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Critical Path Method and Time-Cost Tradeoff Analysis – A Review

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Abstract: *This paper aims to incorporate the knowledge on Critical Path Method (CPM) of scheduling and Time Cost Tradeoff (TCT) analysis, to understand their limitations, and latest advancements in research so as to further the existing research to obtain breakthrough in practical application.The review was done by sourcing the literature with a strict acceptance criteria which ensures that only quality original works are cited,and then categorizing the obtained literature to form a structured review.The limitations and unawareness of modern methodologies among project managers, their rigidity in being practically applicable on site despite being extremely beneficial and the lack of research in considering the Time Value of Money as a factor of variability in estimation of cost are seen through the various literature studied.The future research through the process of implementing Time Value of Money and incorporating the overheads into the analysis of Time-Cost Tradeoff to obtain results synchronous to real-time data,which has not been rigorously researched even after proof of its benefits decades ago, are discussed alongside the practical implications of simplifying the same.*

Keywords: *Time-Cost Tradeoff, Critical Path Analysis, Resource Management, Time-based Management, Cost Control, Construction Management, Cost Allocation, Optimization.*

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I. INTRODUCTION

The proverb 'time is equal to money' fits the construction industry better than most other business. As defined by Silva (2016) a construction project is "A mission undertaken to create a construction facility or a service with predetermined performance objectives with the involvement of different project participants with different expectations".There exists a very complex entanglement between time, cost and scope of the project whose combined effect influences the overall quality of the project (Pour et al. 2012). Hencethe construction industry is where delivering projects within boundaries of the iron triangle: time, cost, and quality, is more than just signing the contract and waiting for the project objectives to be achieved by themselves (Eccles 1991; Egan 1998). The projects require constant supervision and direction to prevent deviation from the proposed and planned schedule.Poor project management has been cited as the main reason for delays in construction in developing countries, but research has yet to establish a feasible solution for improving it (AlSehaimi 2013).

It was found that ineffective planning and supply chain management caused the most repairable damage to the completion of the projects in developing countries. The cost overrun due to poor project management has tremendous effect on the contractor and the client (Morris 1990) and leads to many projects being stalled to clear the financial disputes.Most contractors consider overheads as a percentage of the total contract's cost, as there is no generalized method to calculate overheads for every project. This has led to many companies going into debt (Assaf et al. 2001). The factors which further complicate the analysis are the presence of uncertain variables such as weather, labour skill, and managerial experience (Pathak and Srivastava 2007).

Thus in real-life projects the tradeoff between the project cost and the project completion time along with the uncertainty of the environment play a major role in the decision makingprocess during construction (Ke et al. 2009).It is therefore important to estimate with accuracy the schedule and the various resources utilized in a project else the irregular resource requirements over time will lead to additional acquirement and release costs (Larson and Gray 2014).The early research in such techniques of time-cost tradeoff was done by Gordon and Tulip (1997), where the authors established steps and guidelines for resource levelling and smoothening.

For the implementation of an activity in a time shorter than normal, it is necessary to increase the volume of resources i.e. employ more expensive equipment and power, and change the technical methods used in finishing the activity (Sonmez and Bettemir 2012). The time-cost tradeoff is an optimization problem where two objectives can be sought after, namely resource optimization and time optimization (Mathews 1994). There have been many researchthat deals with time-cost tradeoff with constraints in either duration or resources, however in reality there is usually a limit on both resources and time. But integrating the effects of time and resource constraints in the scheduling process posed a challenge(Kandil and El-Rayes 2006) as multiple constraint optimization was more complex and required more knowledge and computing power to solve.As optimization is usually a computation heavy technique and requires the aid of various computer simulations and algorithms to solve (Jarboui et al. 2008) the improvements in computing power has led to incredibly fast solution to mathematically formulated time-cost tradeoff problems (Hariga et al. 2019) and made viable the integration of both time and resource constraints in scheduling a construction problem.

1.1. Critical Path Method

Critical Path Method (CPM) has been in practice sincethe 1950s and its utilization has gone unchanged in the fields of schedule and controlof construction projectsfor decades. CPM is a technique of scheduling the activities based on certain precedence to obtain the most optimum time of completion of the project. CPM allows the manager to determine the critical activities that will delay the total project completion and allows them to be supervised properly. Broadly there are two approaches to categorize a CPM network, the first is resource constrained scheduling where the main objective is to minimize project duration given a constraint on resources (Senouci and Adeli 2001). The second approach is resource levelling where the main objective is to smoothen the ups and downs of the resource histogram given a limit on project duration (Doulabi et al. 2011;Ponz-Tienda et al. 2013).

It can be seen that construction professionals were well-versed in software utilizing CPM for planning and controlling a project (Liberatore et al. 2001).However there have been issues faced by the contractors of small scale projects in developing countries, such as the ability to manipulate the schedule by the managers which made them opt out of utilizing the benefits of the software (Galloway 2006).But the increased transparency between the contractors and the managersalong with the increasing benefits of utilizing the various scheduling software (Owing to the development of computing technology and research) has led to the widespread utilization of CPM scheduling in small scale and even some medium scale projects.

1.2. Time-Cost Tradeoff

In a project there exists an optimum time where the sum of direct and indirect cost is the least. This relationship between time and cost in a project is known as Time-Cost Tradeoff (TCT) (Geem 2010). The objectives of the TCT analysis are compressing or accelerating the project activities to the optimum duration which minimizes the total project cost (Sonmez and Bettemir2012).TCT is an optimization problem, where multiple constraints on resources and duration of the project must be accounted for to provide the best schedule and optimum cost. The methods of achieving TCT are broadly classified into two categories, first is the Mathematical Programming method, which includes but not limited to Linear, integral and dynamic programming. The second is the Heuristic approach, which includes but not limited to Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization(PSO) and Cost loop method (El-Sayed and Nasr 1986, Tsai and Chiu 1996).

