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Abstract

Investment decisions have to be made when there is little information about the scope of the project. New projects have to depend on historical evidences and experiences gained from previous projects of similar nature. However, such projects lack historical data and even if such data are available, they cannot be applied owing to the very unique nature of the projects and their locations. In such circumstances, subjective judgments of the experts based on their experience are very useful inputs for the success of any projects. In risk analysis, determining a numerical value to such judgments without distorting the subjective judgments is very essential. An approach is taken in this study that will prioritize the existing risks and assign a cost value to all the major risks through systematic risk analysis. The proposed methodology will be demonstrated through its application to a case study of Nyadi Hydropower Project in Nepal.

Key Words: Risk Analysis, Nyadi Hydropower Project, AHP, Monte Carlo Simulation, Contingency

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1. Introduction

Hydropower projects undertaken in the past have dismal record of cost and time overruns. One data-base is the World Bank Tenth Annual review of project performance audit results showing a gradual decline in performance, partly because projects are getting more risky, with cost overruns shown up to 560%, and time over-runs average 61%. It is well accepted fact that hydropower projects are very risky undertakings involving many unforeseen risks like unfavorable geological conditions, floods etc. These conditions make the construction projects susceptible to cost variations. Funding agencies like, World Bank, Asian Development Bank make it mandatory to perform risk analysis for such power projects. Risk Analysis involves both qualitative and quantitative aspect. In the absence of quantitative data, there is a need for a subjective approach to project risk assessment with there being the necessary objectivity in the methodology (Dey et al.,1994). For Nyadi Hydropower Project (NHP), a similar approach of combining qualitative as well as quantitative data for risk analysis is adjudged appropriate.

Nyadi Hydropower Project is a run-of-the-river (ROR) type hydropower project located in Lamjung district. The project will have a generation capacity of 20 MW and will be able to generate 127.3 GWh of energy annually. The feasibility study that was carried out in year 2000 projected the construction cost to be 32.25 million USD, and it was expected to be complete in 5 years from the start of construction. This is a project initiated and developed by Lamjung Electricity Development Company (LEDCO) from the fund raised through the local shareholders and other financial organizations. The feasibility study of the project was carried out by Hydroconsult division of Butwal Power Company (BPC) in March 2000. The major structures of the project include a concrete weir across Nyadi river, an intake and an underground de-silting basin. The water is then taken to the powerhouse via approximately 3.7 km tunnel and 564 m underground steel penstock pipe. The powerhouse is located underground and houses three number of 6.7 MW turbine and generator sets. The construction of a road to the powerhouse site is considered essential for this project. The length of road to join the powerhouse site from the nearest motorable road is about 3.97 km.

2. Data collection methodology

Where quantitative data are available that describe past projects, a statistical analysis can provide a valuable basis for project risk assessment. The analysis requires records of the estimated cost and durations of the activities and the eventual outcomes from a number of similar projects. Statistics are then derived that summarize the variations between the plans and the outcomes for various categories of activities. However, when no similar work has been done in the past acquiring data for the purpose of statistical analysis is almost impossible. However, from the experiences of project personnel, the impact and likelihood of risks and the effect on the overall objective of the project can be approximated well enough to a certain degree of accuracy through proper data elicitation even if the numerical data is absent. In the context of hydropower projects in Nepal, a similar approach of obtaining data was necessary for carrying out the risk analysis. This was because of the fact that even though there were quite a few hydropower projects done prior to the construction of this project taken for the case study, there were no records of such projects regarding the risks and the cost associated with them. The best remaining alternative was, therefore, to elicit responses from the people who had been involved in the construction of hydropower projects.

The project personnel chosen were such that they had substantial experience and knowledge on technical and managerial aspect of the project and were able to provide reliable input to the risk analysis. The respondents comprised of managerial level employees from both the consultant party and the contractor’s party who were actively involved in the project and also had considerable experience in the hydropower sector. The list of interviewed personnel is shown in Table 1.

