Contingency Estimation based on Risk Events of Tunnel Construction: Case study Nam Thuen 1 Hydropower Project

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Abstract

This study aimed to integrate risk event occurred in tunnel construction and calculate contingency project duration using the Monte Carlo Simulation technique and apply as lag time on PDM network to estimate duration for constructing a tunnel. The study started by reviewing the PDM scheduling method, tunnel excavation process, and risk assessment process. The tunnel construction network was then modeled and calculated based on geological conditions and risk occurrence. By applying the Monte Carlo Simulation technique, the contingency duration of activities based on the risk occurrence can be estimated and then added with a normal duration of the activities to estimate excavation time per cycle. For a total distance of 320 meters, the estimated duration of the tunnel construction in the good rock condition was finished in 73 days with the production rate of 0.92 days per four meters. Besides, the construction in the fair rock condition was finished in 107 days with the production rate of 1.00 days per three meters. Lastly, in the poor rock condition, the construction was finished in 173 days with the production rate of 1.08 days per two meters. The actual completion time of the ADIT 1 tunnel construction was 175 days, which is close to the poor rock condition obtained from the Monte Carlo Simulation technique. Meanwhile, the tunnel construction duration set by the traditional PDM without risk incurred would be within 122 days; therefore, the proposed method in this study could be used and provide reasonable results.

Keywords: *Monte Carlo Simulation, Tunnel Construction, Precedence Diagramming Method (PDM), Risk*

1. Introduction

Nam Theun 1 Hydropower Project has a total capacity of 650 MW, including three units (2x260MW+1x130MW) and located in the central of Lao People's Democratic Republic (Song Da 9, 2016). Government of the Lao PDR set up a policy of turning a country into a battery of Southeast Asia by producing large-scale hydropower plants. Hydropower plant tunneling method using a tunnel boring machine (TBM) excavation is inflexible and requires a large investment, but it is an expectedly fast and safe method. When unfavorable conditions are encountered without warning, time schedule and practical consequences are often far more significant in a TBM driven tunnel than in a drill and blast tunnel. Time estimations of tunnel construction are usually subject to uncertainties caused by uncertain geotechnical conditions, varying performance of the utilized excavation technologies, and human and organizational factors (Tamrock, 1999). One of the major challenges in terms of risk events of this project was the construction of ADIT 1 Tunnel, called Fair Rock condition (mostly found sandstone interceded with siltstone). Even the risk of events has relatively small probabilities but cannot be neglected as they often lead to massive delays and damages.

Monte Carlo Simulation (MCS), which is used for modeling a probabilistic prediction of construction time, considers the risk of extraordinary events from available data in previous projects, such as geotechnical uncertainties recorded during the excavation of tunnels under similar conditions.

2. Objectives

The purpose of this study is to integrate risk event occurred in tunnel construction and calculate contingency project duration using the Monte Carlo Simulation technique and apply as lag time on PDM network to estimate duration for constructing a tunnel.

3. Materials and Methods

To conduct this research, the Precedence Diagramming Method (PDM) with lag time from evaluating uncertainty was reviewed. Drilling and blasting excavation methods were also studied. A concept of Work Breakdown Structure (WBS) was used to breakdown an excavation work of tunnel into activity level. Risk assessment includes risk identification and risk analysis was explained in details. Finally, the MCS model is applied to a case study, allowing an estimating time contingency from risk events of tunnel construction.

3.1 Precedence Diagramming Method

Precedence Diagramming Method is a technique used for constructing a schedule model in which activities are represented by nodes and are graphically linked by more than one logical relationships. The linkages exhibit the sequence in which the activities are performed. The PDM includes predecessors, successors, four basic types of dependencies or logical relationships, and the effect of applying leads and lags. This technique is also known as Activity on Node (AON). A description of each relationship was described as follows;

Finish-to-Start (FS) Links; the normal type of link is a finish-to-start link. With this type of link, the succeeding activity cannot start until after the finish of the preceding activity as shown in Figure 1.

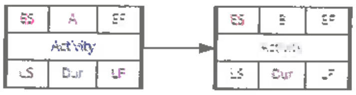

Figure 1 Finish-to-Start (FS) Links

Start-to-Start (SS) Links; the start of the succeeding activity is delayed until after the start of the preceding activity. This type of dependency primarily controls the start of activities (not the finish) as shown in Figure 2.