To achieve optimal time-cost tradeoff, various heuristic approaches were used since traditional Mathematical Programming cannot handle large project schedules(Ling and Fang 2011; Hegazy and Menesi 2012; Menesi et al. 2013). The heuristic models provided a workflow to guide the process of crashing and levelling but they did not provide an optimal solution (Leu et al. 2001; Hariga et al. 2019).In the early days, the critical chain method had stirred a lot of criticism during its first introduction as an alternative to project planning techniques (Rand 2000; Leach 2000; Herroelen et al. 2002). The critical chain method displayed better performance compared to earlier methods to reduce project execution time by eliminating existing uncertainties in the timing of activities (Wei-Xin et al. 2014), thus providing a flexibility of time buffers in planning, which was accepted by the project managers (Ghoddousi et al. 2016). However for large scale projects with thousands of activities GA, PSO and ACO proved more efficientwith the improvement in computational power over the years, due to the parallel processing nature of the algorithms used.

II. RESEARCH METHODOLOGY

This study was done by assessing literature obtained from selective journals of proven quality. Articles that belonged to Journal of Construction Engineering and Management, International Journal of Project Management, Journal of Management in Engineering, Project Management Journal, KSCE Journal of Civil Engineering, Applied Mathematics and Computation, Automation in Construction and many more were selected for this study. The initial collection of literature was through computerized search in major search engines such as ASCE Library, Science Direct, Taylor and Francisand Research Gate using keywords such as Critical Path Method, resource management, Time-Cost Tradeoff, cost control, construction management software, cost

allocation and optimization. This resulted in the collection of many literature, from which 84 was found to be relevant to the topic of study and was further analyzed.
The articles obtained were classified into the following categories

- Articles dealing with the limitations of CPM and its workarounds.
- Articles discussing the various techniques employed in TCT optimization (Mathematical, Meta-Heuristic).
- Articles involving case studies and comparison studies involving software that implements the optimization techniques.

The 84 cited literature can be split as shown in table 1 based on the publishers of the source journal. Out of the 20 papers from ASCE library 16 was from the Journal of Construction Engineering and Management and 4 from Journal of Management in Engineering; 7 literature was published through International Journal of Project Management by Science Direct; The various literature obtained was read and critically reviewed to prepare a structured review which summarizes the recent advances in TCT optimization and the gap in research. The study involves a period of 34 years from 1986 to 2019 with one fundamental article from the year 1971.

Table 1. Literature source classification

Publisher	Journal	Count	Total
ASCE Library	Journal of Construction Engineering and Management	16	20
	Journal of Management in Engineering	4	
Science Direct	International Journal of Project Management	7	20
	Applied Mathematics and Computation	2	
	Automation in Construction	2	
	Expert System with Applications	2	
	Others	7	
Taylor and Francis	Journal of Civil Engineering and Management	2	8
	Journal of Global Information Technology Management	2	
	Others	4	
Springer	KSCE Journal of Civil Engineering	3	7
	Others	4	
Research Gate	International Transactions in Operational Research	2	14
	Others	12	
Conferences			15
			84

III. LIMITATIONS TO CPM

Although there are various uses for the traditional CPM, it has many limitations as traditional analysis assumes static unlimited resource utilization(Abeyasinghe et al. 2001). However in real projects the resource constraints and the objective are subject to dynamic variation (Pinha and Ahluwalia 2018) hence the optimization problem should assume a dynamic nature. CPM is inappropriate for scheduling resource constrained projects, and project managers should not rely only on this method when dealing with limited resources (Herroelen and Leus 2005).The reliance on CPM in real-time projects with unaccounted 'resource critical' activities, which can delay the critical activities if not properly analyzed, has led to huge disputes and incorrect dispute resolutions in the past (Fondahl 2001). This can be seen as phantom floats in software packages due to discrepancies between the forward and backward pass calculations (Kim and Garza 2003).Another limitation is that CPM becomes complex for large projects with multiple activity relationships. Also it cannot account for the multiple constraints in a project such as resource and time limits (Hegazy and Menesi 2010). Also the project duration is assumed to be unchanging (Hariga and El-Sayegh 2010) but in reality various factors affect the duration of each activity. A study on the effect of various objective functions on the levelling of resources of a CPM model showed that different resource utilization histograms were obtained for each objective function (Damci and Polat 2014).

A factor which affects the flexibility of the traditional CPM method is thatresource calendars bring about changes to the critical path as it affects the availability of resources and hence causes delays in the project. But the calculation of float in CPM model is difficult when multiple resource calendars are used (Lu and Lam 2008).The most widely used software utilize CPM to schedule activities and theydo not support multiple task modes and do not support accuracy in calculating task durationwhen multiple resources and calendars are used (Pinha and Ahluwalia 2018).Even in Resource Constrained CPM (RCPM) models, resource links are not detected when they do not affect the total floats of activities so a separate RCPM algorithm to find resource links is required whenever the schedule is updated (Kim and Garza 2006).All these pose a great obstacle to the flexible use of the method in the dynamic day-to-day construction process.

When it comes to the flexibility of the method, Siemens (1971) proposed the algorithm involving the cost-slope to determine the optimum crashing of activities so as to complete the project within the required duration and at the least cost. This algorithm made hand calculations possible in crashing activities which led to the widespread utilization of the method in crashing construction activities. However this simplicity and flexibility is what is lacking in today's computer simulations which is a major obstacle to its widespread utilization in construction (Primarily in small scale constructions in developing countries).

IV. TECHNIQUES TO OVERCOME LIMITATIONS

To overcome the limitations of traditional CPM subtle techniques and modifications to the existing CPM goes a long way. A novel approach was researched by Moselhi(1993) where the entire CPM network is considered analogous to a structure and when the compressed schedule is incorporated as compressed displacement, the total member forces represents the additional costs incurred. This method makes use of "Direct Stiffness Method" which is used in structural analysis to solve the time-cost tradeoff problem.However it is more complex to be easily applied on field in large scale projects and is neither widely utilized nor researched to warrant the development of software utilizing the technique.The various research done in overcoming the limitations of time-cost tradeoff optimization can be classified into

- **Mathematical Programming** – Which consists of the very first methods established to deterministically find the optimum schedule considering time-cost tradeoff.
- **Meta-Heuristic Approach** – Which was developed to overcome the limitations of Mathematical Programming in its applicability in large scale project scheduling.

The improvement in the computation power has made tremendous leaps in both the above techniques and this has increased their applicability in various projects, even interchangeably, to allow more flexibility to the project managers in determining the suitable technique to schedule the project.

