# A State of Art Review on Time Cost Trade off Problems in Project Scheduling

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**ABSTRACT**

***In this paper study of time cost trade off problems (TCTP) have been carried out. This study shows different outcomes of previous research papers with application of various techniques/algorithms used to solve time cost trade off problems. In this review use of analytical techniques such as critical path method (CPM), Project Evaluation Review Technique (PERT), mathematical methods (linear programming, integer programming), heuristic methods (simulated annealing) and evolutionary algorithms (genetic algorithm) in different areas of project scheduling problems have been focused.***

**Keywords-** Project Scheduling, Time Cost Trade off Problems, Genetic Algorithm

## 1. INTRODUCTION

In real life activities are performed using different resources in a regular manner. The combination of all activities form project and arrange the project activities according to project requirement in optimum way are known as project scheduling [RKO, 01]. During project scheduling different decisions are taken regarding time and cost of each activity for overall network, the set of decisions that resulting desirable time cost realization constitutes time cost trade off problem [PRA,95]. This tradeoff between time and cost gives project planners both challenges and opportunities to work out the best plan that optimizes time and cost to complete a project and is therefore of considerable economic importance [BHU,08]. For scheduling of project two criteria are very important first is time and second is cost. Different types of methods with utilization of different sources are required to complete the project in shortest time with minimum expense of cost. To compress the project time project manager have to accelerate some activities at an additional expense.

There are hundreds or even thousands of activities with in real life project and it is almost impossible to enumerate all possible combinations to identify the best decision for completing a project in the shortest time and minimum cost. The problem gets further complicated due to presence of many uncertain variables such as weather condition, labour skill, managerial experience etc, which dynamically effect both the project direction and cost [BHU,07]. For specified budget project manager has to reduce project time by hiring more workers or extra resources due to which direct and indirect cost of project is affected [NSH,10]. In TCT analysis project manager has to schedule project completion time with minimization of total project cost by considering all unexpected parameters.

## 2. PROJECT SCHEDULING

Project is set of interrelated activities which utilize various resources. Project is finite, homogeneous, complex, non-repetitive and has definite goal. Scheduling is process of devising or designing a procedure for particular objective, specifying the sequence or time for each item in procedure for eg., project scheduling, railway time tabling, hydropower scheduling, production scheduling etc scheduling problems can be categorized in three parts: problem in known deterministic world, problem in benign real worlds, and problem in hostile real worlds. [SJN,91]

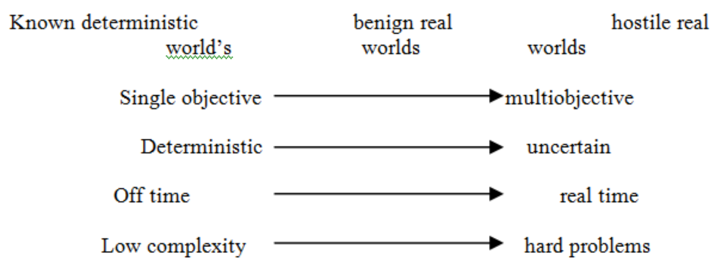


**Fig 1** Spectrum of Scheduling Models [SJN,91]

Project scheduling problems is concerned with single item or small batch production where scare resources have to be met when scheduling activities over time. It is important for make to order companies where capacities have been cut down in order to cope with lean management concepts.[PET,99] Project scheduling problem involves uncertainty which arises from variability (trade off performance measures like time cost and quality), uniqueness (no similar experience) and ambiguity (lack of clarity, lack of data etc.). The basic inputs for each activity such as time cost and resources are affected by uncertainty [VAH,07]. Project scheduling has attracted attention in recent years in different fields such as science, engineering etc.

