MONTE CARLO SIMULATION RISK ANALYSIS AND ITS APPLICATION IN MODELLING THE INCLEMENT WEATHER FOR PROGRAMMING CIVIL ENGINEERING PROJECTS

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ABSTRACT

Delays due to inclement weather conditions within construction projects are generally planned for. Up until now, Deterministic Analysis has been the most common methodology used to determine the extent of the problem for construction projects. However it is the lack of risk consideration inherent in Deterministic Analysis that creates the opportunity for improving executive decision making by applying Probabilistic Analysis through quantitative risk analysis and different techniques like Monte Carlo Simulation (MCS).

This caste study review outlines the application of MCS to generate a distribution of the likely of inclement weather for a road construction project in Ballina, north of NSW, Australia. The paper also examines the application of MCS methodology for project programming, the advantages and challenges, and provides practical guidance for a probabilistic analysis with the application of MCS for managing the high risk of rainfall and optimizing the float at the activity level and the project level.

Introduction

Ballina Bypass Alliance Project (Case Study)

One of the most common climate uncertainties in civil engineering projects is inclement weather (rainfall) during the project execution phase. This weather factor directly impacts on the project schedule through the increased non-working days and consequently needs to be addressed in the project time management plan. For planning an accurate and reliable programme, the number of non-working days per year should be estimated with desired probability and risk level. In other words, the rainfall probability and its risks need to be integrated with the project programme to improve the chance of achieving the project targets.

A major challenge associated with this project programme is the high risk of rain in the area and the number of non-working rainy days in the construction programme. This challenge could significantly impact upon the project objectives and deadlines. The aim of this paper is to prepare a comprehensive risk assessment through Deterministic Analysis as well as Probabilistic Analysis with the application of the Monte Carlo Simulation technique. For the purpose of this MCS analysis, the assumption of a constant rate of non working rainy days for different stages of earthworks construction was considered [1, 2].

Rainfall Database

In the Ballina area, rainfall has been recorded since 1892 at two stations. Lismore station (Centre Street) operated from 1892 until 1992 before Ballina Airport AWS site commenced at 1992. The Lismore site was located approximately 20 kms from project site; therefore the database is accurate enough for our analysis without any adjustment. The Ballina Airport AWS station is located at Latitude 28.84S and longitude 153.56E.

Review of the statistical distribution of the rainfall data for Ballina shows a high probability of the number of days with rain. Average Rainfall Annual data from the Australian Government Bureau of Meteorology from 1961 to 1990 (Figure 1) has indicated that average rainfall for Ballina ranges from 2000 to 2400 mm per year [3].

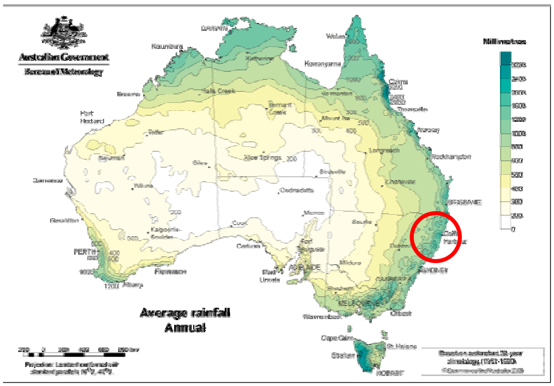


Figure 1: Average Rainfall Annual 1961 – 1990 Bureau of Meteorology

According to the recorded rainfall data for Ballina, the average number of days with rain exceeding 5mm ranges from 50 to 75 days per year (Figure 2). This is equal to from 7 to over 10 weeks per year, or approximately 13 to 21% of calendar day per year [3].

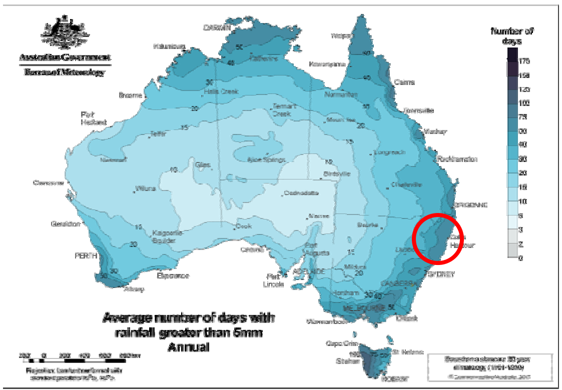


Figure 2: Average Number of Rain Day exceeding 5 mm Bureau of Meteorology

On the other hand, the Consequential Factor (CF) considers the non-working time associated with different rainfalls. Depending on different factors such as ground condition, construction discipline and phase, it is known that after rain, activities are sometimes unable to proceed straight away on the following days. The concern is to evaluate how many non-working days should be allowed as consequential days. Local experiences and practical examples in the area and/or the industry will help to answer this question and establish the Consequential Factor (CF).