4.1. Mathematical Programming

The earliest implementation of Mathematical Programming was by Siemens (1971) whose algorithm made hand calculations possible in crashing activities and gave deterministicsolutions in the optimization of time-cost tradeoff. However in the modern day software has become widely integrated to the construction scheduling process, especially CPM based scheduling. But to allow for the use of CPM as a scheduling process, the various errors in the method needs to be addressed and work-around for the most deviating flaws needs to be researched.

The first modification required is to correct the error found in float calculation of traditional CPM,namely the phantom float i.e. the difference between CPM total float and resource-constrained total float. This leads to over-estimation of the float time of non-critical activities, which may at worst lead to schedule blockage and costly delay of the entire project.The splitting of activities into time segments of one day each allows for reducing complex relationships into a simple Finish and Start (FS) relationship, while introducing zero time lag. This prevents the float calculation problems encountered in traditional CPM models (Hegazy and Menesi2010) and is one simple modification to the existing CPM model that solves the problem of phantom float.

Resource management is a key element to activity resource estimation and project human resource management. Both are essential components of a comprehensive project management plan to execute and monitor a project successfully (PMBOK 2017). Hence the second modification required is to integrate the resource dimension to the CPM scheduling process. Resource constrained projects require novel techniques to schedule as even non-critical activities can end up delaying the critical activities due to bottleneck of resources. One such modification is to add the resource dimension to the activity in addition to time, hence the activities are a function of the resources and not just time. This will allow constraints in resources without making the CPM obsolete (Lu and Li 2003; Van Peteghem and Vanhoucke 2010).

The third modification is to combat the issue of practical application and feasibility of the CPM model.In view of this an integer programming model integrating indirect costs to the objective function considering the discrete time-cost curves produced a more realistic representation of actual problems (Shtub et al. 1994) and made the application of TCT more meaningful in practice. Also to avoid considerable tradeoff between project cost and quality a non-linear multi-mode resource constrained problem was developed and the total quality cost which included prevention cost and failure cost was minimized (Fu and Zhang 2016).Also the utilization of a Short term resource allocation software helps in imparting realistic decision making abilities to the project managers (Pinha and Ahluwalia 2018).

All the above discussed techniques are some of the existing work-around to the limitations of CPM in scheduling small and medium scale projects.

4.2. Meta-Heuristic Approach

Larger projects cannot be scheduled optimally using deterministic methods as they require enormous computing time. Hence Meta-Heuristic techniques which trade accuracy for performance is seen as a better alternative. Meta-Heuristic approach involves non-deterministic models such as PERT (Baradaran et al. 2012), Monte Carlo Simulation, Genetic Algorithm, Ant Colony System and many more in conjunction with time-cost tradeoff to determine near-optimal schedule during uncertain conditions (Leu et.al 2001).

4.2.1. Teaching Learning Based Algorithm

Teaching Learning Based Algorithm (TLB) was introduced by Rao et al. (2011) as a new optimization method. As the name implies, it simulates teaching learning between the educator (Teacher) and the students (learners) in a class.In the TLB algorithm, a group of learners is considered as the population of solutions, and the fitness of the solutions is considered as results or grades. Teaching Learning Based Algorithm was applied to solve multi-objective optimization problems related to robotic arms, mechanical and structural systems (Rao and Patel 2012). A TLB Algorithm alongside the Modified Adaptive Weight approach (MAW) was used to optimize time-cost tradeoff problems having activities ranging from seven to sixty three and its results were comparative to the optimal or near optimal solutions of other optimization models (Toğan and Eirgash 2019). The MAW approach made the achieving of optimal solution faster by giving importance (weights) to certain activities over others. This proved to increase the performance of the normal TLB algorithm by a significant margin.

4.2.2. Genetic Algorithm

Genetic Algorithm (GA) differs from other processes as it imitates natural biological process of evolution. It consists of an initial set of solutions known as population whichcan be effectively used to simulate the various resource allocation histograms to determine a near-optimum solution for a construction project (Damci and Polat 2014).Earlier models using GA had much less processing time than the later models, but they were not as accurate (Hartmann 2001).A Multi-objective approach to optimize time-cost-quality of a construction project was done through the help of GA where the chromosomes were represented by random keys (Mendes 2016). This proved the viability of utilizing GA for multiple constraint project scheduling.And as seen in the Mathematical Programming, there exists the limitation of scheduling resource constrained projects in GA too. For solving such a problem an implicit enumeration model utilizing the power of artificial intelligence can be used alongsideGA model to effectively solve the resource allocation optimally (Zamani 2017).In a typical multi objective optimization problem, a set of solutions are superior to others when all objectives are considered. Such solutions are non-dominated and are preferred to other dominated solution sets. A non-dominated sorting GA was modeled to give various Pareto responses for the perusal of the project managers (Amiri et al. 2018). This threw light on the superior accuracy of the GA model over other heuristic approaches.

4.2.3. Ant Colony Optimization

Ant Colony Optimization (ACO) is another such model where the shortest path is determined by numerous iterations simulating that of an ant colony.The ants use pheromones to identify pathways and the more pheromones in a path the more ants follow that path. This is analogously used to identify the optimum solution of a TCT problem, where the past data serves as the reference pathways, which get optimized with further iterations of the model.Time-Cost tradeoff was done through the use of ACO by integrating both time and cost constraints simultaneously (Zhang and Ng 2012). This was possible due to the parallel processing algorithm which utilized the growing computational power to solve the multi-constraint problem.Earlier to that a Multi-objective Adaptive Weight (MAW) basedACO was proposed as an attractive alternative to traditional time-cost tradeoff analysis (Xiong and Kuang 2008) as the MAW increased the performance of the model by giving appropriate weights to the speed of the iteration process. The advantage in utilizing ACO over other methods has to do with the ability of ACO in adapting to dynamic changes to the problem, which closely simulates real-time environment. This was expressed byMokhtari et al. (2011) where, distribution of activity duration is employed in a multi-mode time-Cost tradeoff problem using ACO to simulate the dynamic nature of real-time construction projects.

