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

Lakshmi C R
Department of Civil Engineering
Cochin College of Engineering and Technology Valanchery, Kerala, India

Abstract— Construction planners often face the challenge of optimum resource utilization to compromise between different and usually conflicting aspects of projects. Time, cost and risk of project delivery are among the crucial aspects of each project with both client and contractor striving to optimize the project duration and cost concurrently. Studies have been conducted to model the time–cost relationships, ranging from heuristic methods and mathematical approaches to genetic algorithms. Emergence of new contracts that place an increasing pressure on maximizing the quality of projects while minimizing its time and cost, require the development of innovative models considering risk 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 Optimization 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.

Keywords: Time-Cost-Risk Optimization, Ant Colony Algorithm, Construction Planners

I. 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.

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

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 30 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 analysed.

II. Aim

To optimize the trade-off between time, cost and risk in the construction projects using Multi-Objective Ant Colony Optimization for construction projects and to find their impacts on the selection of resource options for various activities of the projects. To accomplish this aim, the thesis was done:

- To develop an ant colony optimization algorithm to do the time-cost-risk trade-off optimization.
- To study the importance of time, cost and risk parameters in choosing a better resource option in construction projects
- To find the extend of impact of each of these parameter in choosing a resource option.
- To find any relationship between each of the parameters.

III. Overview of the Thesis

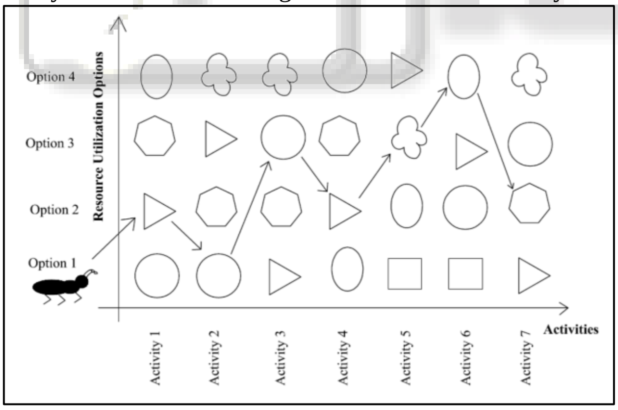
The entire thesis is divided into a number of chapters. The followings are the summary of each chapter on this thesis report. This thesis report contains 8 chapters as follows:

The second chapter provides a literature review about the background of the thesis. The third chapter describes about the development of ant colony optimization algorithm from the swarm intelligence. It also explains the general algorithm (the three basic steps) of the ant colony optimization method, the various steps involved in finding the optimal/near-optimal solutions. The fourth chapter focuses on the three important parameters that should be taken care of for the successful completion of any project, namely, time, cost and risk. The fifth Chapter details the model proposed for the multi-objective optimization. It explains about all the main phases of the algorithm proposed, the values for initialization of parameters used in algorithm, the assumptions made and explains algorithm execution. In the sixth chapter a sample project is used as a case study. The seventh chapter gives the discussion of results obtained after using the model on the sample project. The eighth chapter focuses on the conclusions arrived at the end of the thesis study, limitation and the scope of future work for this thesis study.

IV. MODEL DEVELOPMENT

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.



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.

A. *Ant Colony Optimization Algorithms*

In recent years, evolutionary and meta-heuristic algorithms have been extensively used as search and optimization tools in various problem domains, including science, commerce, and engineering. Ease of use, broad applicability, and global perspective may be considered as the primary reason for their success. Ant colony optimization algorithms are inspired by the fact that ants are able to find the shortest route between their nest and a food source, even though they are almost blind (Dorigo et al. [6]). Researchers have reported the robustness of ACO and their capacity to efficiently search for and locate an optimum/near optimum especially in discrete optimization problems. In general, ACO algorithms employ a finite size of artificial ants with defined characteristics which collectively search for good quality solutions to the problem under consideration. Starting from an initial state, selected according to some case-dependent criteria, each ant builds a solution which is similar to a chromosome in a genetic algorithm. While building its own solution, each ant collects information on its own performance and uses this information to modify the representation of the problem, as seen by the other ants (Dorigo et al.[6]). The ant's internal states store information about the ant’s past behavior, which can be employed to compute the goodness/value of the generated solution. Artificial ants are permitted to release pheromone while developing a solution or after a solution has fully been developed, or both. The amount of pheromone deposited is made proportional to the goodness of the solution an artificial ant has developed (or is developing). Rapid drift of all the ants towards the same part of the search space is avoided by employing the stochastic component of the choice decision policy and the pheromone evaporation mechanism. In order to simulate the pheromone evaporation, the pheromone persistence coefficient (ρ) is defined which enables greater exploration of the search space and minimizes the chance of premature convergence to suboptimal solutions. A probabilistic decision policy is also used by the ants to direct their search towards the most interesting regions of the search space. The level of stochasticity in the policy and the strength of the updates in the pheromone trail determine the balance between the exploration of new points in the state space and the exploitation of accumulated knowledge (Dorigo et al. [6]).

Let (*t*) *ij* τ be the total pheromone deposited on path ij at time t, and (*t*) *ij* η be the heuristic value of path ij at time t according to the measure of the objective function. Transition probability from node i to node j at time period t may be defined as (Dorigo et al. [7]):

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

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

$$\tau_{ij}^{new} = \rho\ \tau_{ij}^{old} + \sum\nolimits^{NA}_{K=1} \tau_{ij}^{k}$$

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).

1) The main phases of ACO algorithm

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

2) Assumptions Made

The main assumptions made in this project are

- All the activities have finish start relationship
- Only one activity is done at a time and all the activities have the preceding activity as its predecessor.
- Indirect cost for each activity is Rs 5000/day.

V. CONCLUSION

In this report the Multi-Objective Ant colony Optimization 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.

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