Project scheduling problems are made of activities, resources, precedence relations and performance measures. Each activity has to be processed in one of several modes to complete the project successfully. The mode determines the duration of activity, requirement for resources of various categories and possible cash inflows or outflows occurring at start, during processing or completion of activity [RKO,01]. Resources utilized by activities are classified as renewable, nonrenewable, and partially renewable and doubly constrained. Some activities have to be finish before other can start. So activity is represented by node and precedence relation between activities is represented by directed arc, called activity on node representation**.** Scheduling of activities and allocating resources for large projects requires different analytical tools, in which Critical path method and Project evaluation and review technique are major techniques for planning and scheduling the project.

Critical path method (CPM) is best known technique to support project scheduling. In this method critical path is calculated which takes maximum time to complete the project (set of activities beginning from start activity and ending with final activity is called path and longest path is critical path) [BHO,08]. It is not used where uncertainty exist in scheduling problems .CPM is deterministic technique in which shorter time is achieved by crashing one of more critical activities by providing additional resources to these activities. CPM is used for developing strategies to complete a project in less than what would normally be regarded as minimum time [SMF,09]. CPM is not used where uncertainty exist in scheduling problems.

Project evaluation and review technique (PERT) is used for determining probabilities associated with completion times when activities duration are unknown. Many uncertain variables such as weather condition, productivity level etc affect activity duration during project implementation and cost could also change [SMF,09]. PERT have been developed to deal with uncertainty in project completion time

## 3. TIME COST TRADEOFF PROBLEMS

Time and cost are two important aspects in any field of engineering. Generally there is non increasing relation between time and cost.[BHU,07] In TCTP the objective is to determine the duration of each activity in order to achieve the minimum total direct and indirect cost of project[AMI,05]. Direct cost includes materials, human resource and equipment used. Indirect cost includes lease holds, machinery hiring, and management operations. Additional cost paid for reducing the normal time of an activity is defined by cost slope [BHO,08]. Manufacturing cost of any product nay be calculated by following formula

$$\frac{\text{Direct cost (man + machine +material) + Indirect cost (man + machine +material) + Factory overheads}}{\text{No of products manufactured in a space}}$$

Graphically it can be easily represented by fig no 2.

$C_1$- forced cost (total direct cost of activity when it is quickly completed by forced situation).

$C_2$-normal cost (total direct cost of activity when it is preferred for its normal situation)

$D_2$- normal duration (time that an activity is completed using the least direct cost)

$D_1$- force duration (shortest time that an activity is done by supplying more resources)

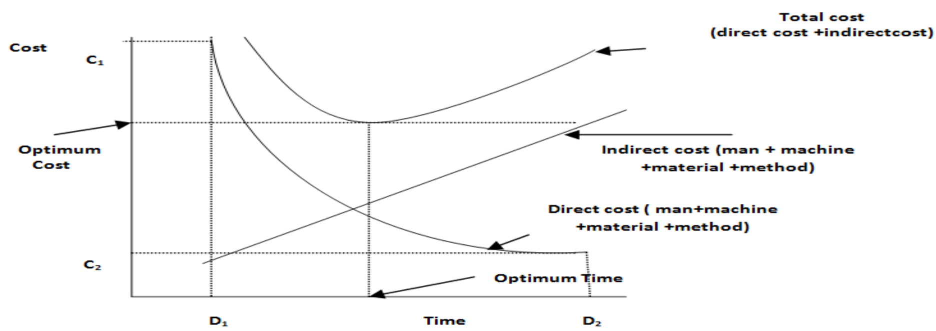


**Fig 2** Cost Slope Curve

To solve time cost trade off problems different techniques were used which are divided into two areas: mathematical programming method and heuristic methods. Mathematical programming method use linear programming, integer programming, and dynamic programming to solve TCTP. Linear programming approach is not suitable for discrete time cost relationship [CHU, 97]. Integer programming requires more computational efforts for large and complex networks. Dynamic programming is used to solve TCTP for networks that can be decomposed to pure series or parallel sub-networks. Heuristic methods do not guarantee for optimal solution but it provides good solutions. The heuristic approach select the activities to be shortened or expanded based on certain selection criteria which do not guarantee optimal solutions.[GHO,11] Generally methods consider linear times cost relationship with activities and also do not provide range of possible solutions.