Rainfall Data and Programming

Deterministic Analysis

In this case study, the rainfall database from 1892 to 2006 was obtained from the Australian Government Bureau of Meteorology. Using this database, the numbers of specific rainy days for each month were identified. The mean, median and mode for this database have been tabled for each month. Using the Deterministic approach, the number of rainy days per year is predicted by adding the total median or mean or mode for each month subject to consideration of other factors and issues.

The main concern in utilizing the Deterministic Analysis is the lack of attached probabilities to the output. The technique does not identify the probabilities and risks associated with the outcome. For areas like Ballina, with a high level of uncertainty of rainfall and the potentially dramatic impact on the construction programme, the analysis is complex to be addressed by strict and traditional Deterministic Analysis.

Probabilistic Analysis

There are many techniques to quantify and link the statistical distribution of databases and probabilities of uncertain events within an integrated system. The Monte Carlo Simulation technique is one of those methods for analyzing uncertainty propagation and address the associated probability to the environment. It is a combination of logical probability and experimental probability. The MCS technique determines logical probability of events and simulates them in trial situations. It is a method for iteratively evaluating a deterministic model using sets of random numbers as inputs. This method is often used when the model is complex, non linear, or involves more than a few of uncertain parameters. By using random inputs, it essentially turns the deterministic model to become a stochastic model.

Monte Carlo Simulation (MCS) Process

Risk analysis using the Monte Carlo Simulation technique involves three main steps described below:

1. Step 1 - Deterministic Analysis: using the rainfall database to calculate the statistical information such as Average (arithmetic mean), mode, median and standard deviation (STD) for the number of rain days each month. The historical database will help managers to have a better understanding of the statistical distribution of the data.
2. Step 2 - Estimate the uncertainty in the number of rainy days and try to determine which probability distribution for the inputs most closely matches the database. The target of this step is to identify that distribution for the number of rainy days per month.
3. Step 3 - Perform the Monte Carlo Simulation method with computer-based software and analyse the result for a better decision. MCS simulation uses the statistical information and probability distribution to create a combination of outcomes integrated with their probabilities [5, 6].

The next step is the determination of parameters and appropriate probability distribution considering the event’s characteristics. Using the historical database and statistical distribution of rainfall data, the monthly distribution of rainy days are calculated. Goodness of Fit (GoF) – Kolmorogrov-Smirnov Analysis is preferred to validate the assumption of the monthly probability distribution chosen.

After the appropriate probability distribution is identified for the database, the final step for MCS analysis is to perform the simulation scenarios with computer based software. MCS will use its statistical parameters to simulate the situation with the chosen probability distribution. For instance for an event with the Triangle Distribution, the model usually uses three point estimates that represent the uncertainty associated with each task with Triangle Distribution probability. In this case, the three point estimates are the minimum, maximum and most likely number of rain day for each month.

Once the three point estimates are determined, a probability distribution for each month is adopted. Then a uniform random number (between 0.0 and 1.0) is generated by the computer for each monthly distribution and simulated to forecast the number of rainy days. This step is performed a number of times with the computer to provide statistical information of the outcome at the end of the process. The statistical information assists decision-makers to determine the risk to be incorporated into programme.

Results and Discussion

Deterministic Analysis

Considering the Ballina Bypass Alliance project characteristics, ground conditions and local experiences, the numbers of rainy days each month from 1892 to 2006 periods are identified within four categories:

- Number of rainy days with rain exceeding 5mm
- Number of rainy days with rain exceeding 7.5mm
- Number of rainy days with rain exceeding 10mm
- Number of rainy days with rain exceeding 30mm.

For each category, monthly statistical information such as minimum, maximum, mean, median, and standard deviation are calculated from this rainfall database. Figure 3 presents the monthly average number of rainy days and Average Daily Rainfall (mm) for each category.