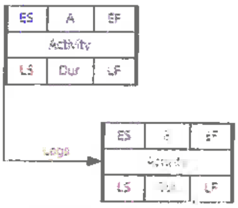

Figure 2 Start-to-Start (SS) Links

Finish-to-Finish (FF) Links; the completion of the succeeding activity is delayed until after the completion of the preceding activity. This type of dependency primarily controls the finish of activities as shown in Figure 3.

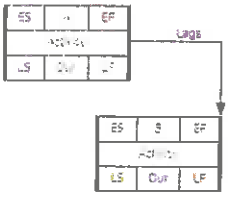

Figure 3 Finish-to-Finish (FF) Links

Start-to-Finish (SF) Links; the finish of the succeeding activity is constrained by the start of the preceding activity as shown in Figure 4.

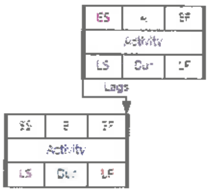

Figure 4 Start-to-Finish (SF) Links

Leads and Lags applied to Links as shown in Figure 5. A Lag has the effect of delaying the succeeding task by the number of time units specified. Leads (or negative lags) have the effect of accelerating the succeeding task by the number of time units specified. Negative lags (or leads) are allowed in some software packages, but they need to be used with care.

Figure 5 Leads and Lags time

3.2 Work Breakdown Structure

A Work Breakdown Structure provides structural views into the project. It is an essential tool for planning and executing the project. A WBS is a decomposition of all the work necessary to complete a project, arranged in a hierarchy and constructed with clear and logical groupings, either by activities or deliverables. The WBS should represent the work identified in the approved Project Scope Statement and serves as an early foundation for effective schedule development and cost estimating. Project managers typically develop a WBS as a precursor to a detailed project schedule. The case study can be described as follows.

Drilling and Blasting (D&B) method is mostly used for the excavation throughout the world. This method can be used in all types of rocks, and the initial cost is lower than the mechanical method like TBM. D&B method involves the use of explosives. Compared with using TBM, blasting generally results in a longer duration of vibration levels. The typical cycle of excavation by drilling and blasting method is shown in Figure 6 (Tamrock, 1999).

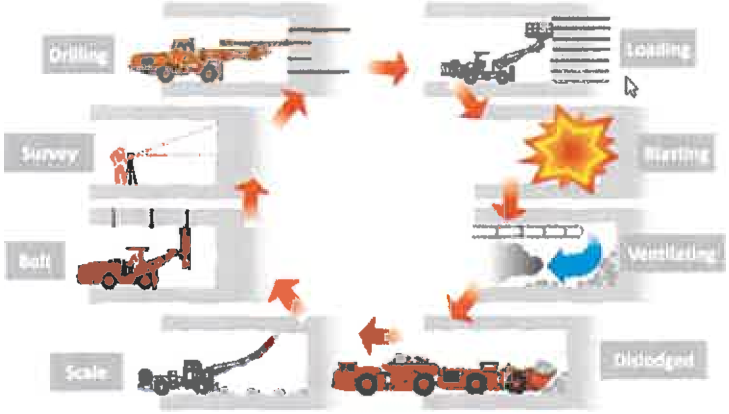

Figure 6 The cycle of excavation by drilling and blasting

Although there are different methods of decomposing project work and creating a WBS, the most straightforward and effective way is that use some form of visual display of the deliverables, phases, or activities. Ideally, all Project Team members will convene and brainstorm all work required for completing project deliverables. Involvement of all team members causes WBS comprehensive. Team members start identifying all project deliverables or milestones and then decompose them one at a time into a detailed and sequential list of the detailed activities required to complete the deliverable. One way of visually conducting this process is by using post-it notes to represent each deliverable and sub-activity (Margaret, 2015). The Project Team create a WBS Dictionary to capture task characteristic information, including task names, work products, level of effort, resources, dependencies, and others as created in Table 1.

