Resource Constrained Project Scheduling Problems - A Review Article

Prof. B Prakash Rao [1], K M Chaitanya [2]

[1]Manipal University, Manipal Institute of Technology, Manipal, Karnataka - 576104, India

[2] Manipal University, II Sem M-Tech (CEM), Manipal Institute of Technology, Manipal, Karnataka - 576104, India

Abstract: ***The science of construction scheduling has gained importance in the past few decades and has become the focal point of construction management practitioners. Scheduling involves listing of a project's milestones, activities, and deliverables with intended start and finish dates. These are estimated in terms of resource allocation, budget and duration. Resource limits (manpower, machinery, materials and money) are practical constraints that exist in most projects and it limits a constructor's ability to execute and deliver a project as originally planned. The resource-constrained single project scheduling problem (RCPSP) as well as resource-constrained multi-project scheduling problem (RCMPSP) has become a well-known standard problem in project scheduling and has attracted numerous researchers from multiple areas. This article reviews the various approaches adopted like Ant Colony Optimization (ACO), Constraint Programming (CP) and Backward-Forward Hybrid Genetic algorithm (BFHGA) and focuses on providing researchers the future scope in this area to look into.***

Keywords: Construction management, Scheduling, Resource constrained scheduling, Ant colony optimization, Constraint programing, Backward-forward hybrid genetic algorithm

1. Introduction

In project management, a schedule is a listing of a project's milestones, activities, and deliverables, usually with intended start and finish dates. These items are often estimated in terms of resource allocation, budget and duration, linked by dependencies and scheduled events.

Successful project management is subject to both an ability to accurately map a project's logic and requirements, as well as a manager's ability to manage the stated requirements and available project resources. Typical construction resources include manpower, machinery, materials, money, information, and management decisions (Halpin and Woodhead 1998 [10]). A project map is fundamentally a unidirectional, fully connected graph of the activities defining the project which is also resource and cost-loaded and can be solved for the most critical activities in the project. Within this framework of mapping a project's logic network i.e., the flow of activities and identifying the activities that are the most critical to accomplishing specified milestones, the science of construction scheduling has gained in importance and has become the focal point of construction management practitioners.

Despite its importance, practitioners opt to rely on traditional and proven methods, as the construction industry by nature is slow to adopt new methodologies.

Resource limits are practical constraints that exist in most projects and it limits a constructor's ability to execute and deliver a project as originally planned. During the last decades resource-constrained single project scheduling problem (RCPSP) has become a well-known standard problem in project scheduling (Hartmann and Briskorn 2010 [12]) and has attracted numerous researchers from multiple areas including operations research and construction management. RCPSP is nondeterministic polynomial-time hard (NP-hard) in the strong case (Blazewicz et al. 1983 [3]), the optimal solution can only be achieved by exact methods for small projects, usually with less than 60 activities (Alcaraz and Maroto 2001 [1]). Hence, many researchers have proposed heuristic and meta-heuristic methods for RCPSP. The heuristic studies mainly focused on priority rule-based methods. The meta-heuristics, however, included a variety of methods, such as genetic algorithms (GAs), simulated annealing (SA), particle swarm optimization (PSO), ant colony optimization (ACO), honey-bee mating optimization (HMO), and hyper-heuristics.

But in today's business environment, companies manage multiple concurrent projects also that share resources. Frequently the availability of the shared resources is limited and is not sufficient to concurrently schedule the activities. In these circumstances, optimal allocation of limited shared resources is crucial for minimizing the project duration and costs to achieve project portfolio success.

2. Literature Review

2.1 Ant colony Optimization (ACO)

Ant colony optimization is a population-based, artificial multi-agent, general-search technique, proposed by Dorigo et. al. (1996) [9]; Dorigo and Stutzle (2002) [7] and Dorigo and Blum (2005 [8]) for the solution of difficult combinatorial problems. Ant colony optimization is inspired by the collective behavior of natural ant colonies as they optimize their path from an origin (ant nest) to a destination (food source).

Symeon Christodoulou (2010) [24], proposed a new improved methodology to schedule resource-constrained construction projects using algorithms based on ACO by use of previously acquired knowledge. He studied the application of ACO artificial agent to a resource-unconstrained network topology and then the method was applied to a resource-constrained network. The effects of resource availability constraints to critical path calculations and project completion time were examined by taking case studies.

A comparison of the presented ACO-based resource constrained scheduling problem (RCSP) algorithm with traditional CPM algorithms and with artificial intelligence techniques, such as genetic algorithm (GA) and particle swarm optimization (PSO) algorithms was made. The ACO-based resource constrained scheduling problem algorithm proved to be a better alternative by considering various aspects such as arbitrary node-to-node calculations, the absence of activity start time flexibility and computational time.