4.2.4. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is an algorithm based on swarm theory which imitates the behaviors of biome. It is a computational method that optimizes a problem by iteratively trying to improve a candidate solution (Time-Cost Tradeoff) with regard to a given measure of quality (Constraints). Each particle's movement is influenced by its local best known position and is also guided toward the best known positions found by other particles. This is expected to move the swarm toward the best solutions thereby optimize the objective function. It is highly efficient in parallel calculation and has perfect performance on large-scale optimization problems (Yang 2009).Aminbakhsh and Sönmez(2016) developed an efficient method based on PSO for the solution of large-scale discrete Time–Cost Trade-off problem which proved a much better optimization tool compared to traditional techniques which required huge computing power. The performance of PSO algorithm is the best out of all the previously mentioned techniques in terms of computation time as the algorithm utilizes parallel processing.

V. SOFTWARE COMPARISONS

Over the years various advancements in computational power has resulted in the development of incredible software to optimize complex problems and to overcome the limitations faced in the already existing software. In the early days, a computer application package known as TORA optimization system (Taha 2000) was used in the computation of CPM schedule. The development of the IT field has enhanced its application in construction by reducing fragmentation in scheduling (Nitithamyong and Skibniewski 2004). However there is a scarcity of literatures dealing with the software model's application in transitional economies (Roztocki and Weistroffer 2008; Travica et al. 2007) and the investment in software development is considerably lower in transitional economies as compared to developed nations (Bingi et al. 2000; Izetbegovic et al. 2003; Izetbegovic et al. 2004). This can be seen as a direct indication of the lack of Research and Development in developing countries, as the nation focuses more on survival and enhancement of the standard of living rather than on investing in research which does not have any immediate material gain for the country.

5.1. Primavera

Since 1983 Primavera Systems have been developing their Project Management System package for construction and today it has become a leading provider of the Project Portfolio Management solutions for the construction industry (Galloway 2006). While Primavera was once mostly used to handle large and complex projects, later on it was also used for many smaller projects too. Recent research compared the various project management software on the basis of their compliance to PMBOK and other guidelines (Pereira et al. 2013). Another study compared the results obtained in three different project management software packages in scheduling two real-time construction projects. The study conducted byKastor and Sirakoulis (2009) concluded that deviations of 41.11 percent to 167.79 percent was seen and the lowest deviation or most accurate results was given by Primavera P6 as shown in table 2.

A case study consisting of twenty two activities for the construction of SMIT campus utilizing CPM to analyze the effect of time delay in particular activities and its effect in the overall project duration (Aliyu 2012) was done at Yola, Nigeria using Primavera to understand the limitations of the software. It was found that Primavera was subject to the same flaws as discussed for the CPM model and required proper work-around to obtain a schedule which is synchronous to the field data.

Table 2: Duration and percentage deviation obtained by the different project management software (Kastor and Sirakoulis 2009)

Rule	1st Instance			2nd Instance			Average percentage deviation from CPM (%)
	Duration	Percentage deviation from CPM (%)	Rank	Duration	Percentage deviation from CPM (%)	Rank	
LST	709	52.8	1	308	29.41	1	41.11
P6 Default	709	52.8	1	308	29.41	1	41.11
MS Project standard	744	60.34	2	314	31.93	2	46.14
PWM	744	60.34	2	319	34.03	3	47.19
LFT	744	60.34	2	319	34.03	3	47.19
EPWM	823	77.37	3	308	29.41	1	53.39
MSLK	823	77.37	3	327	37.39	4	57.38
SPT	893	92.46	4	336	54.18	5	66.82
Open workbench standard	863	85.99	5	832	249.58	6	167.79

5.2. Other Software

There have been various other software to tackle the problem of scheduling and tradeoff optimization. These software have their own pros and cons and were exhaustively researched so as to improve the accuracy between simulated and real-time results.One hundred and ten scheduling problems having various constraints to resources and duration were computed to compare the thirteen versions of seven different project management software packages to test the accuracy of the simulated results (Johnson 1992). Through this study the author concluded that it is possible to utilize heuristic approaches to provide optimized solution and that the vendors should consider providing such optimization schedule as an option in the software packages. But even after more than two decades there has yet been any corrective measure to rectify the flaws of Phantom float and Multi-resource constraints, let alone introducing heuristic approaches to leading project management software by the industry (Franco Duran and de la Garza 2019).

5.3. Constraint Programming

Constraint programming (CP) combines operations research and logic programming techniques to solve complex combinatorial problems (Heipcke 1999; Chan and Hu 2002).However the limitation of constraint programming has to do with the enormous computations required to analyze the objective function over given constraints. However this limiting factor was overcome by the enormous surge in computing power over the years. IBM ILOG CPLEX Optimization Studio was designed to aid the use of CP algorithms in scheduling problems (Beck et al. 2011).Over the years various researchers reported the advantages of CP in scheduling problems for solving the resource-constrained project scheduling problem (Liess and Michelon 2008) and the time-cost-resource optimization in large-scale projects (Menesi et al. 2013).Both of which lies in the strengths of CP as parallel elimination of solutions along with rapid iterations leads to extremely fast optimization as shown in figure 1.

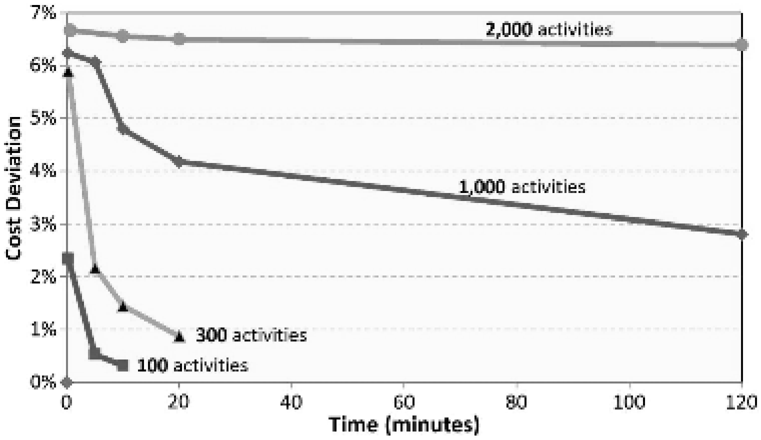

Figure 1:CP solution quality versus processing time for different problem sizes (Menesi et al. 2013)

The speed of obtaining the optimized solution was researched on by (Hariga et al. 2019) and the CPLEX software solveda complex multi-mode resource constrained problem with allowed crashing of activities to obtain the optimal solution within 4.1 seconds.This integration of both resource constraints and resource levelling to crash the activities so as to obtain the optimum duration of the project is what is needed in the current industry. However, despite the enormous benefits of CP in optimizing construction project schedules, though easily programmable, requiring the scheduling expert to have computer programming skills is a serious obstacle to implementing CP modelsin the field (Menesi and Hegazy 2015). Also it is not flexible enough to update the schedule on the fly, as is the norm in any construction project subject to the extreme variables on field.