Table 1: List of respondents

SL. N.	Company	Designation
1	Butwal Power Company (BPC)	Director, Hydroconsult division
2	Butwal Power Company (BPC)	Senior Geologist
3	Butwal Power Company (BPC)	Site Manager
4	Butwal Power Company (BPC)	Chief, Estimation and Design
5	Butwal Power Company (BPC)	Planning Engineer
6	Butwal Power Company (BPC)	Site Manager
7	Himal Hydro and General Construction	Senior Geologist
8	Himal Hydro and General Construction	Site Manager
9	Himal Hydro and General Construction	Civil Engineer
10	Lamjung Electricity Development Company	Project Manager
11	Lamjung Electricity Development Company	Project Engineer
12	Lamjung Electricity Development Company	Project Engineer

3. Identifying Risks

The study considered a range of cost variations, due to a variety of causes, referred to as risks. In general these were variations within the normal range for projects of this kind. The risks that affect individual line-item costs can be grouped according to whether or not they affect the quantity estimate, the unit cost estimate, and the schedule. Risks comprising a fourth group, termed here as global risks, act uniformly on all activities. Cooper et al. (1985), in performing risk analysis of a construction cost estimate, also grouped risks in a similar classification. Charoenngam and Yeh (1999) classified the risks in hydropower construction in six risk categories. Isaksson (2002) also endorsed the same classification to estimate the time and cost based on risk evaluation applied on tunnel projects. Categories of risks and the common risk factors for construction based on this classification are presented in Table 2.

As the objective was to determine the contingency of the construction projects, only the construction related risks were emphasized. Risks that were likely to occur in the operation phase or any other risks that did not affect construction related activities were not considered. Moreover, risks that were believed to be abnormal or risks that involved catastrophic variations were also not included in the scope. If these risks were considered, it would make the contingency allowance too high to be realistic. Even if the impact was great due to these risks, the likelihood of occurrence was simply too low for them to be given due consideration.

The checklist prepared was given to the project personnel for review. This was to ensure that there were no major risk factors excluded from the list. Respondents were free to add any risk indicators that they felt was important and similarly were also allowed to remove those indicators from the checklist if they thought that they were not important. However, a consensus was tried to reach among the participants through interviews. From the responses obtained from the project participants following risks were considered to have major role in determining the cost variations for the projects.

Table 2: Categories of Risks (Charoenngam and Yeh, 1999)

Construction related • Changes in the work • Construction delay • Delayed site access • Late drawings and instructions • Availability of resources • Damage to persons or property • Defective design • Cost of tests and samples • Actual quantities of work	**Contractual and Legal** • Delayed dispute resolution • Delayed payment on contract and extras • Change order negotiations • Insolvency of contractor or owner
Financial and Economic • Inflation • Funding • National and international impacts	**Physical** • Subsurface conditions of geology • Subsurface conditions of ground water • Acts of God (Earthquake, fire, etc)
Performance related • Productivity of labor • Productivity of equipment • Suitability of materials • Defective work • Conduct hindering performance of the work • Labor disputes • Accidents	**Political and Social** • Environmental issues • Regulations (e.g. safety or labor law) • Public disorder

