

COMPARATIVE ANALYSIS BETWEEN CRITICAL PATH METHOD AND MONTE CARLO SIMULATION

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Abstract - Time is a major factor in almost all areas of engineering. Every project is estimated for the completion time required based on the tasks and objectives involved for its execution. Project management enterprises mainly work on completing a project by the set schedule. A constant evolution has been made in determining the completion time of every project to best suit the real time execution. The techniques involved to determine the time of completion are critical path method, program evaluation and review technique, precedence network analysis and Monte Carlo simulations. These methods are employed based on the risk and uncertainty involved in the projects. The objective of this project was to analyse the difference between the critical path method and the Monte Carlo simulation. For this purpose a live project was taken up and the activities involved in the project were listed. The project completion time using the critical path method was found out using Microsoft Project 2013, while the project completion time using the Monte Carlo simulations was found out using Oracle Crystal Ball Software. The results obtained from the both the softwares were compared to determine the percentage difference. Based on the variance between the actual and scheduled durations, the durations for the three time estimates were modified and the simulations were performed again to determine the probable completion time of the project. The results were obtained and conclusions were made on the applicability of Monte Carlo simulation in the Construction Industry.

Key Words: Construction project, Scheduling, Critical Path Method, PERT, Monte Carlo simulation, Project Tracking.

1. INTRODUCTION

Construction has made numerous marvels on the planet and has imbibed numerous technologies for the advantage of the humankind. Construction is a noteworthy segment of the new ventures. The construction industry is fundamental for the development of the economy of any nation. The construction of capital intensive projects is always undertaken by 'projectising' them, i.e. to create a work break down structure of the project into activities or events for smooth execution of the project.

The most important factors that govern the success of any construction project are planning, scheduling, monitoring and controlling. The planning involves understanding the

client's view of the project and developing and designing a plan accordingly, which is followed by estimating the quantity of work and formation of a contract. The scheduling involves the estimation of the complete project duration and creating a database for updating of actual progress. In the monitoring phase the work is performed according to the schedule prepared, lag and lead in activity times is adjusted to keep the project on track. Controlling phase involves applying additional resources on activities that would otherwise prolong the project. This particular paper however deals with the scheduling phase of a project. The various methods used to schedule a project are critical path method, program evaluation and review technique and Monte Carlo simulation.

1.1 Critical Path Method

The critical path method is a well ordered venture administration procedure to recognize activities on the basic way. It is a way to deal with venture planning that breaks the undertaking into a few work assignments, shows us a stream outline, and afterward ascertains the task term in light of evaluated lengths for each errand. It basically tells us the longest path/duration of the project. It is used for deterministic events and has just one time estimate for each activity. It is abbreviated as CPM.

A set of sample activities were considered for understanding the working of this process. The durations were assumed and loaded for each activity. Further the computation was done by calculating the earliest start time, earliest finish time, latest start time and latest finish time. Basically the earliest start time (EST) is the time by which a project can start and earliest finish time (EFT) signifies that an activity can finish by that particular time and is calculated as EST + activity duration. The latest start time (LST) and latest finish times (LFT) signify that the activity has to compulsorily start or finish by that particular time; otherwise the project could be delayed. Latest start time is calculated as the difference between LFT and activity duration and the Latest finish time is calculated using the backward pass method. In the backward pass method the EST and EFT are considered same and the preceding activity duration is subtracted to find the LFT of the preceding activity. Basically the activities whose EST, LST and EFT, LFT are the same are critical activities and take the most time to complete the project. A network diagram connects all the activities and represents their interdependencies.