The ACO meta-heuristic provides users with an alternative way of constructing longest-path solutions in directed network topologies and of solving for both the resource-unconstrained and resource constrained problem. The solutions obtained in the case study by the proposed algorithm show a 100% accuracy in the case of the resource-unconstrained problem and a 97% accuracy in the case of the resource-constrained problem. Convergence to the obtained solutions was achieved in a very small number of iterations and the deviation observed in the resource constrained case was within acceptable margins. But, the limitation of this approach is the assumption that resources can be transferred between projects without any expense in time and cost.

2.2 Constraint Programming (CP)

Constraint programming (CP) combines operations research and logic programming techniques and has been successfully used to solve complex combinatorial problems in a wide variety of domains (Chan and Hu 2002 [4]; Heipcke 1999 [13]). To facilitate the use of CP algorithms in scheduling problems, IBM developed a powerful software library, called IBM ILOG CPLEX Optimization Studio (Beck et al. 2011 [2]). It incorporates a CP modelling tool (CPLEXCP) that has specialized syntax for modelling scheduling problems and other combinatorial problems that cannot be easily linearized or solved using traditional mathematical programming methods. Unlike many meta-heuristic methods, the CP model is fast and provides a near-optimum solution to the multimode resource-constrained project scheduling problem (MRCPSP) for projects with hundreds of activities within minutes.

Wail Menesi and Tarek Hegazy (2014) [25], studied multimode resource-constrained project scheduling problem (MRCPSP) which aims to minimize the total duration as well as the cost of the project in large-scale projects. In addition to the single-objective multimode model, another bi-objective multimode model was developed to minimize the fluctuations in the resource usage (resource levelling). Two case studies were considered and the results were compared.

In the first case study, single-objective CP optimization was considered for small, medium and large projects with number of activities 10, 100, 500, 1000, 1500 and 2000. The results were compared with that of three meta-heuristic methods ant colony optimization (ACO), particle swarm optimization (PSO) and genetic algorithm (GA). Results showed the superior performance of the CP model in terms of solution quality and processing speed. The ACO algorithm achieved the next best result then the PSO and GA.

In the second case study, the bi-objective model was tested for the same activities. The results were found to be much better than that of the single-objective solution for resource profile and did not require any additional processing time.

Thus, unlike many meta-heuristic methods, the CP model with bi-objective is fast and provides a near-optimum solution to the multimode resource-constrained project scheduling problem (MRCPSP) for projects with hundreds of activities within minutes.

2.3 Backward-Forward Hybrid Genetic Algorithm (BFHGA)

A genetic algorithm (GA) is a population-based search algorithm based on evolutionary computation principles inspired by the Darwinian principles of natural selection (Holland 1975 [14]). In recent years, there has been increasing interest in the adoption of GAs to optimize problems in construction management. Resource levelling, planning of construction resource utilization, time-cost trade-off problem and time-cost-quality trade-off problem are among the problems other than resource constrained project scheduling problem (RCPSP) in which GAs are proposed.

Simulated annealing (SA) on the other hand, is a stochastic meta-heuristic algorithm inspired by the physical process of annealing. Simulated annealing is a popular local search meta-heuristic used to address especially discrete optimization problems like resource constrained multi project scheduling problem (RCMPSP). Unlike GA, SA is not a population-based algorithm but attempts to improve the state of an individual, by using an energy function. In construction management, simulated annealing has been adopted for few optimization problems including resource levelling and optimization of cash flows for linear schedules.

Simulated annealing also has fine-tuning capabilities and is usually capable of escaping of local optimum for locating a good approximation to the global optimum (Hwang and He 2006 [15]). But a sole SA has a low search efficiency as it maintains one solution at a time (Rudolph 1994 [22]; Leung et al. 1997 [19]).

In recent years, several skilled combinations of genetic algorithms with simulated annealing were proposed to achieve an efficient search algorithm by integrating the complementary strengths of both methods. The results of the genetic algorithms with simulated annealing have been promising as the hybrid algorithm is capable of escaping local optimum, has fine-tuning capability, and can implement search in parallel architecture (Wang and Zheng 2001 [26]; Chen et al. 2005 [5]; Hwang and He 2006 [1]; Han et al.

2006 [11]; Chen and Shahandashti 2009 [6]; Sonmez and Bettemir 2012 [23]).

The backward-forward (BF) scheduling method (Li and Willis 1992 [20]) combines forward and backward scheduling methods in a special way. The BF scheduling starts with the backward scheduling in which the activities are scheduled as late as possible in the reverse time direction according to a priority list. Once the backward scheduling is completed, the forward scheduling is performed in the order of start times that are obtained in backward scheduling.