Time cost trade off problem is multi-objective optimization problem with two objectives time and cost that need to be optimized simultaneously. In multi-optimization problem number of optimization solution are obtained rather than single optimum solution. The set of optimum solutions is called non-dominated or pareto optimal [BHU,07]. The members of pareto front are not dominated by other members in solution space.

To solve multi-objective optimization problem evolutionary algorithms (EA) are preferred. EA deal with set of possible solutions and allows finding entire set of pareto optimal solutions in single run of algorithm [GHO,11]. Setting of different parameters of EA for different applications may be highly time consuming. EA enables the user to find the optimal value of priorities that determine the sequence of allocating resource to activities [PIO,06]. EA produce different results for different runs of same algorithm on given problem, So multiple runs are required to explain their performance in that problem.

## 4. GENETIC ALGORITHM

Genetic algorithm (GA) employs a random but locating globally optimum solution. It is one of the effective techniques for determining optimal solutions when problem is fairly large. It is an optimization procedure that operates on sets of design variables [HEN, 97]. GA differ from other search techniques which rely on analogies to natural and biological evolution process start with an initial set of random solutions called population and use a process similar to biological evolution to improve upon them[MAR,08]. Each string of population is represented as linear string called chromosome whose length varies with each application. The characters in each string may be binary or digital. In fig 3 characters in each block represents time for particular activity and number above the block shows activity.

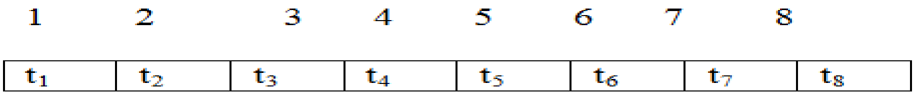


**Fig 3** Chromosome Representation

Basically three operators are used in genetic algorithms: reproduction, crossover and mutation. In reproduction process strings are duplicated according to their fitness magnitude. Each string is assigned a probability of being selected as a parent string based on string fitness. Reproduction does not affect the features of parent string. In crossover operation two members are randomly selected from population as parent strings, broken into segments and new strings are produced by exchanging the information between them (fig 4). Crossover occurs only with some probability, range lies normally 0.5-1.0.

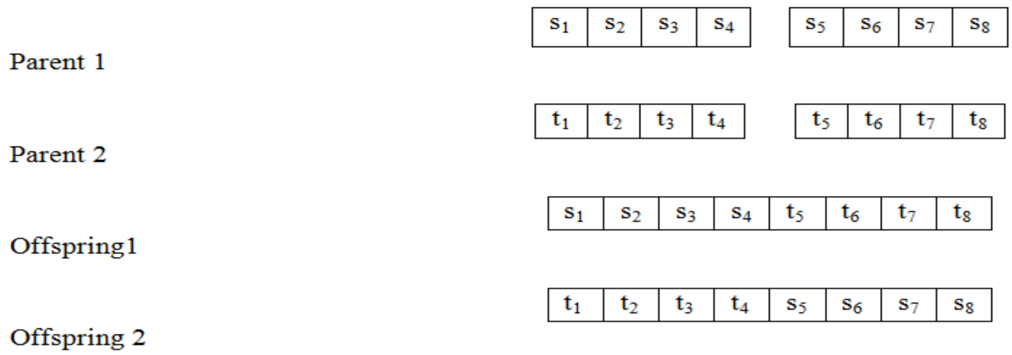


**Fig 4** Single Point Crossover

In mutation changes in solution population is done with some probability. Mutation restores unexplored or genetic information into population to prevent the premature coverage of GA to suboptimal solutions. The probability range lies between 0.001 to 0.05

## 5. REVIEW PROCESS

Initially it was decided to study on project scheduling but during the review process it was experienced that the applications of subject under consideration is very enormous. Hence the present study was limited to the following objectives

- Project scheduling was identified as a major or broad area.
- Identification of sub-areas of project scheduling and used these subareas as keywords in collection of papers
- Identification of tools methodologies, software, etc generally used in project scheduling .
- Collection of review papers regarding different areas, subareas of projection scheduling