Table 1 WBS of excavation by drilling and blasting

WBS FIELDS Nam Thuen 1 Hydropower Project

WBS#	Task	Description of Task	Work Products	Owners	Est. Level of Effort
1	Nam Thuen 1 Hydropower Project	All task management and management activities	Hydropower Plant	Government Lao PDR	
1.1	Tunnel Excavation	- Excavation by drilling and blasting	Tunnel	Project Manager	24 hrs.
1.1.1	(A) Drilling & Blasting	- Controlled use of explosives to break rock for excavation	Tunnel Distance	Contractor	6 hrs.
1.1.2	(B) Mucking & Scaling	- Loading and hauling the muck, transport out of the tunnel - Remove any loosened rock	Clearing	Contractor	6 hrs.
1.1.3	(C) Mapping	- Special-purpose map to show geological features, rock unit and geologic strata	Geological Data and stratigraphic contour line	Owner, Engineer	3 hrs.
1.1.4	(D) Survey checking	- Checking and align the center line in the ground and transfer that to the tunnel - Position marking for all drilling holes	Tunnel Axis Line	Owner Engineer	2 hrs.
1.1.5	(E) Steel Rib Installation	- Wood block or steel installation for rock tunnels, with close spacing against the rock to reduce bending stress in the rib	Tunnel Stability for very poor quality rock masses	Contractor	2 hrs.
1.1.6	(F) Wire mesh Installation (1st Layer)	- Welded wire-mesh attached to the rock surface before shotcrete	Tunnel Stability for fair quality rock masses	Contractor	2 hrs.
1.1.7	(G) Shotcrete (1st Layer)	- Mixing cement, sand, fine aggregate and admixture concrete conveyed through a hose and pneumatically projected at high velocity onto a surface	Tunnel Stability for fair quality rock masses	Contractor	1 hrs.
1.1.8	(H) Wire mesh Installation (2nd Layer)	- Welded wire-mesh attached to the rock surface before shotcrete	Tunnel Stability for fair quality rock masses	Contractor	2 hrs.
1.1.9	(I) Shotcrete (2nd Layer)	- Mixing cement, sand, fine aggregate and admixture concrete conveyed through a hose and pneumatically projected at high velocity onto a surface	Tunnel Stability for fair quality rock masses	Contractor	1 hrs.
1.1.10	(J) Rock Bolt & Drain hole Installation	- Install long anchor bolt for stabilizing rock excavation - Install PVC perforated pipes for provide drainage through the shotcrete layer to reduce ground water pressure to the tunnel	Tunnel Stability	Contractor	1 hrs.

3.3 Baseline Schedule

At the beginning of project execution, the Project Schedule was the same as the baseline schedule. During the project, the actual progress is updated on the project schedule. At any given date, the latest version of the actual (project) schedule refers to the "Project Schedule." Another meaning, Project Schedule is the "actual," whereas baseline schedule is the "plan." For this project, the schedule baseline was developed as PDM as shown in Figure 7. Activity A, B, C, E, F, G, H, I, and J are a critical activity that forms a critical path, while Activities D is off the critical path with 1-hour float.

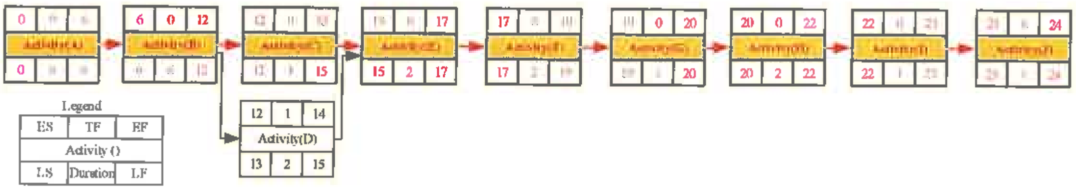

Figure 7 Baseline Schedule of tunnel excavation of Nam Thuen 1 Hydropower Project

3.4 Risk Assessment

3.4.1 Risk Identification

In order to understand which areas of the project might require special attention and whether there were any recurring risk themes or concentrations of risk on a project, it would be helpful if there were a simple way of describing the structure of project risk exposure. Therefore, in the tunnel excavation, risks include anything unplanned and unforeseen that can negatively impact the tunnel construction. One of the important tools available for managing risks is the Risk Breakdown Structure (RBS). Creating RBS, it starts from higher levels risks and goes down to finer levels ones by analyzing records from previous projects, actual construction, and experienced interview as shown in Table 2.

