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Analysis of Probabilistic Times In A Construction Project Using Monte Carlo Simulation Technique

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Abstract

The general requirement in day to day construction management is availability of a reliable schedule. Many models have been tested from time to time. Many among them have been found reliable. In this study yet another model which is based on Monte Carlo principles is put to test theoretically. A case study of a project which is in process is chosen. The project had a well laid out schedule already. In middle of the project the completed portion of project is studied and the same is compared with interpreted schedule for same based on Monte Carlo Simulation method. This comparison will suggest how reliable the schedule is. The main objective of this study is to develop a tool so that any change necessary in the schedule can be identified and brought up before it is too late in the project.

Introduction

The control of project schedule and cost is a vital part in construction projects, especially for those projects which consider project time and budget as targets. Delivering project on-time or not has much to do with earning or losing a profit and/or a return on investment for parties. The result of manual scheduling is usually exactly one schedule because the manual creation of construction schedules is very time consuming. Engineers involved in managing construction deal with the production aspects of realizing a facility.

Without reliable predictions on the quality, cost, duration, and safety impacts of a suggested change, the designers and contractors cannot accurately plan their activities or allocate the associated costs and benefits. During manual scheduling most of the decisions that are made are based on empirical values. In general, theses values are neither formalized nor stored, because they are the result of the planner’s experience.

To improve both the construction process and the performance of the completed facilities, innovative designs and technologies are constantly being developed and introduced into the design and construction industry.

Objectives and Scope

- To identify, analyze and assess possible project risks to develop risk mitigation and contingency plans for complex project.
- To quantify the effects of risk and uncertainty in project schedules and budgets, giving the project manager a statistical indicator of project performance.
- To apply it further to the areas like time management (scheduling) & cost management (budgeting)

This study will help us to develop a model which will quantify the probabilistic variables in a construction project & their impact on the project performance so that inference can be drawn in order to take corrective actions beforehand. It will help to improve the overall project performance.

Simulation Workflow

Using simulation for construction scheduling requires several pre-processing steps. During Pre-processing, information available about the construction project needs to be analyzed and prepared. The result of the pre-processing steps is used as input data for the simulation and is stored in a simulation database. The simulation database is the central access point for all simulation components during the entire workflow. After pre-processing, the construction simulation can be performed using any suitable simulation software. The simulation results are also stored in the database to allow systematic evaluation.

During evaluation, the input data and assumptions have to be checked for accuracy and the results have to be compared with the objectives of project planning. Although the result of each simulation run is technologically feasible, it might be contradictory to certain project objectives, such as cost or allowed execution time.

To generate different alternatives or change assumptions, the pre-processing must be performed again based on the results of the previous simulation. The generation of efficient solutions is usually an iterative process.

A) Monte Carlo Simulation

One method used by some project managers to handle the difficult situations that occur in execution of a construction project and to successfully complete that project com is Monte Carlo Simulation. It is a useful technique for modeling and analyzing real-world systems and situations.

In a construction project, we can estimate the time it will take to complete a particular job based on some expert knowledge, we can also estimate the absolute maximum time it might take, in the worst possible case, and the absolute minimum time, in the best possible case.

The key feature of a Monte Carlo simulation is that it can tell us based on how we create the ranges of estimates how likely the resulting outcomes are. This thesis reviews the applications of Monte Carlo simulation in preparing schedule of activities involved in a construction project and to an extent of its application in cost control and concludes with a recommendation that more project managers should take advantage of this simple and useful tool in managing project schedule and cost.

If the same model were based on ranges of estimates for each of the parts of the project, the result would be a range of times it might take to complete the project. When there is a range of values as a result, there is a beginning of understanding the risk and uncertainty in the model.

B) Steps of Simulation

- Establishing probability distribution for important input variables.
- Build a cumulative probability distribution for each variable.
- Establishing an interval of random numbers for each variable.
- Generating random numbers.
- Simulating a series of trial.