- Segregation of review papers in terms of techniques used, areas, type of problem with concluding remarks have been done as shown in table 1
- Analysis of usage of project scheduling problems in different areas have been done and shown graphically year wise (fig 5,6,7,8)

**Table 1** Literature review

| S.No | Year | Code | Area | Technique /Algorithm | Type Of Problem | Remarks |
|---|---|---|---|---|---|---|
| | 1990 | JAM90 | Miscellaneous | Back tracking algorithm | Precedence and resource constrained network | Provide good heuristic solutions to realistic problem and optimal solution to small problem |
| | 1991 | SJN91 | software | Artificial intelligence, expert system | Survey on different approaches | Modeling of real world problem from close deterministic world to complex real world with project scheduling example. |
| | 1991 | MAS91 | Industrial | Mixed integer linear programming, CPM | Time cost trade off problem (TCTP) | Minimum total cost is achieved by crashing |
| | 1995 | PRA95 | Project management | Centralized and decentralized dynamic programming | Discrete TCTP | Useful for complex network |
| | 1995 | LIA95 | Construction | Linear and integer programming | Time cost trade off problem | Hybrid method provide efficient and exact solutions |
| | 1997 | CHU97 | Construction | Genetic algorithm(GA) | Time cost trade off problem | Algorithm shows its efficiency by searching only a small fraction of total search space. |
| | 1997 | HEN97 | Construction | Improved GA | Time cost trade off problem | Improved GA generates a whole class of alternative solution close to optimum. |
| | 1999 | HEN99 | Construction | Machine learning and GA based system | Time cost trade off problem | MLGAS is efficient and generates better solution to nonlinear TCTP. |
| | 1999 | PET99 | Industrial | Review paper | TCTP | Review of exact and heuristic algorithm for simple and multimode case for different problems |
| | 2001 | RKO01 | Miscellaneous | - | Review paper | Study of different previous techniques |
| | 2001 | MAT01 | Construction | Project management software | Survey on different analytical techniques and software | Found construction respondents are heavy users of CPM for planning control. Project scheduling. |
| | 2002 | HST02 | Project management | Theory of constraint | Allocate common resources to multiple projects | Reduce project cost, and ensure reduction of risk |
| | 2003 | SGP03 | Industrial | GA | Sequencing | MS1992 and GA for sequencing are compared and found better performance of GA, |
| | 2004 | AAZ04 | Management | Goal attainment method | TCTP | Minimized total direct cost and mean project completion time |
| | 2005 | AMI05 | Miscellaneous | GA, goal attainment technique | TCTP in PERT network | Minimum objective function value occurs with low level of population size and high eve log generation within a given execution time. |
| | 2006 | AHM06 | Miscellaneous | GA | TCT multiple crew strategies | Can handle both linear and complex non serial linear projects which could not be solved using classical linear scheduling methods. |
| | 2006 | PIO06 | Construction | Evolutionary algorithms, | RCPSP | Enable to solve practical problem in complex conditions |
| | 2007 | ASH07 | Construction | GA, integer programming | TCTP | Maximized project profit through minimized direct cost, overheads, financing costs and resource fluctuating under credit and resource limit |