Table 2 RBS of excavation by drilling and blasting

Level 0	Level 1	Level 2	Level 3
Project risk	Management	Corporate	R1-Organizational stability
			R2-Financial
		Customer & stakeholder	R3-Contractual
			R4-Requirements definition
			R5-Stability
	External	Natural environment	R6-Physical environment
			R7-Facilities/site
			R8-Local services
		Culture	R9-Political
			R10-Legal/regulatory
			R11-Interest groups
		Economic	R12-Labor market
			R13-Labor condition
			R14-Financial market
	Technology	Requirements	R15-Scope uncertainty
			R16-Conditions of use
			R17-Complexity
		Performance	R18-Technology maturity
			R19-Technology limits
		Application	R20-Organizational experience
			R21-Personnel skill sets & experience
			R22-Physical resources

This step involves identifying the risks associated with project activities. Each activity is considered for risk identification. A list of risk events for each activity can be obtained.

3.4.2 Risk Analysis

Risk analysis is performed as identified in section 3.4.1. The probability of occurrence and the impact of each risk on a particular activity are assessed. The probability value signifies the degree of confidence that the project team has on the occurrence of risk identification. The impact considered in this study is the extension time needed. Due to the progressive elaboration nature of construction projects, this extension time is difficult to estimate with certainty in the planning stage. MCS has been introduced to overcome this limitation. It is a simulation-based procedure that requires significant computational effort. MCS allows the project team to assess the probability of a certain project's target dates. The MCS also provides the estimation regarding the probability that a particular activity is on the critical path (Pawan and Lorterapong, 2015). The construction of an ADIT 1 tunnel in Nam Theun1 Hydropower Project, which falls between the fair rock condition and the poor rock condition tunnel, was used as a case study as shown in Figure 8.

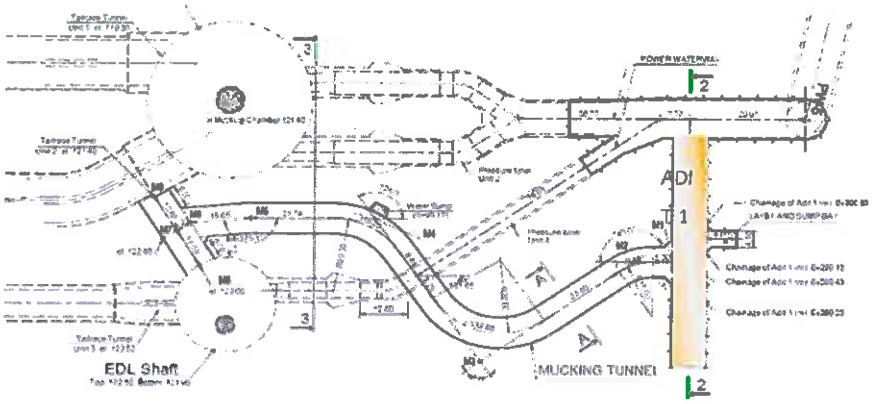

Figure 8 General Layout of ADIT 1 (320 meters)

4. Results and Discussion

Risk analysis has been performed to determine the probability of risk occurrence and the impact of those risks. This study referred to class support from geological conditions as shown in Table 3.

Table 3 Class Support from geological conditions

Support	Rock Condition	Activity Path	Distance (m)
Class 1	Good Rock (Sandstone)	A-B-C-D-F-G-H	3-5
Class 2-3	Fair Rock (Sandstone and Siltstone)	A-B-C-D-F-G-H-I-J	2.5-3
Class 4	Poor Rock (Siltstone)	A-B-C-D-E-F-G-H-I-J	1-2.5

Table 3 indicates the probability of risk occurrence and the potential time extensions caused by those risks that were estimated by the project team. The case study can be applied once all project activities have been defined, and their sequences and normal durations have been established. The normal duration of the project activities was 122 days, which was determined based on normal working conditions. The actual time of the completion of ADIT 1 tunnel construction was 175 days. However, after performing risk analysis based on geological conditions, tunnel excavation network was adjusted, and some activities can be cut into three classes as shown in Figure 9 to Figure 11.

