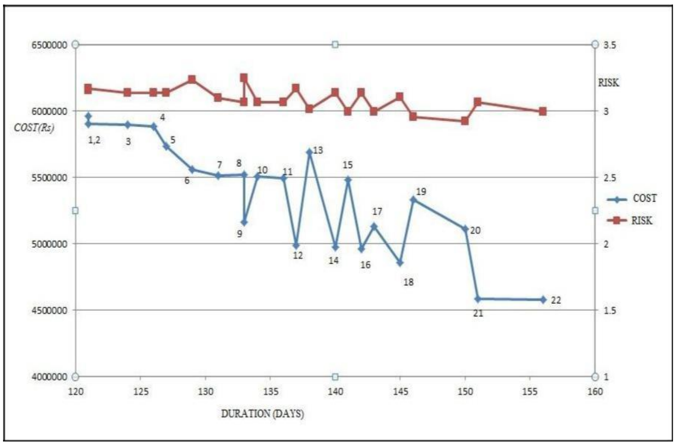

Fig 9.1: Time-Cost-Risk Combination Graph

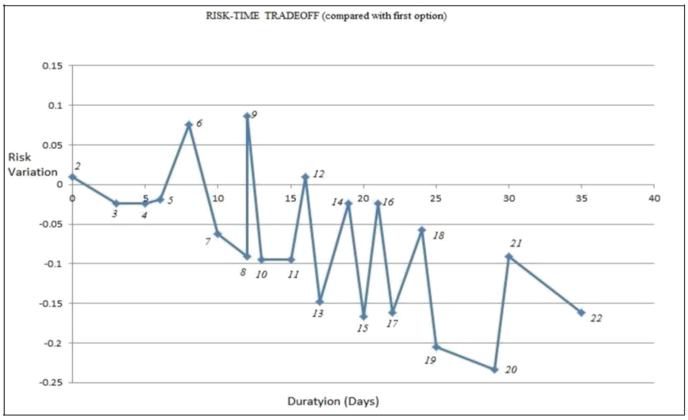

Fig 9.2: Risk-Time Trade Off

Inference:

In fig 7.8, considering the trade-off between time and risk in the feasible pareto-optimal solutions, the risk value of all the options lie within a small range of [-0.25, +0.1], ie, irrespective of the change in duration of the project the risk values do not show much significant trade-off for the options. But still when required to compare two options the graph could be used to make a better decision on the basis of risk and time.

10. CONCLUSIONS

In this report the Multi-Objective Ant colony Optimisation was used for the optimization on time-cost-risk trade-off, for a sample project of 7 activities with different resource options. The method provided 70 distinct possible solutions considering all the three parameters, 48 pareto-optimal solutions and after providing the constraints a final set of 22 feasible solutions were obtained.

Analysing the results, showed the relationship between the parameters. The time and cost are inversely related and time and risk are inversely related. Furthermore on analysing the final set of feasible solutions, it was found that time and cost shows significant changes when various options are changes, but the risk does not show such significant changes in values. Hence time and cost is found to be the dominant parameters in choosing the options, but risk also plays a role in choosing a solution among comparable solutions, ie, if the time and cost of two or more solutions are comparable to choose a better option the risk parameter could be used effectively.

The quantification of risk depends on the parameters considered, availability of data, method used and so on. In smaller projects the risk variation between various options are not very large and hence the risk is not as influential as time and cost but could be effective in choosing among the comparable solutions. Choosing an option with lesser risk leads to less undesirable impacts during the construction such as cost overrun, schedule exceedance, safety during construction, shortage of resources etc. In this thesis, for the sample project considered, the risk level associated with each options do not show large variations for different alternatives, but in large projects or new innovative projects where the uncertainty is large the risk variations between various options, when quantified, could be high. If such projects are considered the risk values for the alternatives may have larger differences when compared to each other and in such cases the risk parameter may play a dominant role in choosing the resource options.

11. LIMITATION

The main limitation is the problem of quantification of risk. The quantification of risk of risk is done for the operational stage of the project alone (risks will be apparent at all stages of the life of a construction project: at appraisal, sanction, construction and operation). The risk values may vary with various factors and the choice of risk values depends entirely on the project. The value of risk for the same activity with the same resource option may vary from project to project depending on circumstances such as ground condition, weather conditions etc. Hence a general quantification of risk cannot be made for all the projects.

In this project a general quantification of risk is made from a questionnaire survey for the calculation of risk for various activities but the risk may vary from depending on the firms, experience, working conditions etc. In reality the risk values are very much subjective than it can be generalized.

12. FUTURE EXPANSION.

The proposed ant colony Optimisation algorithm can be used to solve multi-objective problems of any 3 parameters provided all the parameters are to be minimized. The program could be modified even to solve minimisation problems too. The quantification of risk is a major constrain in the problem, as it is more difficult to quantify parameters such as risk. Risk again consists of two vague components, namely, probability and severity of risk. The accuracy and dependability of the solution could be improved if better methods for risk quantification are used, such as a more detailed survey. This project takes up a sample project and optimises the time, cost and risk for the construction stage of the project. It can be extended to other stages such as planning stage, maintenance stage etc.

13. ACKNOWLEDGEMENT

The author thanks Dr.K.R Hareendran Nair (HCT-Abu Dhabi), my parents and my friends for their valuable time spending with me for the completion of this project.

14. REFERENCES

1. Afshar A., Kaveh A., and Shoghli O. R. (2007), "Multi-objective optimization of time-cost-quality using multi-colony ant algorithm", Asian Journal of civil engineering

   (Building and Housing), Vol. 8 (2), pp. 113 – 124.

2. Babu, A.J.G., Suresh, N., Project management with time, cost and quality considerations, European J. Operations Research, (1996), 88, 320-327.

3. Arun c. (2011) ,"Time-cost-risk trade off using ant colony optimization", Journal of Construction in Developing Countries, 2011

4. Bidhandi H. M. (2006), "A New Approach Based on the Surrogating Method in the Project Time Compression Problems". Ann Oper Res, 143: 237 – 250.

5. Blum C. and Samples M. (2004), "An ant colony optimization algorithm for shop scheduling problems." J Math Modelling Algorithms, Vol. 3(3), pp. 285 – 308

6. Burns S. A., Liu L., and Feng C. W., (1996), "The LP/IP hybrid Method for Construction Time-Cost Trade-off Analysis". Construction Management and Economics, 14: 265 – 276.

7. Bullnheimer, B., R.F. Hartl, C. Strauss, 1999. "A New Rank Based Version of the Ant System – A Computational Study," Central European Journal for Operations Research and Economics, 7: 25-38

8. Colorni, A., M. Dorigo, F. Maffioli, V. Maniezzo, G. Righini and M. Trubian, 1996. "Heuristics from Nature for Hard Combinatorial Optimization Problems," International Transactions in Operational Research,3(1): 1-21.

9. Deneubourg, J.L., S. Aron, S. Goss and J.M. Pasteels, 1990. The self-organizing exploratory pattern of the argentine ant, J. Insect Behav., 3: 159–168.

10. Dorigo, M., V. Maniezzo, A. Colorni, 1996. Ant system: optimization by a colony of cooperating agents, IEEE Trans. Systems, Man, Cybernet.-Part B 26(1): 29–41

11. Dorigo, M., T. Stutzle, 2004. Ant Colony Optimization, MIT Press, Cambridge, MA. Fogel, L.J., Owens ,A.J., Walsh, M.J .1996. Artificial Intelligence Through Simulated Evolution, Wiley, New York.