1.2 Program Evaluation and Review Technique

This technique is also abbreviated as PERT. The activities of the project and their network relationships are well defined but it allows uncertainties in activity durations. It is extremely difficult in today's scenario to determine the exact time one activity may take as there are a lot of uncertainties involved. Therefore there are three time estimates for every activity that take into account these uncertainties which are described as follows:-

a) Optimistic time: It is the minimum possible time which an activity requires for its completion under ideal conditions. In other words, it is the shortest time required for activity completion assuming that everything during its execution will go right. It does not include any sort of setback or delay. It is denoted as t_o .

b) Pessimistic time: It is the maximum possible time that an activity requires for its completion or the longest estimated time period of an activity completion. It estimates time assuming that lack of resources would be there and so the activity may take excess time for completion than actually required. It is denoted as t_p .

c) Most likely time: It is the most probable time or simply a more realistic time that an activity requires for its completion. It normally considers a few delays which is common for project execution. It is denoted as t_m .

d) Expected time or Average time: It is the weighted average time of the optimistic, pessimistic and most likely time, or is basically converting the three time estimates to one time estimate. It is denoted as T_e . The formula for its calculation is given below.

$$T_e = \frac{t_o + 4t_m + t_p}{6} \text{ where } t_o \leq 4t_m \leq t_p$$

Once the expected time is calculated, it can be loaded back into the network diagram from which the project completion time is determined.

1.3 Monte Carlo Simulations

This technique works on the basis of probability distributions and is a large amalgamation of statistics, theoretical probability and random number generator. Although it involves complex algorithms for calculation of results, the working of it is quite straight forward. Suppose we want to know the probability that a combination of activities will occur we input into the system all the three time estimates of all the activities along with their respective variance. The Monte Carlo simulation will generate a set of random numbers between 0 and 1 and match those numbers with the probability of the occurrence of the activity time. Suppose the probability of

the activity is 0.9 and the random number generated is 0.9, the system will simulate that the activity will occur. Thousands of such simulation can be run within the system to find the combination of the frequently occurring results. For instance if a 1000 trials were run and 900 trials returned the same result then that would be the final output of the simulation. In a nut shell we humans understand three time estimates but a system understands the three time estimate data in the form of probability distribution. The probability allows the system to randomly select values from the probability distribution chart and compute the output. The concept of randomness is emphasized in the simulation to imitate the real life scenario which is basically random meaning anything could happen at any time.

2. LITERATURE REVIEW

The concept of this project was derived from reference through various research papers that dealt with the application of Monte Carlo Simulation in Construction Industry. The work done by various researchers in this area is briefly discussed by extracting relevant information. Although the concept is similar the work done by the respective researchers is unique in its own way. The researchers have applied the concept of Monte Carlo simulation to projects with different constraints to obtain their desired outcomes and therefore present their conclusions on the applicability of this simulation in the field of construction.

K K Chitkara has in his book discussed the application of probability distributions and Monte Carlo simulations in determining project completion time. From his discussion one cannot be sure of the actual value of the project completion time in the initial stages of the project and therefore probability distributions help to quantify the uncertainties in a project. The application of Monte Carlo simulation which is meant to imitate real life situations was also detailed. The simulations are based on the probability distributions. The results from the simulation represent the uncertainty in the entire project.

K. Kirytopoulos *et al.* have in their research made a comparison between the application of PERT and Monte Carlo simulation in low risk projects. They concluded that the simulation techniques allow for more efficient modeling of the project than the conventional methods such as critical path method and PERT.

Goran Avlijaš has in his paper dealt specifically with the application of Monte Carlo simulation on Project time management. He found that the Monte Carlo simulations help in addressing the uncertainties in the project time and networks to obtain a reasonable duration. The durations estimates according to him can be more accurate when risk adjusted schedules are used. Crystal Ball software was used for applying the Monte Carlo simulation, he assumed that the random variables follow a

Beta PERT distribution. A 1,000 trials were run and the project completion time was found to be 45.89 days, and the critical path duration was found to be 43 days. The variation according to him was because of the path mergers. He also determined the probability of completing the project in 50 days and found it to be 77.69%. He finally concluded that Monte Carlo simulation was a useful tool in estimating project activities.

Pratik Ganame and Pravin Chaudhari have in their work focused on risk identification by performing quantitative and qualitative analysis. Their objective was to identify key risk factors that affect project schedule and also to determine the probability of completing the project within the scheduled date. The qualitative analysis was done by probability impact matrix and the quantitative analysis was done by PERT and Monte Carlo simulation using software called @RISK by Palisade corp.