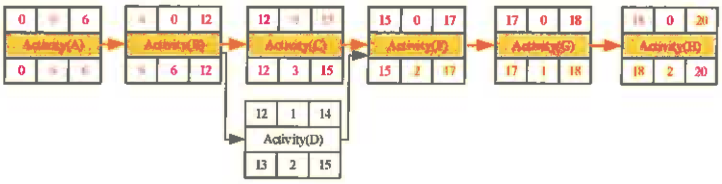

Figure 9 PDM Network of Class 1

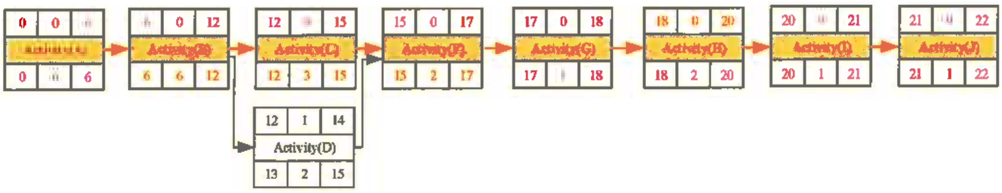

Figure 10 PDM Network of Class 2-3

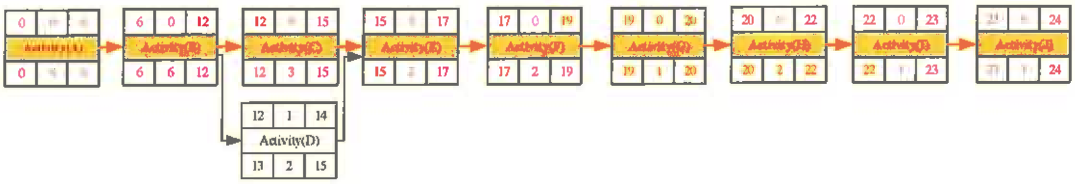

Figure 11 PDM Network of Class 4

The study then conducted the data collections and expert interviews of time contingency of construction activities (risk occurrence) as shown in Table 4. Besides, the PDM Network from risk occurrence of was modified by adding activity lag time to activity A and D while the rest of activities were no lag as depicted in Figure12 for Class 1 as an example.

Table 4 Data collection from risk occurrence

Activity	Normal Duration (Hours.)	Risk Event	Contingency Duration (Hours.)						
			Expert No.						
			1	2	3	4	5	6	7
A-Drilling & Blasting	6	R6	1	1	1	2	1	1	1
		R7	1	2	2	2	1	3	1
		R13	2	1	1	2	1	3	1
D-Survey Checking	2	R6	1	1	2	2	1	1	1

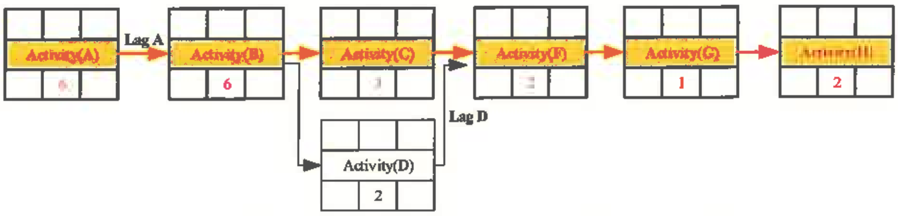

Figure 12 PDM Network from risk occurrence of Class 1 condition

The key feature of a Monte Carlo simulation is that it can create the ranges of estimating likely the result. In a Monte Carlo simulation, a random value is selected for each of the tasks based on the range of estimates. The model is calculated based on a random value. The results of the model were recorded, and the process was repeated. A typical Monte Carlo simulation calculates the model ten-thousands of times, each time using different randomly selected values. The contingency durations due to risk events attached to the activity were concluded in Table 5.

Table 5 Average Contingency Duration from simulation

Activity	Risk Event	Contingency Duration (Hours)	Standard Deviation (Hours)
A	R6	1.14	0.35
A	R7	1.72	0.70
A	R13	1.72	0.70
D	R6	1.28	0.45

Since activity A has three risk events when an event occurs extra time needed to add to the activity will be only one event because in general there would be one event occurring at a time. However, if multiple events are occurring, contingency duration due to each risk event can be independently paralleled. In this paper, the maximum values of contingency duration which was 1.72 hours for lag A as shown in Figure13 and 1.28 hours for lag D were used to add in the PDM network as a lag time for calculating the process duration for all geological conditions. For PDM Network of Class 1 as shown in Figure 14, after adding the lag time, the total process duration was 22 hours, and the critical path of the network was changed. Activity D became a critical activity. Therefore, a total of 2.00 hours was added to the excavation process duration in each geological condition. Table 6 shows the construction time per cycle of each geological condition.