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|---|---|---|---|---|---|---|
| | 2007 | BHU07 | Miscellaneous | MOGA, fuzzy logic | TCTP | Can solve the problem under varying condition of existing uncertainties in realistic projects |
| | 2007 | VAH07 | Management | Bayesian network model | Uncertainty in project scheduling problem | Empowers CPM to handle uncertainty and provide explanatory analysis to represent and manage different source of uncertainty in project planning. |
| | 2007 | IZA07 | Management | Affinely adjustable robust counterpart | Stochastic TCTP | Able to get solution that are immune to uncertainty |
| | 2008 | BHU08 | Miscellaneous | ANN, MOGA | Nonlinear time cost trade off problems | Can effectively produce optimal values of processing times and direct cost of project activities for minimum project duration and project cost. |
| | 2008 | HIR08 | Miscellaneous | FastPGA | Time cost quality tradeoff problems | Find pareto optimal front of time, cost and quality of project. |
| | 2008 | TAG08 | Management | Integer linear programming | Tome constrained project scheduling problem | Schedules generated are of high quality and flexible due to parameter setting and computational effort. |
| | 2008 | MAR08 | Miscellaneous | Particle swarm optimization | DTCQTP | PSO gives good results for large problems |
| | 2008 | PKS08 | Software | PERT,C++,Simulation | Cost and schedule problem | Reduce software project duration at minimum cost by locating minimal cut in duration of activity |
| | 2008 | BHO08 | Miscellaneous | GA | TCTP | Comparison between GA and Siemens classical algorithm is done and found GA is more suitable large and complex problem. |
| | 2009 | AKA09 | Software | Project management software package | RCPSP | Different software results are compares and Primavera P6 give best solution |
| | 2009 | ZHA09 | Miscellaneous | Arithmetic model | Multimode double RCTCP | Optimal project during in MDRCPSP is longer than traditional DTCTP |
| | 2009 | ZOH09 | Industrial | Linear programming | Workload distribution problem | Evaluated the possible benefits from improving the workload distribution in project network by determining a lower bound of projection completion time. |
| | 2009 | JOS09 | Miscellaneous | Multi-agent technology, dynamic programming | Multi-project environment | Systems provide dynamically resources to project and able to handle the complexity of multi-project environment |
| | 2009 | WBI09 | Miscellaneous | Ant colony optimization algorithm | Multimode RCPSP | Algorithm outperform GA, simulated annealing and tabu search |
| | 2009 | SMF09 | Agriculture | CPM, PERT, Winqsb Software | establishment of 300 hectare grape garden | Completion time of project is reduced based on normal time and PERT method. |
| | 2010 | REF10 | Construction | Line of balancing, CPM, GA | TCQTO | Developed multi-objective optimization system to optimize resource utilization in order to minimize project cost and duration while maximizing its quality. |
| | 2010 | NSH10 | Miscellaneous | NHGA,ANOVA | DTCTP | Useful for large projects due to high speed and quick convergence. |
| | 2010 | HAD10 | Industrial | Cutting plane method, Monte Carlo | STCTP | Model increased project completion probability in prescribed deadline to predefined value. |
| | 2010 | HNI10 | Miscellaneous | Integer programming | TCTP (PERT) network problems | Use concept of time value of money to develop cost function and reduce total cost of project |
| | 2010 | EAH10 | Industrial | Branch and price approach | Multimode resource leveling | Approach is suitable with only 30 jobs to find optimality. |
| | 2011 | HAD11 | Miscellaneous | Ant colony system algorithm | DTCTP | Improve project completion probability from initial risky value to maximum possible value using limited available |

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|---|---|---|---|---|---|---|
| | | | | | | budget. |
| | 2011 | NRA11 | Construction | Stochastic dominance rule, | TCQTP | Optimize time, cost and quality with various resource allocation |
| | 2011 | AMI11 | Construction | MILP. lingo 12 | TCTP | Minimize total cost of project |
| | 2011 | AMI11 | Industrial | Hybrid simulated annealing, lingo | Project scheduling and material ordering | Minimize total material handling and ordering cost |
| | 2011 | ORS11 | Construction | Traditional techniques | Survey | |
| | 2011 | MOH111 | Industrial | Scatter search algorithm | RCPSP | algorithm provided results close to optimal in less time comparing with exact branch and bound algorithm |
| | 2011 | GHO11 | Industrial | MOGA | TCTP | Study developed GA pareto front approach to solve CPMTCTP and find optimal solution useful for large projects due to high speed and quick convergence |
| | 2011 | MOH112 | Construction,pharmaceutical | Optimal procedure | Used for problem in which activity have fixed modes | Produced optimal mode corresponding to minimum possible duration of each activity |
| | 2012 | MOH12 | Miscellaneous | Branch and bound algorithm | Multimode RCPSP | Able to find optimal solutions in short time for small size and medium size test problem |