4. Assessing the effect of risk factors on work packages

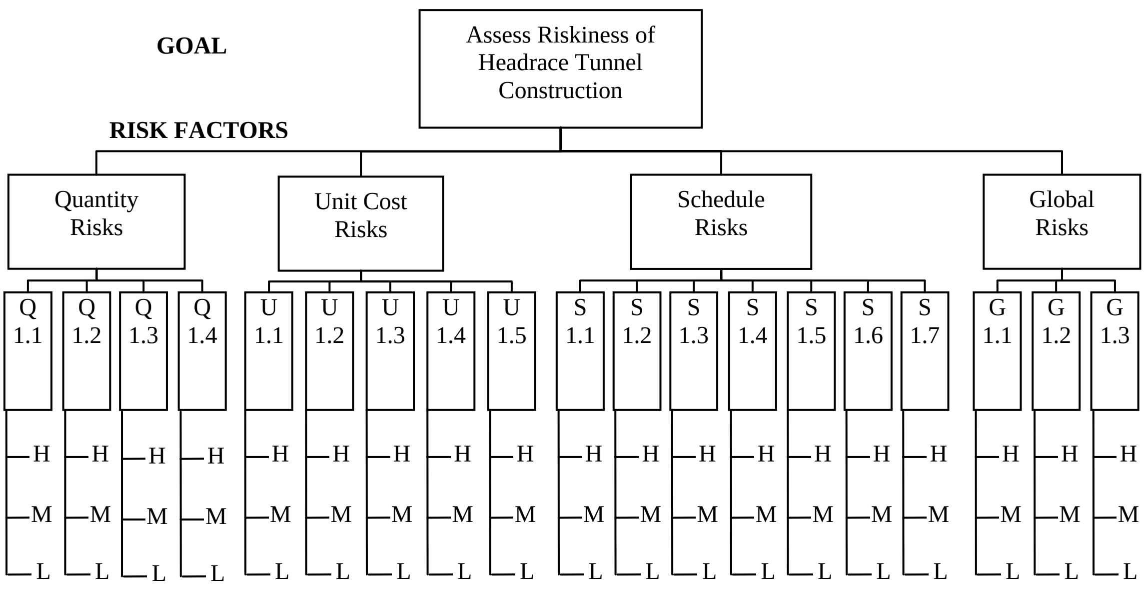
Having identified the risks that have impact on the cost, it was then necessary to approximate how much influence each of these risks had on different work packages in quantitative terms. The idea behind this was to apportion the contingency fund to different work packages depending upon the impact of these risks.

In order to find the relative importance of the identified risks, the project personnel were asked to rate the level of importance of these risks for their project and the likelihood of occurrence of these risks. In this survey they were asked to rate the importance of risks ranging from low to extreme with intermediate levels at slight, moderate, high and extreme in succession.

4.1 Prioritizing Risks Using Analytical Hierarchy Process (AHP)

AHP utilizes pairwise comparison between criteria at each level of the hierarchy and between possible alternative courses of actions (decisions). However, when there are more than seven alternatives at the bottom of the hierarchy it becomes increasingly difficult to make a comparison. In such cases a variant of the pairwise comparison is used. In this research too, keeping in mind the numerous comparisons that the respondents would have to make if the pairwise comparison was adopted direct rating of the risk factors and sub-factors was adopted. Since a single work package of the project had four risk factors and nineteen risk sub-factors, the work associated with pairwise comparison for all the work packages would be enormous. In order to reduce the work that each respondent had to do in filling the survey forms, a direct rating form of AHP rather than pairwise comparison as used by Schmoldt et al. (2001) has been considered in the survey. Eliciting response from the project participants is done by asking them to fill the direct rating forms. The risk factors and sub-factors related to the work package-Headrace tunnel are arranged hierarchically to form a risk structure as is done in the AHP. This is shown in Figure 1.

The subjective form of rating elicited from project participants has to be transformed to a rating scale to deduce the importance level of the risk factors and sub-factors in numeric value. AHP provides such a methodology to use the subjective information in the form of some importance levels. The result of the application of AHP in determining the weights of the risk factors and sub-factors for NHP has been illustrated in Table 3 without going into detail about the calculations. For Nyadi Hydropower Project as shown in Table 3, quantity and schedule related risks contributed more a less equally to determine the final cost of the project. Unknown geological subsurface condition and overbreak in tunnel excavation were two risky situations which could raise the cost of the project by increasing the amount of work. Equipment failure and unavailability of equipment and resources on time were other concerns for the project management that could delay the project, ultimately affecting the final cost of the project. Another significant risk identified was civil disorder and terrorism. All the other risks had similar scale of impact on the project cost.