Rafiq M. Choudhry, *et. al*, have in their research identified and analysed risks associated with bridge construction in Pakistan. They started off by identifying various risks associated with a construction project and categorised them under seven main sections which were distributed in the form of questionnaires to engineers to determine the impact of risks on the construction. The feedback was used to create risk adjusted schedules. The simulation was performed and the system generated schedule and cost outputs were compared to the actual progress of the project. This comparison showed that the simulation results very nearly accurate with the actual project progress of the project than the planned Critical Path Method. Therefore the researchers concluded that a risk analysis must be performed and loaded with the project schedule to determine a more realistic schedule and cost. Nurazin Jupri and Muhammad Rozi Malim had conducted a case study on a medical campus, in which they analysed the various risk management processes associated with the construction of the campus. They identified two major risk factors following which they performed schedule analysis using PERT and Monte Carlo simulation. They concluded that the project had a very low probability for on time completion.

3. METHODOLOGY

The implementation was done on a live project, which is a prayer hall having an area of 5000 sq ft. The first approach was to create a sequence of activities that are to be followed for the execution of the project, the second was to take in account the number of days each activity would require for completion. The next process involved loading all of the activities with their respective durations into Microsoft project, which is project management software. This is done to determine the critical path and understand the total project completion time, as doing this manually would be an arduous task. Specific settings are made to obtain the required output. Thereafter three time durations are assigned for each activity, the optimistic

time, the most likely time and the pessimistic time. These are then loaded with the activities into crystal ball, which is basically a simulation software. A simulation is run to determine the project completion time by that method, also the probabilities of completing the project at any given time is determined. The percentage difference between the two time estimates is computed. Lastly the actual progress of the project is compared with the two time estimates to understand the accuracy of those time estimates.

3.1 Project duration using Critical Path Method

The process followed to load the durations for each activity was to first create a calendar within Microsoft Project that matches the start time of our first activity. The working days were set from Monday to Saturday with a daily working time of eight hours. The work was expected to start from 9:00 AM in the morning till 6:00 PM in the evening. The lunch break of one hour was given from 1:00 PM to 2:00 PM. Sunday was designated as a non-working day. The next task was to set holidays within the calendar anticipating the absence of workers on those days. Once the calendar was prepared it was assigned to the project. The start date was taken as the 14th of December 2017. The next most important step was to assign the activity precedence relationship which basically signifies which activity is to be executed after the completion of a particular activity. Activities can start successively or simultaneously. For instance bar bending of reinforcements required for footings can start while the excavation of the soil is happening, also the bar bending of plinth beam reinforcements can happen simultaneously with the backfill of excavated earth. However the backfill of soil can only happen after the curing of footing concrete which is a successive order. Therefore it was important to establish this in order to obtain a critical path. Then the precedence relationship was established, as shown in figure 1.