Methodology of Study

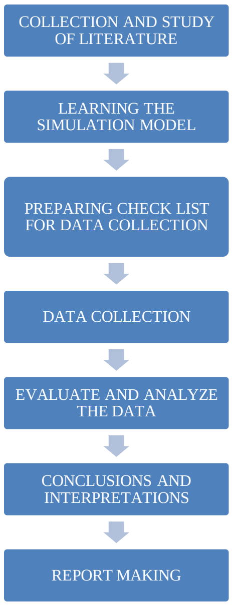

Figure 1: Methodology of study - flowchart

Step 1: Collection and study of literature

The first step in the work will be doing a literary study regarding Monte Carlo Simulation and its application in infrastructure field. From those experiences from various people who worked on the same topic we will take out the various things done and I will plan the work procedure accordingly.

Step 2: Learning the Simulation Method

From text books and previous woks we will learn the procedure to do simulation in MS excel software in detail.

Step 3: Preparing Check list for data collection:

Based on the scope of our work and data required for my thesis I will prepare a check list and will determine what approaches to use to examine in depth and which instruments and data gathering approaches to use. Tools to collect data can include documentation review, observation, and even the collection of physical artefacts.

Step 4: Data Collection

In a systematic way I will collect the data in the formats that I finalize. Renegotiation of arrangements with the objects of the study or addition of questions to interviews may be necessary as the study progresses. Case study research is flexible, but when changes are made, they are documented systematically.

Step 5: Evaluate and analyze the data

Specific techniques include placing information into arrays, creating matrices of categories, creating flow charts or other displays, and tabulating frequency of events. I will use the quantitative data that has been collected to corroborate and support the qualitative data which is most useful for understanding the rationale or theory underlying relationships.

Step 6: Conclusions and Interpretations

Based on the data analyzed I will come to know about the present application and method in which simulation technique is used and I will suggest valid points or ways which will improve the application this technique along with proper justifications.

Simulation Procedure

Step 1.Describe system probability distributions

Describe the system and obtain the probability distributions of the relevant probabilistic elements of the system. This step requires intimate familiarity with the system and incorrect assumptions at this point invalidate the rest of the simulation.

Step 2.Decide on the measures of performance

Define the appropriate measure of system performance. If necessary, write it in the form of an equation. This depends on the objective. System reliability studies focus on unsaved energy and loss of load indices. Investment feasibility studies generally focus on average energy prices and plant capacity.

Step 3.Compute cumulative probability distributions
Construct cumulative probability distributions for each of the stochastic elements.

Step 4.Assign representative ranges of numbers
Assign representative numbers in correspondence with the cumulative probability distributions.

Step 5.Generate random numbers and compute the system's performance
For each probabilistic element, take a random sample.

Step 6.Compute measures of performance
Derive the measures of performance. Each Monte Carlo simulation run is composed of multiple iterations. The question of the number of iterations required involves statistical analysis. The larger the number of iteration, the more accurate the results, but it takes more time and the cost is higher. This issue concerns what are labeled as stopping rules.

Step 7.Stabilization of the simulation process
Simulation begins to represent reality only after stabilization has been achieved. Therefore, we distinguish a start-up period during which the data results are not yet valid. The length of the simulation must be sufficient for the system to reach stability.

Step 8.Repeat steps 5 and 6 until measures of system performance stabilize
When the differences between each sample's indexes of measure, say loss of load probability (LOLP), average prices or other index, becomes small or insignificant, then the process is said to have stabilized. The significance level is set typically by management. Generally, the Monte Carlo procedure involves generating a large number of realizations of the underlying process and, using the law of large numbers, estimating the expected value as the mean of the sample.