VI. DISCUSSION

Further research in super-positioning simulated results with field data will help in fine tuning the simulated results (Abeyasinghe et al. 2001) and could lead to breakthroughs in the existing simulation models. The utilization of Resource Activity Critical Path Method will allow for integrating scheduling and cost estimation so as to provide realistic estimates (Lu and Li 2003).And to provide more realism to the estimated cost and duration of a project during planning stage, the variability of funding and the uncertainty of activity durations can be analyzed together using various software (Kholy 2015).The use of multiple objective functions to integrate resource levelling and time-cost tradeoff using mathematical or heuristic models can lead to a more accurate estimation of project cost and aids real-time decision making (Hariga et al. 2019).Further simplification of the process and research to implement everyday changes into the entire analysis will go a long way in enhancing the practical day-to-day application of time-cost tradeoff analysis on site.

Heuristic models such as Genetic Algorithm and Project Swarm Optimization are widely used and their modified and hybridized versions are more preferred in optimizing complex problems as compared to deterministic mathematical models. But evolutionary multi-objective optimization algorithms falter in the case of maintaining a diverse population to prevent premature convergence. New simulation models which estimates the task duration of an activity based on resources used and historic data of similar tasks can help improve the existing models (Pinha and Ahluwalia 2018). The implementation of a metaheuristic model that levels multiple resources considering different objective functions can enhance the practical application of theoretical research (Damci and Polat 2014).The influence of overhead costs is widely neglected and requires attention to prevent cost overrun in a project. Research must be done in determining a general rule of thumb which can be followed in every construction project such that the overheads need not be assumed arbitrarily based on the contract price.Also the Time Value of Money (TVM) plays a vital role in the investment side of the project as Bankers, investors, and most business decision-makers need to see the effect of time on their investment (Brown 2006). But there is hardly any new research incorporating such a factor which has been proven decades ago to be of great benefit compared to traditional analysis (Sunde and Lichtenberg 1995). Future research integrating TVMand overhead costs into the TCT analysis of construction projects will give a practical estimate of the financial feasibility of the activities in a project.

VII. RESULTS AND CONCLUSION

The traditional CPM method cannot account for the assumption of unlimited resources, the error in multiple calendars,the phantom float and many other such limitations. The deterministic approaches, even with their modifications to overcome the limitations of CPM, are inapplicable in large scale projects due to the sheer complexity in computing series of iterations. Meta-heuristic methods were then researched to prove their viability as an alternative to deterministic approaches in scheduling large construction projects. The improvement in computing power had significantly boosted the range of applicability of both the techniques, however the complexity of utilizing the meta-heuristic approach has remained unchanged or even made more complex by the introduction of constraint programming (CPLEX). So the current need in research is to determine a bridge between the flexibility and ease of use of deterministic approach and the wide range of applicability and performance boost of the meta-heuristic approach. Also it is important to not neglecting the overheads along with the integration of Time-Value of Moneyas critical components of the cost estimation process. The future scope in this field of research was thrown light so as to guide future researchers in the direction of utilizing the theoretical research to obtain practical applicability on siteto the extent of being applicable even in small scale projects in developing nations.

REFERENCE

[1]. A Guide to the Project Management Body of Knowledge, Fourth Edition. Newtown Square, Pennsylvania: Project Management Institute (PMI). 2017.

[2]. Aliyu A.M. (2012), "Project Management Using Critical Path Method (CPM): A Pragmatic Study", Global Journal of Pure And Applied Sciences, Vol. 18, No. 3&4, pp. 197-206. http://dx.doi.org/10.4314/gjpas.v18i3-4.11

[3]. AlSehaimi A., Koskela L. and Tzortzopoulos P. (2013), "Need for alternative research approaches in construction management: case of delay studies", Journal of Management in Engineering, Vol. 29, No. 4, pp. 407–413.https://doi.org/10.1061/(ASCE)ME.1943-5479.0000148

[4]. Aminbakhsh S. and Sönmez R. (2016), "Applied discrete particle swarm optimization method for the large-scale discrete time–cost trade-off problem", Expert System with Applications, Vol. 51, pp. 177-185. https://doi.org/10.1016/j.eswa.2015.12.041

[5]. Amiri M. J. T., Haghighi F. R., Eshtehardian E. and Abessi O. (2018), "Multi-project Time-cost Optimization in Critical Chain with Resource Constraints", KSCE Journal of Civil Engineering, Vol. 22, No. 10, pp. 3738-3752.https://doi.org/10.1007/s12205-017-0691-x

[6]. Assaf S. A., Bubshait A. A., Atiyah S. and Al-Shehri M. (2001), "The management of construction company overhead costs", International Journal of Project Management, Vol.19, pp. 295-303.https://doi.org/10.1016/S0263-7863(00)00011-9

[7]. Baradaran S., FatemiGhomi S. M. T., Ranjbar M. and Hashemin S. S. (2012), "Multi-mode renewable resource-constrained allocation in PERT networks", Applied Soft Computing, Vol. 12, No. 1, pp. 82–90. https://doi.org/10.1016/j.asoc.2011.09.007

[8]. Beck J. C., Feng T. K. and Watson J. (2011), "Combining constraint programming and local search for job-shop scheduling", INFORMS Journal on Computing, Vol. 23, No. 1, pp. 1–14.https://doi.org/10.1287/ijoc.1100.0388

[9]. Bingi P., Leff L. P., Shipchandler Z. E. and Rao S. (2000), "Critical IT implementation issues in developed and developing countries", Information Strategy: The Executive's Journal, Vol. 16, No. 2, pp. 25-34.

[10]. Brown A.S. (2006), "Project Schedules and Return on Investment", PMI College of Scheduling 2006 Annual Conference.