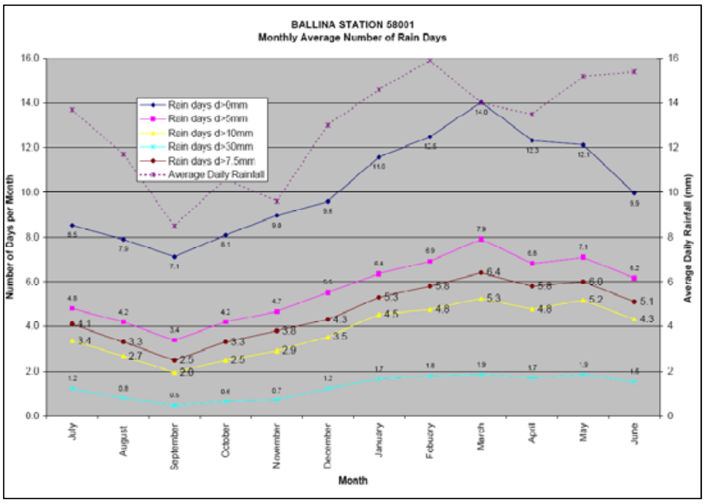


Figure 3: Monthly Average Number of Rainy Days in Ballina - 1892 to 2006

Considering the civil and earthworks parameters in the Ballina Bypass project, after several consultations with local engineers and authorities in the area, a threshold of 7.5 mm seemed appropriate. Previous experience and research from local expertise and the engineers have indicated that rainfall less than 7.5 mm will not significantly affect construction progress on-site, therefore the main concern will focus the analysis on the rain exceeding 7.5 mm. The descriptive statistical information for the rainfall exceeding 7.5 mm from Ballina AWS site is shown in Table 1.

Table 1: Descriptive Statistical information for Rainfall exceeding 7.5 mm at Ballina

Month	**No. of (Rain Days > 7.5mm) per month**					
	Min	**Median**	**Maximum**	**Mean**	**Mode**	**Standard Deviation**
January	0	5	16	5	5	2.9835
February	0	6	18	6	6	2.9906
March	0	6	17	6	3	3.7090
April	0	6	14	6	6	3.3034
May	0	6	15	6	4	3.5285
June	0	5	16	5	5	3.1926
July	0	3	14	4	3	3.2254
August	0	3	10	3	3	2.3574
September	0	2	8	2	2	1.9662
October	0	3	10	3	4	2.2257
November	0	3	23	4	3	3.3076
December	0	4	15	4	3	2.7542
Annual		**52**	**176**	**56**	**47**	

Monte Carlo Simulation (MCS)

Using the Ballina rainfall database (from 1892-2006), the distribution of the number of rain days on a monthly basis is shown on Table 2.

Table 2: No. of Rain Days per month for Period 1892-2006 at Ballina

No. of rains	**How many times?**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	5	3	3	5	5	11	14	18	19	10	17	8
2	14	8	6	8	5	9	8	18	25	21	16	14
3	14	9	16	9	8	12	20	20	18	20	20	23
4	11	16	8	13	14	13	10	9	12	23	6	15
5	19	15	11	12	14	19	14	14	10	12	15	16
6	12	20	9	15	13	11	11	11	7	6	6	8
7	10	7	12	12	14	8	2	7	1	5	7	8
8	9	10	13	12	8	9	8	3	2	0	6	9
9	6	12	10	6	8	6	4	1		4	4	4
10	5	4	4	5	4	4	3	1		1	1	0
11	4	3	5	4	3	3	1				2	0
12	1	2	4	1	3	2	3				0	2
13	0	0	2	4	5	1	0				0	0
14	0	0	2	1	0	0	1				0	0
15	0	0	2		2	0					0	1
16	1	0	0			1					0	
17		0	1								0	
18		1									0	
19											0	
20											0	
21											0	
22											0	
23											1	

From the information presented in Table 2, the 12 monthly distribution graphs for the rainfall exceeding 7.5 mm were obtained. Figure 4 presents the distributions for April, May, Oct and Dec as an example.