RISK SUB-FACTORS

Q1.1 : Subsurface Conditions of geology/ ground condition

Q1.2 : Site and other changed conditions

Q1.3 : Defective design/ errors and omissions

Q1.4 : Overbreak-excavation

U1.1: Inflation

U1.2: Exchange rate fluctuations

U1.2: Defective work

U1.3: Productivity of labor

U1.4: Productivity of equipment

S1.1: Labor disputes/ strikes

S1.2: Accidents/ damages to life and property

S1.3: Late drawings and instructions

S1.4: Equipment failure

S1.5: Availability of resources/ equipment on time

S1.6: Change order negotiation/ dispute resolution

S1.7: Adverse weather conditions

G1.1: Civil disorder/ terrorism

G1.2: Requirements of permits and their approvals

G1.3: Regulations (e.g. safety and labor law)

Likelihood of occurrence of risk
H- High
M- Medium
L- Low

Figure 1: Risk structure for headrace tunnel construction

Table 3: Relative importance of risk - Nyadi Hydropower Project

Risk factor	Risk sub-factor	Relative importance (%)
Quantity risk		**31.6**
	Subsurface conditions of geology/ground contours	9.6
	Site and other changed conditions	5.4
	Defective design/errors and omissions	5.4
	Overbreak excavation	11.2
Unit cost risk		**19.4**
	Inflation	2.5
	Exchange rate fluctuations	4.6
	Defective work	4.0
	Productivity of labor	3.8
	Productivity of equipment	4.5
Schedule risk		**30.8**
	Labor disputes/strikes	3.2
	Accidents/damages to life and property	4.4
	Late drawings	4.2
	Equipment failure	6.9
	Availability of resources/equipment on time	6.6
	Change Order negotiation and dispute resolution	3.4
	Adverse weather conditions	2.1
Global risk		**18.2**
	Civil disorder/terrorism	9.4
	Requirements of permits and their approvals	5.8
	Regulations (e.g. safety and labor law)	3.0