[11]. Chan W. T. and Hu H. (2002), "Constraint programming approach to precast production scheduling", Journal of Construction Engineering and Management, Vol. 128, No. 6, pp. 513–521.https://doi.org/10.1061/(ASCE)0733-9364(2002)128:6(513)

[12]. Chelaka M., Abeyasinghe L., Greenwood D. J. and Johansen D. E. (2001), "An efficient method for scheduling construction projects with resource constraints", International Journal of Project Management, Vol.19, pp. 29-45. https://doi.org/10.1016/S0263-7863(00)00024-7

[13]. Damci A. and Polat G. (2014) "Impacts of Different Objective Functions on Resource Leveling in Construction Projects: A Case Study", Journal of Civil Engineering and Management, Vol. 20, No. 4, pp. 537–547.https://doi.org/10.3846/13923730.2013.801909

[14]. Doulabi S. H. H., Seifi A. and Shariat S. Y. (2011), "An efficient hybrid genetic algorithm for resource leveling via activity splitting", Journal of Construction Engineering and Management, Vol. 137, No. 2, pp. 137–146.https://doi.org/10.1061/(ASCE)CO.1943-7862.0000261

[15]. Eccles R. (1991), "The performance measurement manifesto", Harvard Business Review, Vol. 69, No. 1, pp. 131-137.PMID: 10109469

[16]. Egan J. (1998), "Rethinking Construction: Report of the Construction Task Force on the Scope for Improving the Quality and Efficiency of UK Construction", Department of the Environment, Transport and the Regions, London.

[17]. El-Kholy A. M. (2015), "New Aspects in Time-Cost Tradeoff Analysis", Journal of Management in Engineering, Vol. 31, No. 4, pp. 1-8.https://doi.org/10.1061/(ASCE)ME.1943-5479.0000258

[18]. El-Sayed E. A. and Nasr N. Z. (1986), "Heuristics for resource-constrained scheduling", International Journal of Production Research, Vol. 24, No. 2, pp. 299-310.https://doi.org/10.1080/00207548608919730

[19]. Fondahl J. W. (1991), "The development of the construction engineer: past progress and future problems", Journal of Construction Engineering and Management, Vol. 117, No. 3, pp. 380–392.https://doi.org/10.1061/(ASCE)0733-9364(1991)117:3(380)

[20]. Franco-Duran D.M. and de la Garza J.M. (2019), "Review of Resource-Constrained Scheduling Algorithms", Journal of Construction Engineering and Management, Vol. 145, No. 11, pp. 1-16.https://doi.org/10.1061/(ASCE)CO.1943-7862.0001698

[21]. Fu F. and Zhang T. (2016), "A New Model for Solving Time-Cost-Quality Trade-Off Problems in Construction", Public Library of Science (PLOS One), Vol. 11, No. 12.https://doi.org/10.1371/journal.pone.0167142

[22]. Galloway P. D. (2005), "CPM Scheduling and How the Industry Views Its Use", AACE International Transactions, Vol. 48, pp. 24-29.

[23]. Galloway P. D. (2006), "Survey of the construction industry relative to the use of CPM scheduling for construction projects", Journal of Construction Engineering and Management, Vol. 132, No. 7, pp. 697–711.https://doi.org/10.1061/(ASCE)0733-9364(2006)132:7(697)

[24]. Geem Z. W. (2010), "Multi-objective optimization of time-cost trade-off using harmony search", Journal of Construction Engineering and Management, Vol. 136, No. 6, pp. 711-716.https://doi.org/10.1061/(ASCE)CO.1943-7862.0000167

[25]. Ghoddousi P., Ansari R. and Makui A. (2017), "A risk-oriented buffer allocation model based on critical chain project management", KSCE Journal of Civil Engineering, Vol. 21, No. 5, pp. 1536–1548.https://doi.org/10.1007/s12205-016-0039-y

[26]. Gordon J. and Tulip A. (1997), "Resource scheduling", International Journal of Project Management, Vol.15, No. 6, pp. 359-70.https://doi.org/10.1016/S0263-7863(96)00090-7

[27]. Hariga M. and El-Sayegh S. M. (2010), "Cost optimization model for the multi-resource leveling problem with allowed activity splitting", Journal of Construction Engineering and Management, Vol. 137, No. 1, pp. 56–64.https://doi.org/10.1061/(ASCE)CO.1943-7862.0000251

[28]. Hariga M., Shamayleh A. and Wehedi F.E. (2019), "Integrated time–cost tradeoff and resources leveling problems with allowed activity splitting", International Transactions in Operational Research, Vol. 26, pp. 80-99.https://doi.org/10.1111/itor.12329

[29]. Hartmann S. (2001), "Project scheduling with multiple modes: A genetic algorithms", Annals of Operation Research, Vol. 102, No. 1–4, pp. 111–135.https://doi.org/10.1023/A:1010902015091

[30]. Hegazy T. and Menesi W. (2010) "Critical Path Segments Scheduling Technique", Journal of Construction Engineering and Management, Vol. 136, No. 10, pp. 1078-1085.https://doi.org/10.1061/(ASCE)CO.1943-7862.0000212

[31]. Hegazy T. and Menesi W. (2012), "Heuristic method for satisfying both deadlines and resource constraints", Journal of Construction Engineering and Management, Vol. 138, No. 6, pp. 688–696.https://doi.org/10.1061/(ASCE)CO.1943-7862.0000483

[32]. Heipcke S. (1999), "Comparing constraint programming and mathematical programming approaches to discrete optimization—The change problem", Journal of Operations Research Society, Vol. 50, No. 6, pp. 581–595.https://doi.org/10.1057/palgrave.jors.2600730

[33]. Herroelen W. and Leus R. (2005), "Identification and illumination of popular misconceptions about project scheduling and time buffering in a resource-constrained environment", Journal of the Operational Research Society, Vol. 56, No. 1, pp. 102–9.https://doi.org/10.1057/palgrave.jors.2601813

[34]. Herroelen W., Leus R. and Demeulemeester E. (2002), "Critical chain project scheduling do not oversimplify", Project Management Journal, Vol. 33, No. 4, pp. 48-60.https://doi.org/10.1177%2F875697280203300406

[35]. Izetbegovic J., Oreskovic M. and Bandic M. (2003), "Information Technology as a Tool in Construction Project Management", Croatian Association for Project Management SENET.