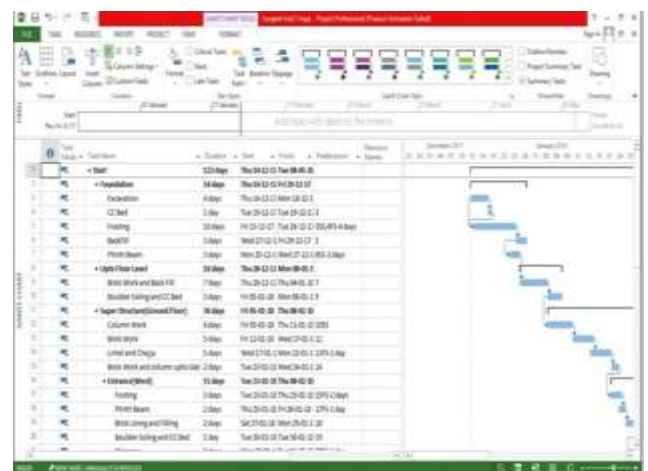


Fig -1: Activities with their durations and precedence relationship

Then few activities were made to start after a certain completion of their preceding activities, for instance placing of the reinforcing bars and their formwork for footing can happen only after the pouring of P.C.C bed, but the bar bending can start while the excavation has started and can continue till the pouring of P.C.C bed. This process of making an activity start after a certain completion of its preceding activity is known as lead and lag of activities. Lead is when an activity can start before its scheduled time and lag is when an activity can start after its scheduled time. In this project the use of lead time was mainly done as a couple of activities could be started in this manner. The bar bending work mainly, could start in conjunction with the preceding activities, in this case a lead time of 4 days was given to footing activity which is a successor activity to both excavation and P.C.C bed, so the relationship given was that it could start with excavation and could also start 4 days before P.C.C bed, however P.C.C bed can start only after excavation. Similarly another activity, which is again the lintel and chejja activity, is made to start with a lead of 1 day while the brickwork is nearing completion.

3.2 Project duration using Monte Carlo simulation.

The optimistic time, most likely time and the pessimistic time was determined. The most likely time for the activities was considered same as the one time duration given by the contractor. The pessimistic time was given by taking into account by considering various factors such as labour shortage, delay in supply of material, shortage of funds, and absence of labour and reconstruction of some structures because of faulty construction that could happen in every activity. For instance the execution time for excavation could take more days than required if only three labourers are employed instead of five labourers; also as procuring natural sand can delay the start of most activities that are dependent on it. The next scenario could be that the clients fall short of funds which causes a break in the project, also the staff of labourers employed may be under experienced or may have in a hurry caused flaws in the construction process. Hence there are many situations that could prolong the duration of any activity. On the other hand, the optimistic time is a complete contrast to the assumptions made for deciding pessimistic time. For instance, given the area of the site, the excavation of earthwork can happen in a day if an excavator is employed. Also instead of procuring natural sand manufactured sand can be procured. Activities may be completed sooner by employing more labourers or the efficiency of labourers may be on the higher side. All the three time estimates have been decided by consulting professionals and have been loaded into the Crystal Ball software.

The new action here was to establish the activity dependence as many activities were given start to start relationships with lead time, it was done by giving the

same start time of the preceding activity and the lead time was subtracted to get the exact start time of the successive activity. This computation was performed for all the activities that had those activity dependencies. Activities that had a finish to start relationship were simply assigned the end time of their preceding activity.



Task ID	Task Name	Predecessors	Duration Estimates	Start	Duration	End
			O _t M _l P _s			
1	Excavation (Foundation)		1 20 1			
2	CC Bed (Foundation)	1	0.71 11 8			
3	Forming (Foundation)	1, 2, 3, 4	0.11 11 10			
4	Reinforcement (Foundation)	1	1 20 1			
5	Plumb Line (Foundation)	4, 5	0 21 17			
6	Check Work and Check RB (Type Bar level)	5	0 21 17			
7	Reinforce Siding and CC Bed (Type Bar level)	6	0 21 17			
8	Column Work (Super Structure)	7, 8	0 17 11			
9	Check Work (Super Structure)	9	0 17 11			
10	Lintel and Chejja (Super Structure)	9, 10	0 8 7			
11	Check Work and column up to date (Super)	10	1 1 1			
12	Forming (Structure)	11, 12	0.1 1 1			

Fig -2: Data input into Crystal Ball Software

The next step was to define the distribution assumption that the activity should follow. Subject matter experts suggest that a Beta PERT assumption must be implemented as it predicts results more accurately. A representation of this has been shown in figure 3, when this distribution is selected a dialogue box appears in which the three time estimates are entered.



Fig -3: Applying Beta PERT assumption

Finally when the assumption is applied to all the activities, The Monte Carlo simulation is run to obtain the project completion time. For accurate estimate of the time 10,000 trials were run. The results thus obtained from the Monte Carlo simulations method are compared with the results obtained from the critical path method.

4. RESULTS AND DISCUSSION

The basic intention was to make a comparison between the critical path method and the Monte Carlo simulation. For this a live project was taken up and the two methods were implemented to find the total project duration. Various efforts were made during the execution of this project, the outputs were obtained and have been analysed as to how they may be helpful in bettering our way of time estimation.