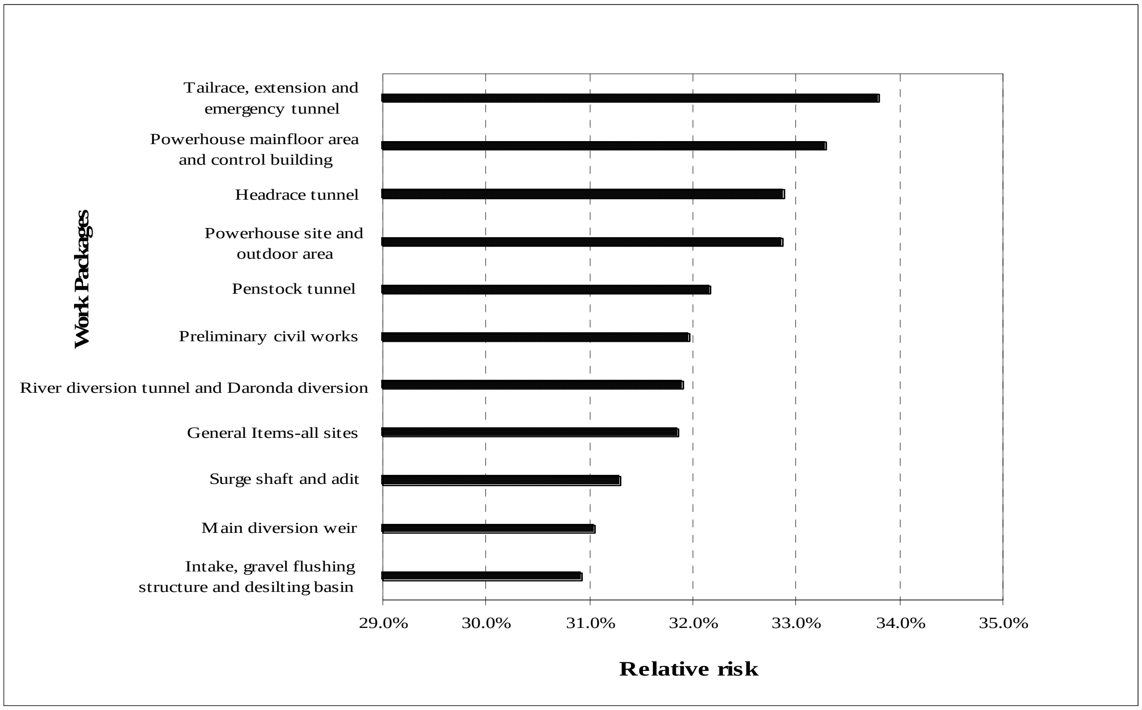


Figure 2: Relative risk weights of work packages- Nyadi Hydropower Project

5. Estimating the cost of risk

Finally, having assessed the risk, a crucial risk management aspect of allocating the funds based on the risk weightage is done. This is done through the following processes illustrated in the next section for the same example of Headrace tunnel construction work package for Nyadi Hydropower Project.

5.1 Ranging

Before any meaningful allocation of contingency can be made, it becomes essential to assess how much each risk factor affects the line items in a work package in monetary value. Since it is difficult to estimate the monetary impact of the risk in a deterministic manner, ranging is done to give a range within which the cost for the line item is most likely fall. The range of the cost for any activity is dependant on how well the scope of the activity is defined at the time of cost estimation. If the definition of the activity is reasonably well defined, then it means that the effects of risk factors, if any, have been considered well and there was relatively less variability of cost change in case of occurrence of the risks. Scope definitions for other classes of risks are enumerated as shown in Table 4. This ranging was based on the one proposed by Yeo (1990) but with modifications to suit the projects considered for the case study. A significant change has been made for the probable upper bound range for undefined scope of activity keeping in mind the prevalent large variations in cost in hydropower projects. The project participants were of the view that since some of the activities at the feasibility stage were undefined or not defined well, increase in cost as much as 100% was possible for the hydropower projects considered.

Table 4: Classification of risk

		Probable Error Range	
Scope definition	**Class of risk**	**Lower bound**	**Upper bound**
Reasonably well defined	Class A	-5%	+20%
Fairly defined	Class B	-10%	+30%
Poorly defined	Class C	-15%	+50%
Undefined	Class D	-20%	+100%

A slightly different approach of assigning a range for activity cost was done. Rather than assigning a single range for an activity cost, ranging was performed for all the risk factors that affected the cost of the activity. This was done to ensure a better estimation with greater detail. An example of this ranging performed by one of the project personnel for the work package - Headrace tunnel construction of Nyadi Hydropower Project is shown in Table 5.

Table 5: Scope definition of activities of headrace tunnel work package- Nyadi Hydropower Project

Sl.No.	**Work Package/ Activity**	**Risk**			
1	**Headrace tunnel**	**Quantity Risk**	**Unit Cost Risk**	**Schedule Risk**	**Global Risks**
1.1	Site establishment	B	A	D	C

1.2	Portal	A	A	B	B
1.3	Tunnel excavation	D	D	D	D
1.4	Rock support by reinforced concrete	C	A	C	C
1.5	Rock support by bolting	B	A	B	B
1.6	Spiling	B	B	B	B
1.7	Probe holes	B	B	B	B
1.8	Grouting works	D	A	B	B
1.9	Concrete lining	D	B	B	B

As a result of direct rating and the ranging of activities, a combined matrix is formed which depicts the influence of each risk factor on the activity cost. The weights of the different Risk Factors obtained from AHP along with the range of cost estimate for each activity is presented in the form of activity/risk factor matrix as shown in Table 6.