[36]. Izetbegovic J., Oreskovic M. and Bandic M. (2004), "Application and development of information technology in the civil engineering sector in Croatia", The Journal of Croatian society of civil engineers, Vol. 56, No. 8, pp. 481-488.UDK: 69.001.3:004.

[37]. Jarboui B., Damak N., Siarry P. and Rebai A. (2008), "A combinatorial particle swarm optimization for solving multi-mode resource constrained project scheduling problems", Applied Mathematics and Computation, Vol. 195, No. 1, pp. 299–308.https://doi.org/10.1016/j.amc.2007.04.096

[38]. Johnson R. V. (1992), "Resource constrained scheduling capabilities of commercial project management software", Project Management Journal, Vol. 22, No. 4, pp. 39–43.

[39]. Kandil A. and El-Rayes K. (2006), "MACROS: Multiobjective automated construction resource optimization system", Journal of Management in Engineering, Vol. 22, No. 3, pp. 126–134.https://doi.org/10.1061/(ASCE)0742-597X(2006)22:3(126)

[40]. Kastor A. and Sirakoulis K. (2009), "The effectiveness of resource levelling tools for Resource Constraint Project Scheduling Problem", International Journal of Project Management, Vol. 27, pp. 493–500.https://doi.org/10.1016/j.ijproman.2008.08.006

[41]. Ke H., Ma W. and Ni Y. (2009), "Optimization models and a GA-based algorithm for stochastic time-cost trade-off problem", Applied Mathematics and Computation, Vol. 215, No.1, pp. 308-313.https://doi.org/10.1016/j.amc.2009.05.004

[42]. Kim K. and De La Garza J. M. (2003), "Phantom float", Journal of Construction Engineering and Management, Vol. 129, No. 5, pp. 507–17.https://doi.org/10.1061/(ASCE)0733-9364(2003)129:5(507)

[43]. Kim K. and De La Garza J. M. (2005), "Evaluation of the resource-constrained critical path method algorithms", Journal of Construction Engineering and Management, Vol. 131, No. 5, pp. 522-532.https://doi.org/10.1061/(ASCE)0733-9364(2005)131:5(522)

[44]. Larson E. and Gray C. (2014), "Project Management: The Managerial Process (6th edition)", McGraw Hill, New York.

[45]. Leach L. P. (1999), "Critical chain project management improves project performance", Project Management Journal, Vol. 30, No. 2, pp. 39-51.https://doi.org/10.1177%2F875697289903000207

[46]. Leu S. S., Chen A. T. and Yang C. H. (2001), "A GA-based fuzzy optimal model for construction time-cost tradeoff", International Journal of Project Management, Vol. 19, No. 1, pp. 47–58.https://doi.org/10.1016/S0263-7863(99)00035-6

[47]. Liberatore M. J., Pollack-Johnson B. and Smith C. A. (2001), "Project management in construction: Software use and research directions", Journal of Construction Engineering and Management, Vol. 127, No. 2, pp. 101–107.https://doi.org/10.1061/(ASCE)0733-9364(2001)127:2(101)

[48]. Liess O. and Michelon P. (2008), "A constraint programming approach for the resource-constrained project scheduling problem", Annals of Operations Research, Vol. 157, No. 1, pp. 25–36.https://doi.org/10.1007/s10479-007-0188-y

[49]. Ling W. and Fang C. (2011), "An effective shuffled frog-leaping algorithm for multi-mode resource-constrained project scheduling problem", Information Sciences, Vol. 181, No. 20, pp. 4804–4822. https://doi.org/10.1016/j.ins.2011.06.014

[50]. Lu M. and Li H. (2003) "Resource-Activity Critical-Path Method for Construction Planning", Journal of Construction Engineering and Management, Vol. 129, No. 4, pp. 412-420.https://doi.org/10.1061/(ASCE)0733-9364(2003)129:4(412)

[51]. Lu M., and Lam H. C. (2008), "Critical path scheduling under resource calendar constraints", Journal of Construction Engineering and Management, Vol. 134, No. 1, pp. 25–31.https://doi.org/10.1061/(ASCE)0733-9364(2008)134:1(25)

[52]. Matthews M. (1994), "Resource scheduling: incorporating capacity into schedule construction", Project Management Journal, Vol. 25, No .2, pp. 44-54.

[53]. Mendes J. M. (2016), "Multi-objective Optimization of Construction Project Time-Cost-Quality Trade-off Using a Genetic Algorithm", WSEAS Transactions On Computers, Vol. 15, pp. 310-318.

[54]. Menesi W. and Hegazy T. (2015), "Multimode resource constrained scheduling and levelling for practical size projects", Journal of Management in Engineering, Vol. 31, No. 6, pp. 1-7.https://doi.org/10.1061/(ASCE)ME.1943-5479.0000338

[55]. Menesi W., Golzarpoor B. and Hegazy T. (2013), "Fast and near-optimum schedule optimization for large-scale projects", Journal of Construction Engineering and Management, Vol. 139, No. 9, pp. 1117–1124.https://doi.org/10.1061/(ASCE)CO.1943-7862.0000722

[56]. Mokhtari H., Bardaran R. and Salmasnia A. (2011), "Time cost trade off analysis in project management: an ant system approach", IEEE Transaction on Engineering Management, Vol. 58, No. 1, pp. 36-43.https://doi.org/10.1109/TEM.2010.2058859

[57]. Morris S. (1990), "Cost and time overruns in public sector projects," Economic and Political Weekly, Vol. 25, No. 47, pp. M154-M168.

[58]. Moselhi O. (1993), "Schedule compression using the direct stiffness method", Canadian Journal of Civil Engineering, Vol. 20, No. 1, pp. 65-72.https://doi.org/10.1139/l93-007

[59]. Nitithamyong P. and Skibniewski M. (2004), "Web-based construction project management systems: How to make them successful", Automation in Construction, Vol. 13, No. 4, pp. 491-506.https://doi.org/10.1016/j.autcon.2004.02.003

[60]. Pathak B. K. and Srivastava S. (2007), "MOGA-based time cost tradeoffs: responsiveness for project uncertainties," IEEE Congress on evolutionary computation, pp. 3085-3092.