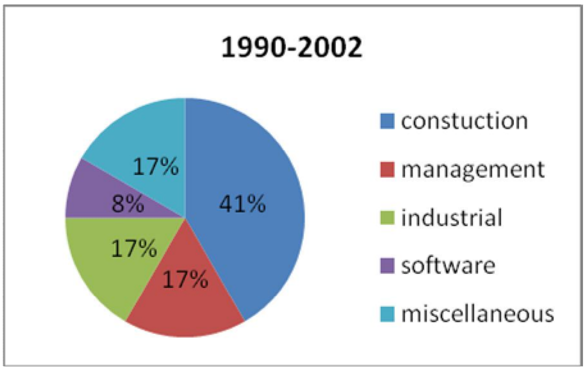


**Fig 5** Pie chart regarding survey of scheduling problems in different areas during 1990-2002

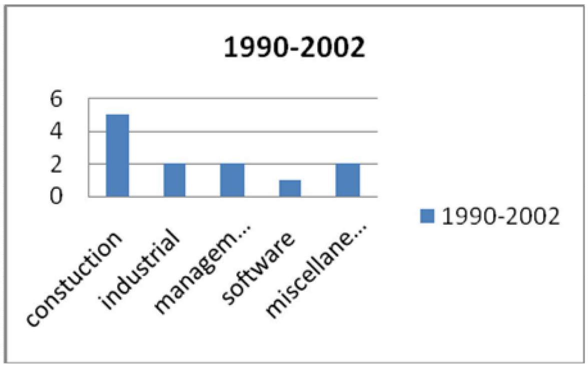


**Fig 6** Bar chart regarding survey of scheduling problems in different areas during 1990-2002

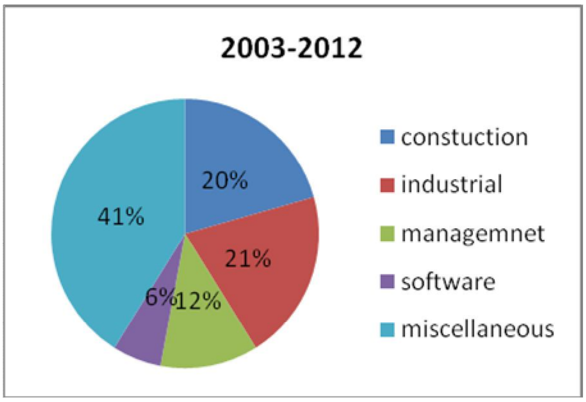


**Fig 7** Pie chart regarding survey of scheduling problems in different areas during 2003-2012

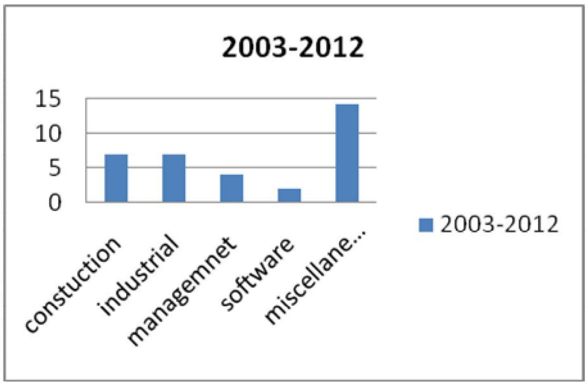


**Fig 8** Bar chart regarding survey of scheduling problems in different areas during 2003-2012

## 5. SOME OBSERVATIONS AND SYNOPTIC CONCLUSIONS

In the present study forty seven research papers (1990 to 2012) of the area under consideration have been comprehensively studied and some important observations are as follows.

- During the 1990-2002 major work had been done in construction area and there is great scope in other areas such as industrial, management and software etc.
- During the 2003-2012 major work had been done in miscellaneous area and there is great scope in other areas such as construction, industrial, management and software etc.
- It is evident from the analysis that in future there is great scope in industrial, management and software field etc.

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