Table 6: Activity/ risk factor matrix for headrace tunnel construction for Nyadi Hydropower Project

Activity			**Risk Factors**			
Description	***Base Cost (USD)***	**Range**	**Quantity risks**	**Unit Cost Risks**	**Schedule Risks**	**Global Risks**
			Weight (0.167)	**Weight (0.5)**	**Weight (0.167)**	**Weight (0.167)**
Site establishment	191,200	-	0.9	0.95	0.8	0.85
		+	1.3	1.2	2	1.5
Portal	23,670	-	0.95	0.95	0.9	0.9
		+	1.2	1.2	1.3	1.3
Tunnel excavation	721,682	-	0.80	0.8	0.8	0.8
		+	2	2	2	2
Rock support by reinforced concrete	773,283	-	0.85	0.95	0.85	0.9
		+	1.5	1.2	1.5	1.3
Rock support bolting	215,592	-	0.9	0.95	0.9	0.9
		+	1.3	1.2	1.3	1.3
Spiling	99,366	-	0.9	0.9	0.9	0.9
		+	1.3	1.3	1.3	1.3
Probe holes	19,376	-	0.9	0.9	0.9	0.9
		+	1.3	1.3	1.3	1.3

Grouting works	162,272	-	0.8	0.95	0.9	0.9
		+	2	1.2	1.3	1.3
Concrete lining	251,197	-	0.8	0.9	0.9	0.9
		+	2	1.3	1.3	1.3
Effect on total			**I_Q**	**I_U**	**I_S**	**I_G**

From the activity/risk factor matrix, the total effect of ranges due to quantity risk for the work package can be determined. The total effect of ranges due to quantity risk, denoted by I_Q, is the sum of the effect of ranges due to quantity risk on each activity making up the work package. Similarly, the total effect of ranges due to unit cost risk, schedule risk and global risk denoted by I_U, I_S and I_G respectively can be determined. The total effect due to all these risk factors, which is the sum of I_Q, I_U, I_S and I_G, gives the risk-weighted or risk adjusted cost for the work package. However, simple addition of these ranges is not possible but can be done easily by employing Monte Carlo Simulation (MCS) and is described in the following section.

5.2 Combining multiple activity risk distributions

When three points of the triangular distribution, namely, the low end cost, most likely cost (base cost estimate) and the high end cost, are defined then an expected cost can be determined from the probable values. Moreover, it can be assumed that addition of several such triangular probability distributions is a normal distribution function whose expected value can be determined. The variance and the standard deviation can also be determined from such normal distribution function. With the help of Monte Carlo Simulation technique, the combination of such distribution functions is possible. In this case study, @Risk software that enabled MS Excel add-in to input the ranges for the triangular distribution was used. Monte Carlo Simulation was then used to combine all the triangular distributions for each of the risk categories. The result was a normal distribution curve under each risk factor. These four normal distribution functions combined together resulted in another normal distribution curve that represented the overall risk of the work package. From this normal distribution curve, an expected risk-adjusted cost for the work package was obtained. However, since it would not be sufficient to be satisfied with merely a 50% chance of cost being under run, a more reasonable likelihood percentage of the cost not exceeding the budgeted value is required. A cumulative distribution curve from the normal distribution curve can be derived so that the cost that would be required to successfully complete work with certain level of confidence is determined. A graphical illustration of the combination process of cost distributions under each risk factor for Headrace tunnel construction of Nyadi Hydropower Project is shown in Fig 3.