[61]. Pereira A.M., Gonçalves R.Q., Von Wangenheim C.G. and Buglione L. (2013), "Comparison of open source tools for project management", International Journal of Software Engineering and Knowledge Engineering, Vol. 23, No. 2, pp. 189-209.https://doi.org/10.1142/S0218194013500046

[62]. Pinha D. C. and Ahluwalia R. S. (2018) "Flexible resource management and its effect on project cost and duration", Journal of Industrial Engineering International, Vol. 15, pp. 119–133.https://doi.org/10.1007/s40092-018-0277-3

[63]. Ponz-Tienda J., Yepes V., Pellicer E. and Moreno-Flores J. (2013), "The resource leveling problem with multiple resources using an adaptive genetic algorithm", Automation in Construction, Vol. 29, pp. 161–172.https://doi.org/10.1016/j.autcon.2012.10.003

[64]. Pour N. S., Modarres M. and Moghaddam R. T. (2012), "Time-cost-quality trade-off in project scheduling with linguistic variables", World Applied Sciences Journal, Vol. 18, No. 3, pp. 404-413.DOI: 10.5829/idosi.wasj.2012.18.03.874

[65]. Rand K. (2000), "Critical chain: The Theory of constraints applied to project management", International Journal of Project Management, Vol. 18, No. 3, pp. 173-177.https://doi.org/10.1016/S0263-7863(99)00019-8

[66]. Rao R. V. and Patel V. (2012), "Multi-objective optimization of heat exchangers using a modified teaching-learning-based optimization algorithm", Applied Mathematical Modelling, Vol. 37, No. 3, pp. 1147-1162.https://doi.org/10.1016/j.apm.2012.03.043

[67]. Rao R. V., Savsani V. J. and Vakharia D. P. (2011), "Teaching-learning based optimization: A novel method for constrained mechanical design optimization problems", Computer Aided Design, Vol. 43, No. 3, pp. 303-315.https://doi.org/10.1016/j.cad.2010.12.015

[68]. Roztocki N. and Weistroffer H. (2008), "Information technology in transitional economies - Editorial Preface", Journal of Global Information Technology Management, Vol. 11, No. 4, pp. 2-9.https://doi.org/10.1080/1097198X.2008.10856476

[69]. Senouci A. B. and Adeli H. (2001), "Resource scheduling using neural dynamics model of Adeli and Park", Journal of Construction Engineering and Management, Vol. 127, No. 1, pp. 28–34.https://doi.org/10.1061/(ASCE)0733-9364(2001)127:1(28)

[70]. Shtub A., Bard J. and Globerson S. (1994), "Project management: engineering", technology and implementations, Prentice Hall, New Jersey.

[71]. Siemens, N. (1971), "A Simple CPM Time-Cost Tradeoff Algorithm", Management Science, Vol. 17, pp. 354-363.https://doi.org/10.1287/mnsc.17.6.B354

[72]. Silva G. A. S. K., Warnakulasuriya B. N. F. and Arachchige B. J. H. (2016), "Criteria for Construction Project Success: A Literature Review", 13th International Conference on Business Management.

[73]. Sonmez R. and Bettemir O. H., (2012). "A hybrid genetic algorithm for the discrete time–cost trade-off problem", Expert Systems with Applications, Vol. 39, No. 13, pp. 11428–11434.https://doi.org/10.1016/j.eswa.2012.04.019

[74]. Sunde L. and Lichtenberg S. (1995), "Net-present-value cost/time tradeoff", International Journal of Project Management, Vol. 13, No. 1, pp. 45-49.https://doi.org/10.1016/0263-7863(95)95703-G

[75]. Taha H. A. (2000), Operations research, 7th Edition, Prentice-Hall, Upper Saddle River (NY).

[76]. Toğan V. and Eirgash M. A. (2019), "Time-Cost Trade-off Optimization of Construction Projects using Teaching Learning Based Optimization", KSCE Journal of Civil Engineering, Vol. 23, No. 1, pp.10-20.https://doi.org/10.1007/s12205-018-1670-6

[77]. Travica B., Jošanov B., Kajan E., Bubanja M. V. and Vuksanovigc E. (2007), "E-Commerce in Serbia: Where Roads Cross Electrons Will Flow", Journal of Global Information Technology Management, Vol. 10, No. 2, pp. 34-56. https://doi.org/10.1080/1097198X.2007.10856443

[78]. Tsai D. M. and Chiu H. N. (1996), "Two heuristics for scheduling multiple projects with resource constraints", Construction Management and Economics, Vol. 14, pp. 325-40.https://doi.org/10.1080/014461996373403

[79]. Van Peteghem V. and Vanhoucke M. (2010), "A genetic algorithm for the preemptive and non-preemptive multi-mode resource-constrained project scheduling problem", European Journal of Operation Research, Vol. 201, No. 2, pp. 409–418.https://doi.org/10.1016/j.ejor.2009.03.034

[80]. Wei-Xin W., Xu W., Xian-Long G. and Lei D. (2014), "Multi-objective optimization model for multi-project scheduling on critical chain", Advances in Engineering Software, Vol. 68, pp. 33-39.https://doi.org/10.1016/j.advengsoft.2013.11.004

[81]. Xiong Y. and Kuang Y. (2008), "Applying an Ant Colony Optimization Algorithm-Based Multi-objective Approach for Time-Cost Trade-Off", Journal of Construction Engineering and Management, Vol. 134, No. 2, pp. 153-156.https://doi.org/10.1061/(ASCE)0733-9364(2008)134:2(153)

[82]. Yang Q. (2009), "Application of Time-Cost-Quality Tradeoff Optimization Model Based on Improved PSO Algorithm to Construction Project", Asia-Pacific Conference on Information Processing, IEEE Computer Society Washington, Vol. 2, pp. 298-301.https://doi.org/10.1109/APCIP.2009.210

[83]. Zamani R. (2017), "An evolutionary implicit enumeration procedure for solving the resource-constrained project scheduling problem", International Transactions in Operations Research, Vol. 24, No. 6, pp. 1525–1547.https://doi.org/10.1111/itor.12196

[84]. Zhang Y. and Ng S. (2012), "An ant colony system based decision support system for construction time-cost optimization", Journal of Civil Engineering and Management, Vol. 18, No. 4, pp. 580–589.https://doi.org/10.3846/13923730.2012.704164