Rifat Sonmez and Furkan Uysal (2014) [21], developed a method by integrating the complementary strengths of genetic algorithm (GA), simulated annealing (SA) optimization techniques and the backward-forward (BF) scheduling method to achieve an efficient algorithm for the resource constrained multi project scheduling problem (RCMPSP). Two case studies one with resource constrained single-project scheduling problem and the other with resource constrained multi-project scheduling problem were considered and compared with Heuristic Methods.

The first case study was for resource constrained single-project scheduling problem and four different projects were considered. These projects had activities between 17 and 25 with resources between 1 and 6. The results were compared with RESCON. The optimal solutions for relatively small resource-constrained project networks including finish to start precedence relations were obtained from RESCON. Backward-Forward Hybrid Genetic Algorithm (BFHGA) was able to obtain successful optimal solutions within less than 0.5 CPU seconds. The results of BFHGA were also compared with that of ACO and were found to be superior.

The second case study was for resource constrained multi-project scheduling problem and two multi-project case examples presented by Chen and Shahandashti (2009) [6],was considered to compare performances of five meta-heuristic methods, namely, a sole genetic algorithm, a sole simulated annealing algorithm, a hybrid genetic algorithm with simulated annealing, an arithmetically improved modified simulated annealing algorithm, and a logarithmically improved modified simulated annealing algorithm. The first part consisted of three test projects including 74 activities and 2 resources, and the second part consisted of three real projects including 130 activities and 11 resources. Results indicate that Backward-Forward Hybrid Genetic Algorithm (BFHGA) significantly outperformed the meta-heuristics for both test and real projects in duration minimization. Among the five meta-heuristics the modified simulated annealing-2 method had the best performance for test project and for the real project, the hybrid genetic algorithm with simulated annealing method was able to find a best solution.

Thus, Backward-Forward Hybrid Genetic Algorithm (BFHGA) proves to be very effective for the approach of resource constrained multi project scheduling problem (RCMPSP).

3. Conclusion and Future Scope

Scheduling is an important part of the project planning and it is affected by resource availability, budget and the duration. Limited resources are one of the common constraint observed in all the projects and it affects a constructor's ability to execute and deliver a project as originally planned. There is a need to develop the most optimum method to schedule a project keeping the resources as constraint.

The approaches mentioned in this paper were resource constrained project scheduling problems (RCPSP), and the objective was to obtain optimum solution. All the approaches were non-deterministic polynomial-time hard (NP-hard) problems. The ant colony optimization (ACO) and Constraint programming (CP) are single project scheduling problems whereas Backward-Forward Hybrid Genetic Algorithm (BFHGA) is a multi-project scheduling problem. The ant colony optimization (ACO) and Backward-Forward Hybrid Genetic Algorithm (BFHGA) aims at single objective of optimum scheduling whereas Constraint programming (CP) model aims at resource levelling along with the optimal schedule.

Many researches have been made in this field in past few years to optimize the solution and have obtained good results. But still there are many future works which the researchers should look for.

Developing a bi-objective Constraint programming (CP) model for much more complex problems, model for linear project scheduling problems which would help the projects having repetitive activities such as road works and railway projects and for resource constrained multi-project scheduling problems may be taken as a future scope.

Modification of ant colony optimization (ACO) approach mentioned in this paper by considering resource transfer times and costs, applying ant colony optimization (ACO) model for much more complex problems, developing a model for linear scheduling problem, bi-objective scheduling and combining ant colony optimization (ACO) with other meta-heuristics to get more optimal solutions for resource constrained project scheduling problem would be a promising area for future work.

Further, the approaches mentioned in this paper viz. ant colony optimization, constraint programming and backward-forward hybrid genetic algorithm may be tested in different type of civil constructions including minor and major irrigation projects.

A comparative study of these approaches for small, medium and large construction projects may also be taken up as future work.

References

[1] J. Alcaraz, C. Maroto, "A robust genetic algorithm for resource allocation in problems with activities' start