4.1 Results obtained from Critical Path Method.

The results were obtained by entering the activities into Microsoft project software, version 2013. Basically the critical path, which is the longest duration of the entire project was estimated from this software. This is represented in figure 4.

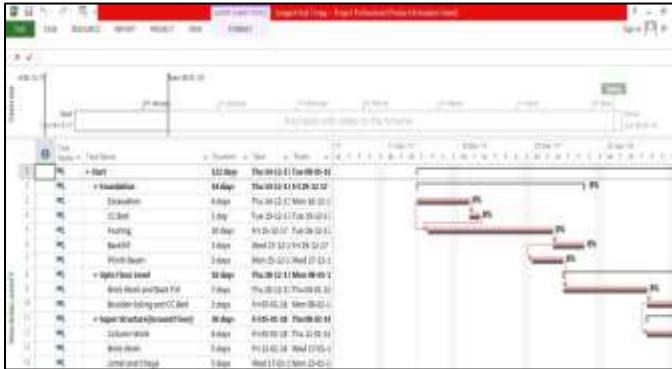


Fig-4: Critical Path duration of project

The total duration of the entire project was found to be 122 days which is approximately 4 months, the project was planned to start on 14th December 2017 and is expected to complete on 8th April 2018. This output was generated by taking into consideration all the constraints in the form of lag and lead times.

The non-critical activities are electrification, ground floor internal plastering, first floor internal plastering all three of which have a slack time of 1 day and ground floor windows has a slack time 18 days. This means that the activities can be delayed to their respective slack days without causing a delay to the entire project. However a delay in the other activities which are critical will cause a delay to the entire project.

4.2 Tracking of Project Progress

The project was monitored during its execution and the progress was updated in Microsoft project. This was done because usually the project varies from its scheduled time. The tracking is represented in figure 5.



Fig-5: Actual project progress

The total project completion time turns out to be 186 days which is approximately 6.1 months. Therefore there is a variance of 2.1 months from the scheduled duration.

The footing activity takes 25 days for completion instead of 10 days, also the difference between the scheduled start and actual start of backfill activity is 25 days, 43 days for plinth beam, 54 days for backfill and brickwork up to floor level, 79 days for boulder soling and cement concrete bed, 107 days for column work and 69 days for brickwork till lintel level.

Also the completion of the brick work up to lintel level happened before the start of column concreting, the sequence of which differs from the scheduled sequence in which the brickwork follows the completion of the column concreting.

The total project duration variance of 2.1 months was mainly caused due to the delay in the activities during 30% completion of the project.

4.3 Results obtained from Monte Carlo simulation

This method basically depends on three time estimates for every activity. A graph was generated which follows the Beta PERT distribution by running the simulation which is represented in figure 6. A cumulative frequency graph was generated to easily understand the frequency of trials and probabilities, as shown in figure 7. The probability of completion can be found at any given day.

The project completion time is forecasted to be completed in 126.05 days which is approximately 4.14 months with a 50% probability. That is because the average result of all the 10,000 trials is 126.05, which is represented as the mean.

The forecast is presented as a mean which is the central tendency of the distribution, also it can be noted from the graph that the standard deviation is 5. That is the dispersion of values from the mean occur by 5 units.

The cumulative frequency graph represents the total trials performed along the right y-axis and the respective probabilities along the left y-axis.