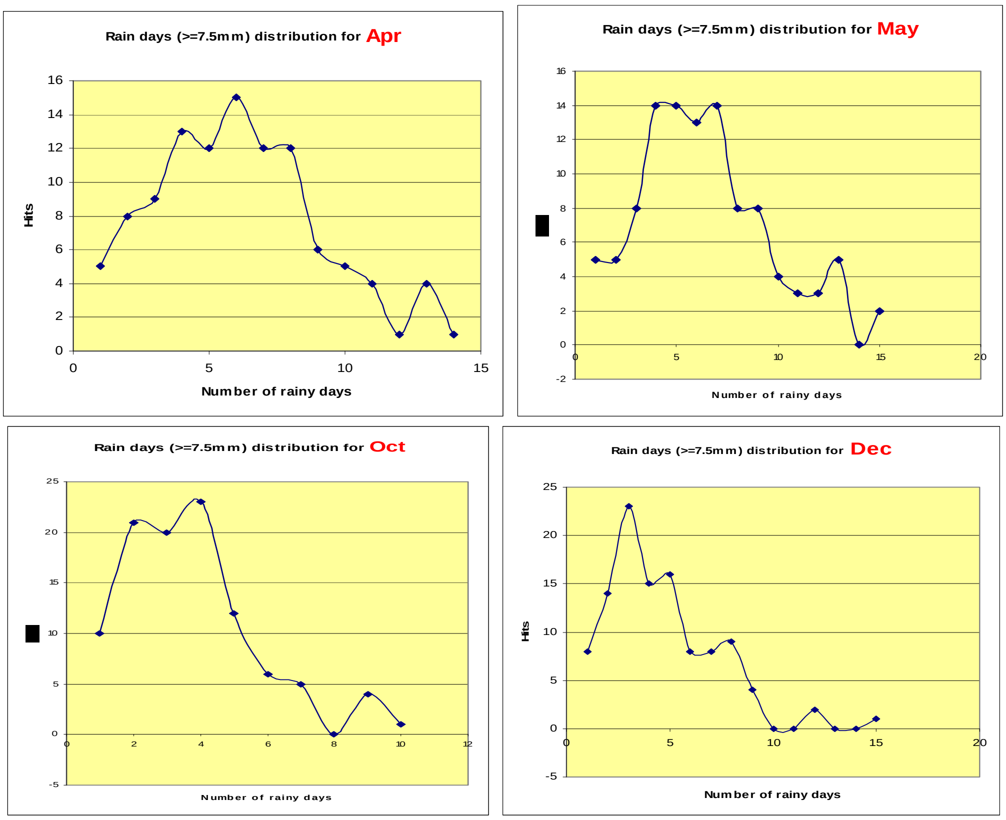


Figure 4: No. of Rainy Days Distribution for Apr, May, Oct and Dec at Ballina

For the purpose of this project the Kolmogorov-Smirnov GoF test was undertaken to validate the assumptions for probability distribution in our rainfall database. The Kolmogorov-Smirnov Analysis results have confirmed that Normal Distribution is accurate and reliable enough for the number of days with rain per month in the Ballina area.

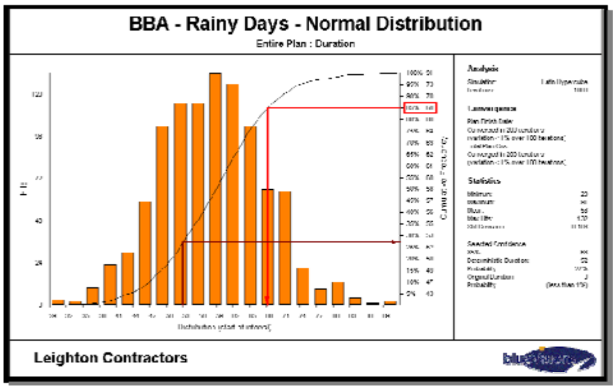


Figure 5: Simulation outcome for Rainy Days >7.5 mm with Normal Distribution

The CF (Consequential Factor) for earthworks activities has been calculated based on the database, local experiences and construction problems for different rainfall. For the Earthworks Programme the CF of 0.7 has been adapted to the plan. On the other hand, CF is equal to zero for the Structure Programme which means there is no consequential rainy days for the Structure Programme subject to site accessibility.