times encoding," Ann. Oper. Res., 102(1–4), 83–109, 2001.
[2] J.C. Beck, T.K. Feng, J. Watson, "Combining constraint programming and local search for job-shop scheduling," INFORMS J. Comput., 23(1), 1–14, 2011.
[3] J. Blazewicz, J, Lenstra, A.H.G. Rinnooy Kan, "Scheduling subject to resource constraints: Classification and complexity," Discrete Appl. Math., 5(1), 11–24, 1983.
[4] T. Chan,W, H. Hu, "Constraint programming approach to precast production scheduling." J. Constr. Eng. Manage., 10.1061, ASCE, 0733-9364(2002)128:6(513), 513–521, 2002.
[5] D. Chen, C.Y. Lee, C.H. Park, "Hybrid genetic algorithm and simulated annealing (HGASA) in global function optimization," Proc., 17th IEEE Int. Conf. on Tools with Artificial Intelligence (ICTAI' 05), IEEE Computer Society, Hong Kong, China, 129–133, 2005.
[6] P.H. Chen, S.M. Shahandashti, "Hybrid of genetic algorithm and simulated annealing for multiple project scheduling with multiple resource constraints," Autom. Constr., 18(4), 434–443, 2009.
[7] M. Dorigo, T. Stutzle, "The ant colony optimization metaheuristic: Algorithms, applications and advances," Handbook of Metaheuristics, F. Glover and G. A. Kochenberger, eds., Vol. 57, Springer, New York, 251–285, 2002.
[8] M. Dorigo, and C. Blum, "Ant colony optimization theory: a survey," Theor. Comput. Sci., 344, 243–278, 2005.
[9] M. Dorigo, V. Maniezzo, A. Colorni, "Ant system: Optimization by a colony of cooperating agents," IEEE Trans. Syst., Man, Cybern., Part B: Cybern, 26, 29–41, 1996.
[10] D.W. Halpin, R.W. Woodhead, Construction management, 2nd Ed., Wiley, Hoboken, NJ, 1998.
[11] M. Han, P. Li, J. Sun, "The algorithm for berth scheduling problem by the hybrid optimization strategy GASA," ICARCV 06 9th Int. Conf. on control automation robotics and vision, Singapore, 1–4, 2006.
[12] S. Hartmann, and D. Briskorn, "A survey of variants and extensions of the resource-constrained project scheduling problem," Eur. J. Oper. Res., 207(1), 1–14, 2010.
[13] S. Heipcke, "Comparing constraint programming and mathematical programming approaches to discrete optimization — The change problem," 1999.
[14] J.H. Holland, "Adaptation in natural and artificial systems," University of Michigan Press, Ann Arbor, MI, 1975.
[15] S.F. Hwang, R.S. He, "Improving real-parameter genetic algorithm with simulated annealing for engineering problems," Adv. Eng. Software, 37(6), 406–418, 2006.
[16] S.F. Hwang, R.S. He, "Improving real-parameter genetic algorithm with simulated annealing for engineering problems," Adv. Eng. Software, 37(6), 406–418, 2006.
[17] IBM Software, "Detailed scheduling in IBMILOGCPLEX optimization studio with IBMILOG CPLEX CP optimizer," International Business Machines Corporation, Armonk, New York, 2010.
[18] J. Oper. Res. Soc. Jpn., 50(6), 581–595. IBM ILOG CPLEX Optimization Studio V12.3., CP optimizer user's manual, International Business Machines Corporation, Armonk, New York, 2012.
[19] Y. Leung, Y. Gao, Z.B. Xu, "Degree of population diversity— A perspective on premature convergence in genetic algorithms and its Markov-chain analysis," IEEE Trans. Neural Networks, 8(5), 1165–1176, 1997.
[20] K. Li, R. Willis, "An iterative scheduling technique for resource-constrained project scheduling," Eur. J. Oper. Res., 56(3), 370–379, 1992.
[21] Rifat Sonmez, Furkan Uysal, "Backward-Forward Hybrid Genetic Algorithm for Resource-Constrained Multiproject Scheduling Problem," ASCE, Journal of Computing in Civil Engineering, 2014.
[22] G. Rudolph, "Convergence properties of canonical genetic algorithms," IEEE Trans. Neural Networks, 5(1), 96–101, 1994.
[23] R. Sonmez, Ö. H. Bettemir, "A hybrid genetic algorithm for the discrete time–cost trade-off problem," Expert Syst. Appl., 39(13), 11428–11434, 2012.
[24] Symeon Christodoulou, "Scheduling Resource-Constrained Projects with Ant Colony Optimization Artificial Agents," ASCE, Journal of Computing in Civil Engineering, Vol. 24, No. 1, January 1, 2010.
[25] Wail Menesi, Tarek Hegazy, "Multimode Resource-Constrained Scheduling and Leveling for Practical-Size Projects," ASCE, Journal of Management in Engineering, 2014.
[26] L. Wang, D.Z. Zheng, "An effective hybrid optimization strategy for job-shop scheduling problems," Comput. Oper. Res., 28(6), 585–596, 2001.

Author Profile

Prakash Rao B received the B.E degree in Civil Engineering from National Institute of Engineering, Mysore University, Mysore in 1984 and M-Tech degree in 1992, from Karnataka Regional Engineering College (presently NITK), Surathkal. He joined Manipal Institute of Technology as a faculty during 1987. At present he is working as Associate Professor (Senior Scale), Department of Civil Engineering, MIT, Manipal University.

K M Chaitanya received the B.E. degree in Civil Engineering from Nagarjuna College of Engineering and Technology, VTU, Bangalore in 2014. He is now pursuing his M-Tech in Construction Engineering and Management in MIT, Manipal University, Manipal (2014-2016).