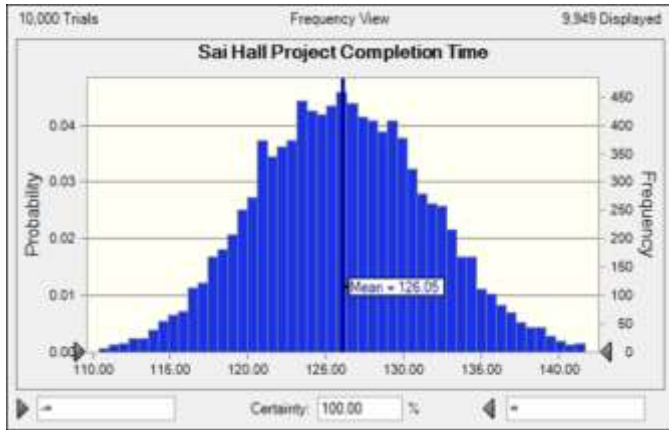


Fig -6: Bell Curve representing project completion time

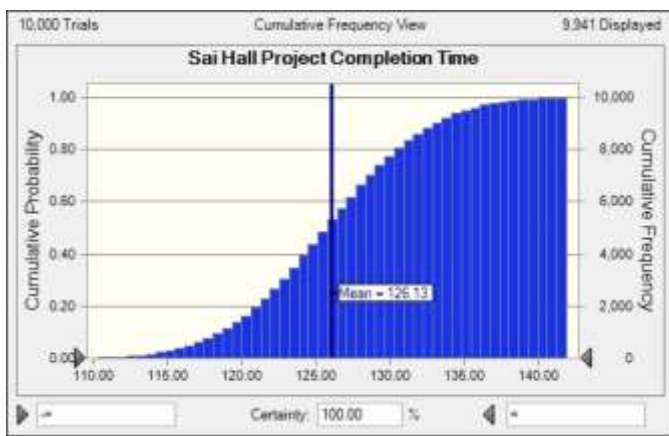


Fig -7: Cumulative frequency graph completion time
 Since the completion time by critical path method was found to be 122 days, the probability of completing the project by this duration was determined and was found to be 24.19% which is shown in figure 8.

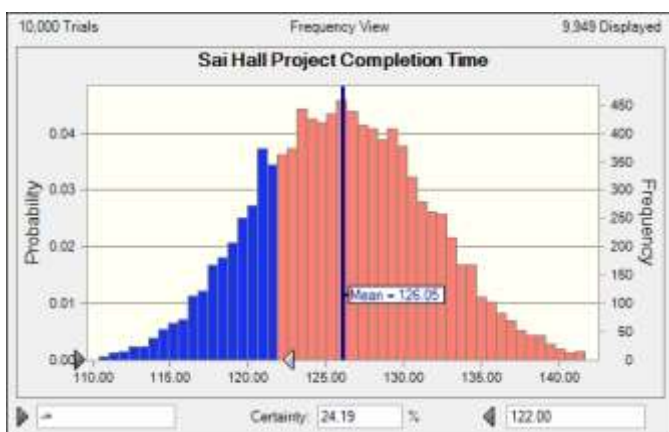


Fig -8: Probability completion at 122 days

As the project was monitored during its execution the delays were re-entered as the most likely value and the pessimistic time was taken by considering both the delay and the completion time. After running the simulations assuming a Beta PERT distribution the completion time

was forecasted at 376.85 days which is approximately 12.4 months. This is represented in figure 9.

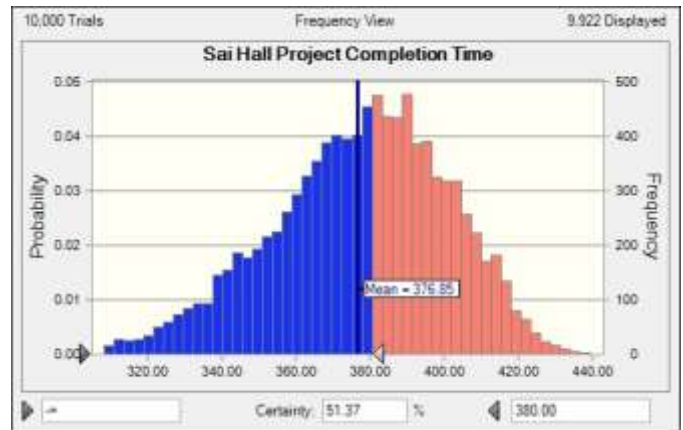


Fig -9: Probability completion after tracking

5. CONCLUSIONS

The implications of time estimation of a project was analysed in this project by using critical path method and Monte Carlo simulation. This project laid emphasis on the impact of time estimates on project and not the implications cost of resources would have on the project. Tracking of a live project was done to analyse the difference between the time estimates made and the actual time taken. Each method have their own unique results. Variation in certain parameters was made to analyse the change in the results obtained.