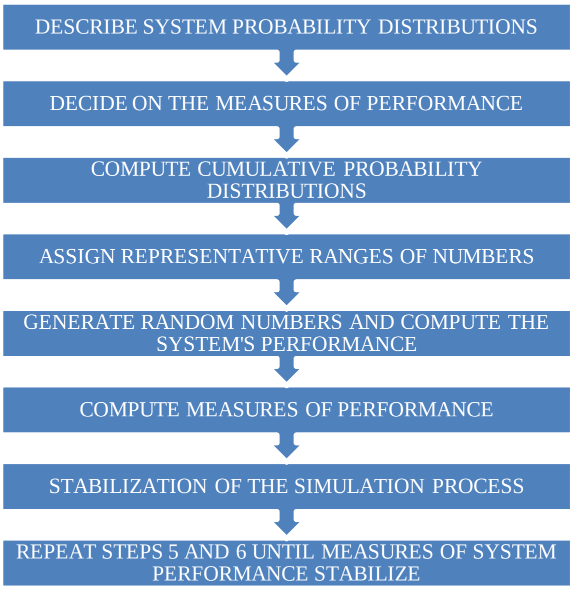

Figure 2: Monte Carlo Simulation procedure flowchart

Case Study

Chennai metro rail project is a joint venture of Government of India and State Government. Phase 1 of the CMRL project consists of two corridors with a combined length of 45kms. Corridor-1 with a length of 23kms (14.3kms underground and 8.7kms elevated) runs from Wahsermenpet to the Airport via Anna Salai. Corridor-2 with a length of 22kms runs from Chennai Central to St. Thomas Mount via Koyambedu.

The portions of Corridor-1 from Washermenpet to Saidapet on Anna Salai and Corridor2 to periyar EVR salai and Anna Nagar 2nd avenue is underground and the remainder is elevated. The total length of the underground section is 24kms with 19 underground stations.

Chennai Metro Rail Limited awarded a tender in 2011 to M/s. Larsen and Toubro, in joint venture with Shanghai Urban Construction Group (SUCG) for the design and construction of 3.342kms of Twin tunnels including three underground stations at Nehru Park, Kilpauk Medical College and Pachaiyappa's College. The work on the site by M/s. L&T-SUCG started on 7th February 2011.

Actual time required for each activity involved in underground excavation works in Design and Construction of Underground Tunnels for CMRL project. The works are carried out by Shanghai Urban Construction Group. The length of this railway tunnel is 3.342kms and I collected actual data for 20 cycles for simulating and finding out the most probable time. The data that is sorted as shown below:

Table 1: Activity time per meter length for 20 cycles

S. No.	**Activity(Cycle)**	**1**	**2**	**3**	**4**	**5**
	Pull Length(m)	1	1	1	1	1
(Time in hrs.)						
A	Drilling, Charging, Blasting & Mucking	07:30	05:11	05:42	11:54	08:12
B	Lattice girder erection	03:32	01:45	03:02	02:51	02:08
C	Forepolling	02:30	01:10	01:47	01:54	01:25
D	Rockbolting	00:25	00:23	00:21	00:33	00:28
E	Shotcreting	02:30	02:38	04:17	06:40	01:47
F	Planned Delays	01:15	00:26	01:00	00:38	00:53
G	Unplanned delays	05:04	02:12	04:38	05:42	05:00
H	**Total**	**22:46**	**13:49**	**20:50**	**30:14**	**19:56**

6	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	1	1	1	1	1	1	1
(Time in hrs.)							
07:40	06:33	06:04	07:23	05:00	12:03	05:53	05:53
02:46	01:52	02:30	02:30	02:33	02:26	02:53	02:33
01:40	01:15	02:08	01:20	01:20	01:32	02:00	01:25
00:20	00:25	00:25	00:20	00:23	00:30	00:30	00:25
01:40	02:48	03:12	02:40	02:40	02:18	02:20	02:08
01:00	00:53	00:57	00:33	00:43	00:57	00:56	00:35
04:40	02:48	04:38	04:00	03:20	03:39	03:50	03:23
19:46	**16:36**	**19:56**	**18:46**	**16:00**	**23:27**	**18:23**	**16:25**