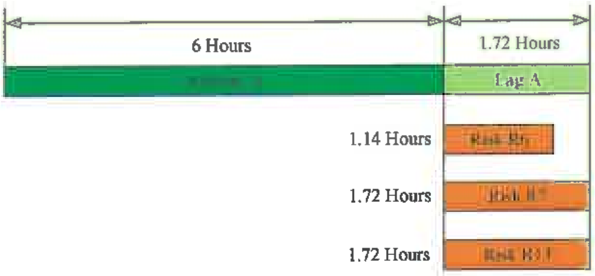

Figure 13 Contingency duration of activity A as lag time

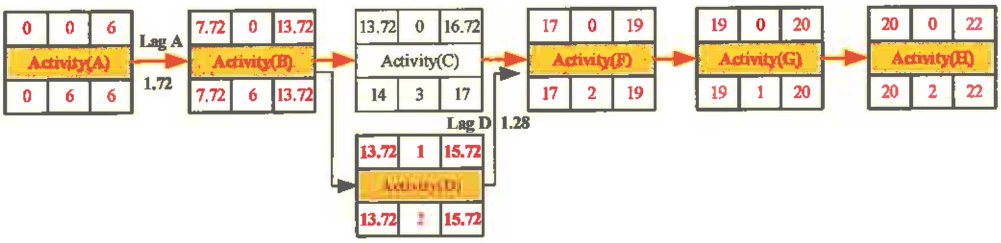

Figure 14 PDM Network of Class 1 condition with lag time added

Table 6 Total time of each geological condition

Rock Condition	Activity Path	Cycle time (Hours)	Contingency Duration (Hours)	Total Duration (Hours)
Good Rock (Sandstone)	A-B-C-D-F-G-H	20.00	2.00	22.00
Fair Rock (Sandstone and Siltstone)	A-B-C-D-F-G-H-I-J	22.00	2.00	24.00
Poor Rock (Siltstone)	A-B-C-D-E-F-G-H-I-J	24.00	2.00	26.00

From this study, the estimated duration of tunnel construction using the Monte Carlo Simulation technique was 73 days with the production rate of 0.92 days per four meters, 107 days with the production rate of 1.00 days per three meters, and 173 days with the production rate of 1.08 days per two meters, in the good rock condition, the fair rock condition, and the poor rock condition, respectively as shown in Table 7 (a total distance of 320 meters).

Table 7 Tunnel construction duration using PDM and MCS

Tunnel Excavation Schedule (Distance = 320 m.)	Excavation Duration for 1 Cycle)		Construction Duration (Days)
	Hours	Days	
Actual Construction	-	-	175
Using CPM (1 cycle=3 m.)	24	1	122*
Using MCS (Good Rock: 1 cycle=4 m.)	22	0.92	73
Using MCS (Fair Rock: 1 cycle=3 m.)	24	1.00	107
Using MCS (Poor Rock: 1 cycle=2 m.)	26	1.08	173

* Data from master schedule

5. Conclusion

In this study, the estimated duration of tunnel construction using the Monte Carlo Simulation technique in the good rock condition was 73 days with the production rate of 0.92 days per four meters. Secondly, in the fair rock condition, the construction was finished in 107 days with the production rate of 1.00 days per three meters. Lastly, in the poor rock condition, the construction was finished in 173 days with the production rate of 1.08 days per two meters as shown in Table 7 (a total distance of 320 meters). The actual completion duration of the ADIT 1 tunnel construction in the project was 175 days, which is close to the poor rock condition in the Monte Carlo Method Planning. From the geological conditions data of ADIT 1 Tunnel, it seemed to be the fair rock to the poor rock conditions (mostly found sandstone interbedded with siltstone). Meanwhile, the tunnel construction duration of the master project schedule set by the PDM would finish within 122 days (a total distance of 320 meters). It indicated that planning by the PDM was notwithstanding project risks and can impact the project's progress. In practice, contractors typically include time contingency in the estimated activity duration. As a result, it is difficult to increase the robustness of construction schedules. Due to the lack of effective tools, most of the contractors would have to set aside an arbitrary time allowance to take the project risks into account.

6. Acknowledgements

Author would like to express gratitude to Mr.Tapanapong Tangsrivorranan for collecting all valuable data needed during his internship time at Nam Theun 1 Hydropower Project located, Lao People's Democratic Republic.

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