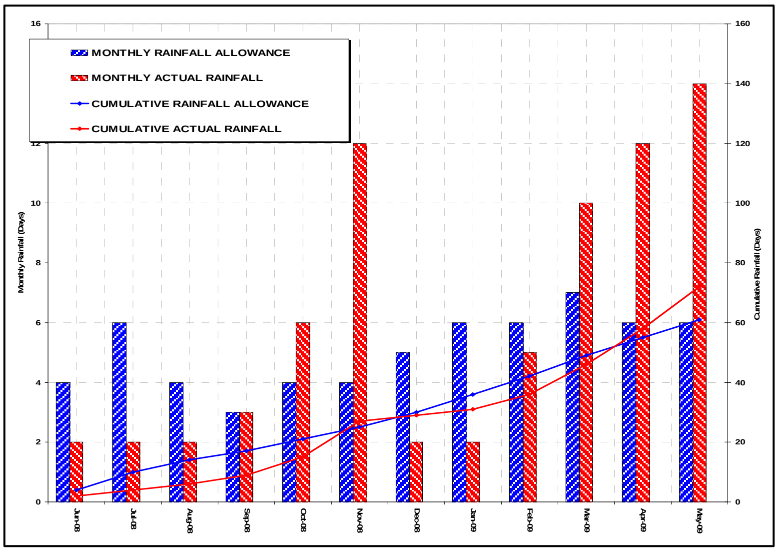
The overlap of the number of rainy days and consequential days with the other non-working days during the year (e.g. Weekends, RDOs, P/Holidays and Christmas, etc.) have been considered. As a result for the Ballina Bypass Alliance project, the programme has a WWF (Wet Weather Factor) of 0.32 and 0.19 for Earthworks and Structures respectively with the probability of 85%. The programmes with different probabilities such as 5%, 50%, 70%, 85% and 99% considering Figure 5, CFs and other non-working days (e.g. Public Holidays, RDOs, etc.) and their overall impacts on the working days per year has been summarised in Table 3.

Table 3: Working Days per year without Rain vs Working Days per year with Rain

P(X)	Discipline	Rainy Days per Yr	CF	Working Days per Year (Without Rain)	Working Days per Year (With Rain)	WWF
P5	Earthwork	43	0.7	230	184	0.20
	Structure	43	0	230	203	0.12
P50	Earthwork	58	0.7	230	168	0.27
	Structure	58	0	230	193	0.16
P70	Earthwork	63	0.7	230	163	0.29
	Structure	63	0	230	190	0.17
P85	Earthwork	68	0.7	230	157	0.32
	Structure	68	0	230	187	0.19
P99	Earthwork	91	0.7	230	133	0.42
	Structure	91	0	230	151	0.34

Actual Data

To be able to assess the initial outcomes and improve the quantitative risk analysis for the future projects, the construction team took the responsibility to record the actual non working days for the earthwork activities due to inclement weather. The results for the first 12 months of the construction have been presented in the Figure 6 below.



Deterministic Analysis: 56 days

Probabilistic Analysis: 68 days – 85%

Management Decision: 63 days

Actual for first year: 72 days

Figure 6: Actual non-working days for Ballina Bypass in the first year of construction

Conclusion

The mean of 56, median of 52 and mode of 47 days with rain per annum are suggested for the Ballina Bypass Alliance Programme by Deterministic Analysis. The results from Probabilistic Analysis with the application of the Monte Carlo Simulation technique, presents a 40% chance for mean of 56 rainy days per annum.

Considering all the results from the different probability distributions and Deterministic Analysis, the MCS Analysis is recommending 68 rainy days per annum with the 85% probability for the Ballina Bypass construction programme.

To make the final decision, the 36 monthly rainfall deciles for New South Wales presented at Figure 3 was considered too. Considering the project contract type, sub-contractors responsibilities and programme deadline constraints by the client, the final decision of 63 rainy days per annum with 70% probability was made by the Construction Manager. Hence the Ballina Programme was adopted with 63 rainy days per year.

Capturing the actual information during the first year of construction shows 72 non working days per year for the earthwork activities as presented in Figure 10. Considering the initial forecast of 68 days with 85% probability, shows a potential of having a good platform for inclement weather analysis in future projects.

Probabilistic Analysis with the application of the Monte Carlo Simulation technique can support scheduling of the civil projects in uncertain conditions. Extra attention needs to be taken to validate the best probability distribution for the database. The distribution assumption should always be tested and proved by GoF tests such as Kolmogorov-Smirnov Analysis.

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BRIEF BIOGRAPHY OF PRESENTER

Pedram is a certified Master Project Director (MPD) and a professional member of Engineers Australia (Civil Engineering Division) with more than 15 years experiences in construction industry. He is highly skilled and technically proficient in most aspects of construction management including Programming, Construction Methodology Development, Tender Programme, Quantitative Risk Analysis, Programme Risk Management, Schedule Risk Analysis (SRA), Cost Risk Analysis (CRA), Project Monitoring & Controls (PMC) Systems, and Earned Value Performance Measurement technique (EVPM.

Following his role with the International Institute of Earthquake Engineering as the Head of Civil Engineering Department, he is currently an associate director with blueVisions Management and leading a team of professional planners and engineers in the infrastructure and civil sector.

With more than ten technical papers in conferences/journals and so many national and international presentations, he is also an executive member of Centre for Engineering and Leadership (CELM), and Risk Engineering Society of Engineers Australia.