14	**15**	**16**	**17**	**18**	**19**	**20**
1	1	1	1	1	1	1
(Time in hrs.)						
06:27	11:18	08:46	09:52	05:00	05:37	07:20
02:30	02:30	01:53	02:19	02:03	01:52	01:56
02:05	01:25	02:00	01:47	01:28	01:52	01:20
00:37	00:28	00:23	00:32	00:26	00:25	00:20
02:55	02:30	01:40	02:30	02:21	02:30	01:40
01:10	00:53	00:53	01:00	00:50	00:56	00:33
03:20	02:40	04:00	03:23	02:38	04:03	02:50
19:05	**21:47**	**19:36**	**21:25**	**14:48**	**17:17**	**16:00**

Data Processing

Grouping of data

After grouping and converting the data collected i.e, the time required for each activity into per meter length basis, Monte Carlo Simulation was carried. The activities were grouped and the relevant probability distributions based on different ranges of each activity were obtained for each activity as in the following table. Here activity 1 alone is shown as an example

Table 2: Grouped data from table 1 for Activity 1

S. No	Range	Counts	Probability	Cum. Probability	Realised Act. Duration	Multi plier
1	00:00-04:30	0	0.000	0.000	04:30:00	0.017
2	04:30-05:00	2	0.100	0.100	05:00:00	0.050
3	05:00-05:30	1	0.050	0.150	05:30:00	0.100
4	05:30-06:00	4	0.200	0.350	06:00:00	0.025
5	06:00-06:30	2	0.100	0.450	06:30:00	0.050
6	06:30-07:00	1	0.050	0.500	07:00:00	0.100
7	07:00-07:30	3	0.150	0.650	07:30:00	0.033
8	07:30-08:00	1	0.050	0.700	08:00:00	0.100
9	08:00-08:30	1	0.050	0.750	08:30:00	0.100
10	08:30-09:00	1	0.050	0.800	09:30:00	0.100
11	09:30-10:00	1	0.050	0.850	11:00:00	0.100
12	11:00-11:30	1	0.050	0.900	11:30:00	0.100
13	11:30-12:00	1	0.050	0.950	12:00:00	0.100
14	12:00-12:30	1	0.050	1.000	12:30:00	0.100

Following steps describe the procedure of Monte Carlo Simulation for activity 1 (Drilling, Charging, Blasting & Mucking) as an example

Step-I

The time is distributed in 30mins intervals.

Step-II

The probability of each time interval is calculated. The occurrence of each time intervals is calculated out of the 20 samples.

Probability = no of occurrences/no of samples

E.g. For time interval 4:30-5:00, the no of occurrence is 2

So the probability of occurrence for interval 4:30-5:00

= 2/20 = 0.100

Step-III
The cumulative probability is calculated by adding the probabilities of each interval.

Step-IV
In realised activity duration the min duration for each range is found out.

Step-V
The multipliers for each interval are calculated.
E.g. For interval 4:30-5:00
For 10 change in probability the time changes by 30 mins
For each 1 change in probability= 30/10=3 mins=0.05 hrs
So the multiplier for interval 4:30-5:00 is 0.05

Step-VI
The random numbers (B) are generated for 1000 iterations

Step-VII
For correspondence random number the lower range time (as shown in A) is calculated by the VLOOKUP formula

Step-VIII
For correspondence lower range time the multiplier (as shown in C) is calculated by the VLOOKUP formula

Step-IX
For correspondence random number the lower range probability (as shown in D) is calculated by the VLOOKUP formula
Step-X
The calculation of interpolation time [E=C*(B-D)]
E.g. For random number (B) 0.372
The correspondence lower interval time (A) is 6:00
The multiplier correspondence to 6:00 (C) is 0.025
The lower probability range (D) is 0.35
The interpolated time (E) = 0.025*(0.372-0.35) =0:00:48
i.e. 48seconds