The project completion time by the critical path method was found to be 122 days that is 4 months and the completion time by the Monte Carlo simulation was found to be 126.05 days that is 4.2 months. Therefore the percentage difference between the two estimates turns out to be 3.26%. Thus the two estimates were almost the same. This is because the most likely time for the Monte Carlo simulation was taken same as the one time estimate from the critical path method, also the variation between the optimistic and pessimistic times was not high. Therefore the variation isn't much.

The project progress was tracked till 30% completion and the duration was compared with the estimated durations by both the methods. The total project duration turned out to be 186 days which varies by 41.55% from the critical path estimate and 38.42% from the Monte Carlo simulation. This basically depicts that the project was not executed according to the planned dates. As the project was monitored the delay was found to be caused mainly by the irregularity of labourers and also the supply of materials to the site was delayed by nearly 2 months as the suppliers didn't have the required stock.

Based on the actual progress of the project, changes in the most likely time and pessimistic time were made by considering the sum of delays and the time for completion

as most likely time and an approximate duration was estimated for pessimistic time by considering longer delays and same durations for completion. These times were entered into the software and simulations were run again. The project duration now was found to be 376.85 days and has a zero probability of completion within 187 days. This variation was because the difference between the optimistic and pessimistic value is large. However this estimate should be considered carefully as the project is small and will be completed within a year, nevertheless shortage of funds could prolong the completion time of the project.

The Monte Carlo simulations are only as good as the time estimates. Therefore the optimistic, pessimistic and most likely values must be estimated with a good judgment, which requires a good amount of experience in project management. The technique complexity in applying the critical path method was simple as it had just one time estimate, whereas the Monte Carlo simulation is relatively difficult as three time estimates had to be made.

REFERENCES

- [1] Goran Avlijaš, "Examining the Value of Monte Carlo Simulation for Project Time Management", *Management: Journal of Sustainable Business and Management Solutions in Emerging Economies*, 2018.
- [2] G Lique, J Lozano, M Cascales, "Decision-Making for Risk Management in Sustainable Renewable Energy Facilities: A Case Study in the Dominican Republic", *Sustainability* 2016, pp. 1-21.
- [3] J Wang, Y. Wu and D Haung, "Major Earthquakes around Taipei and a Seismic Hazard Assessment with Monte Carlo Simulation", *Natural Hazards Review*, Volume 16, Issue 4, November 2015, pp. 1-7.
- [4] K. Kirytopoulos, V. Leopulus and V. Diamantas, "Pert versus Monte Carlo simulation in low risk projects", *CME 2007 Conference - Construction Management and Economics: 'Past, Present and Future'*. 1419-1427.
- [5] K K Chitkara, "Construction Project Management", third edition, Mc Graw Hill Education (India) Private Limited, 2014.
- [6] Nurazin Jupri and Muhammad Rozi Malim. "Risk Analysis of Construction Project Scheduling using PERT and Monte Carlo Simulation: A Case Study on NIOSH Campus", *International Journal of Accounting and Business Management*, ISSN: 2289-4519, Volume 1, April 2013, pp. 83-91.
- [7] Pratik Ganame and Pravin Chaudhari, "Construction Building Schedule Risk Analysis Using Schedule Risk Analysis", *International Research Journal of Engineering and Technology*, Volume 2, Issue 4, July 2015, pp. 1402-1406.
- [8] R Choudhry, M Aslam, J Hinze and F Arain, "Cost and Schedule Risk Analysis of Bridge Construction in Pakistan: Establishing Risk Guidelines", *Journal of Construction Engineering and Management*, Volume 140, Issue 7, July 2014, pp. 1-9.
- [9] T Ersahin, B Macabe and M Doyle, "Monte Carlo Simulation Analysis at Lester B Pearson International Airport Development Project", *Construction Research Congress*, 2003, pp. 1-8.
- [10] Z Kong, J Zhang, C Li, X Zheng and Q Guan, "Risk Assessment of Plan Schedule by Monte Carlo Simulation", *International Conference on Information Technology and Management Innovation*, 2015, pp. 509-513.