Step-XI
Calculation of actual time by adding the lower range time (A) to the interpolated time (E)
E.g. The actual time for random number 0.372
= A+E = 11:00:00+0:00:43 = 11:00:43
i.e. an additional 43 seconds

Table 3: Monte Carlo Simulation for Activity 1 for 10 iterations

Iteration	A	B	C	D	E	A+E
1	11:00:00	0.855	0.1	0.85	0:00:43	11:00:43
2	7:00:00	0.526	0.1	0.5	0:03:45	7:03:45
3	7:00:00	0.552	0.1	0.5	0:07:29	7:07:29
4	7:30:00	0.667	0.033	0.65	0:00:48	7:30:48
5	6:00:00	0.442	0.025	0.35	0:03:19	6:03:19
6	4:30:00	0.036	0.017	0	0:00:53	4:30:53
7	7:00:00	0.569	0.1	0.5	0:09:56	7:09:56
8	5:30:00	0.284	0.1	0.15	0:19:18	5:49:18
9	5:00:00	0.115	0.05	0.1	0:01:05	5:01:05
10	7:00:00	0.569	0.1	0.5	0:09:56	7:09:56

Step-XII
Repeat Step-VI to Step-XI for another 999 times

The same process is followed for all the rest 6 activities for simulation and the final simulated values of all 7 activities & the most probable cycle time for each 1m pull is obtained.

Interpretation and Conclusion

The following table depicts the time calculated using the simulation procedure along with the time that actually it took.

Table 4: Most probable time

Most Probable Time			
Sl. No.	**Description**	**Interpreted Time (HH: Mm: Ss)**	**Average Actual Time (Hh:Mm:Ss)**
1	Activity 1 (Drilling, Charging, Blasting and Mucking)	07:20:15	07:27:00
2	Activity 2 (Lattice girder erection)	02:20:05	02:25:00
3	Activity 3 (Fore polling)	01:29:41	01:40:00
4	Activity 4 (Rock Bolting)	00:24:26	00:25:00
5	Activity 5 (Shotcreting)	02:27:20	02:41:00
6	Activity 6 (Planned delays)	00:46:04	00:51:00
7	Activity 7 (Unplanned delays)	03:38:59	03:47:00
8	**Project Cycle Time**	**18:26:49**	**19:20:00**

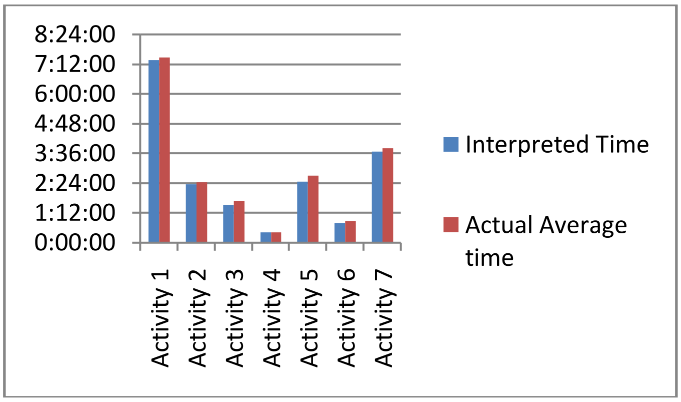

Figure 3: Comparison between Interpreted time and actual average time

- Above table shows the most probable time for each activity in Underground excavation including planned and unplanned delays. These values represent the cycle time for one meter length.
- Most Probable time for completing one cycle of underground excavation as per the site conditions is 18:26:49 i.e., approximately 20hours.
- The average of time actually taken for completion is significantly different from the stimulated value. This implies that the simulated time must be kept as a benchmark and remaining part of the construction process must be modified accordingly.
- Whenever there is a delay experienced in any project the above method of Monte Carlo Simulation can be adopted and the variations with planned time can be found and rescheduled according to that
- This method of simulating the cycle will help in finding out the reasons for delays and knowing about the delays which can be controlled and uncontrolled and helps in taking further decisions

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