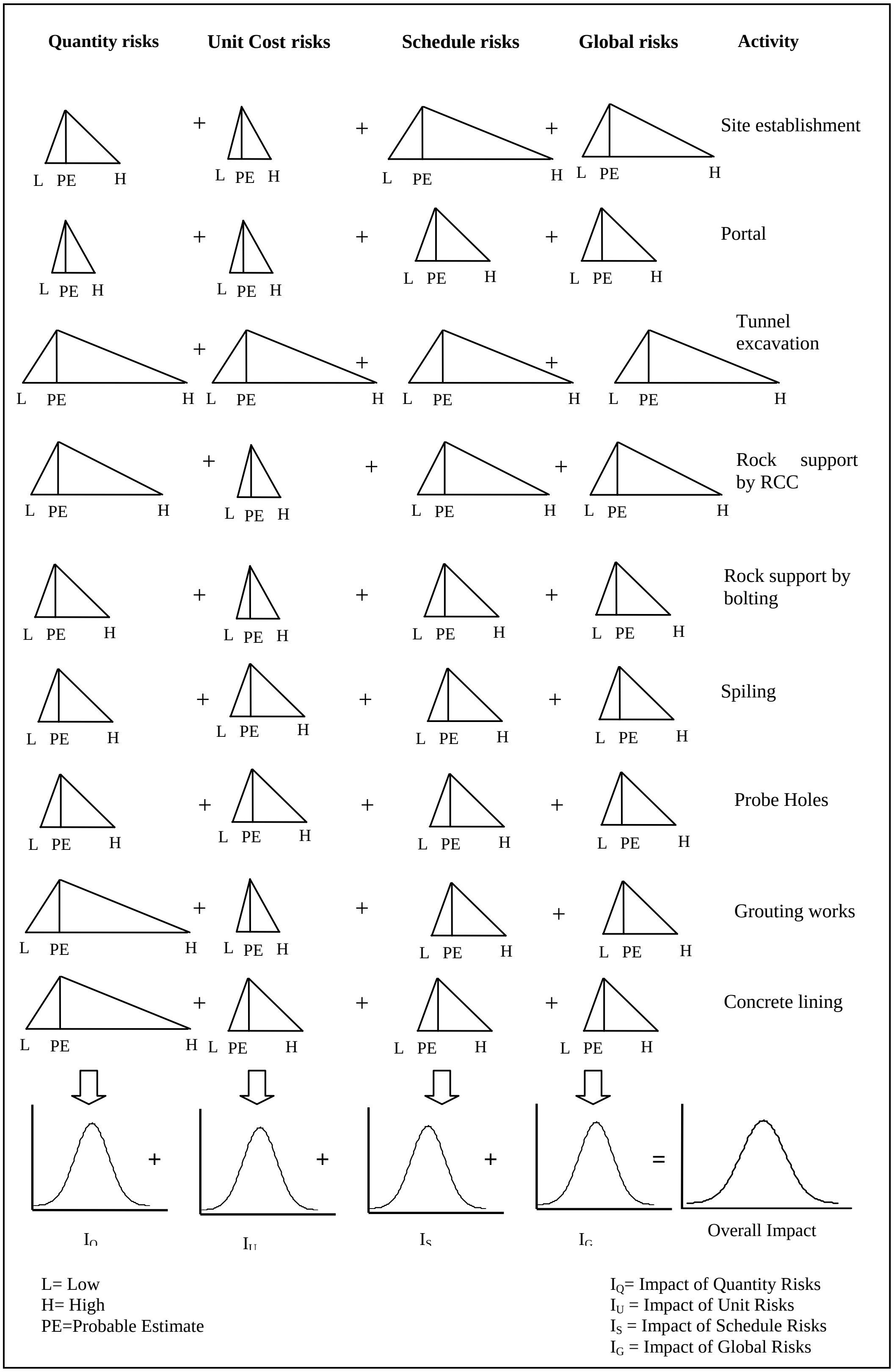


Figure 3: Combining multiple activity risk distribution using Monte Carlo Simulation Contingency allocation based on the overall risk of the work package

What remains now is to allocate contingency fund to accomplish the work taking into consideration the effects of risks on the work package. As mentioned earlier, expected cost could be read from the normal distribution curve or the cumulative distribution curve so that the chance of successfully accomplishing the work with the cost being within the budgeted amount is 50%. However, no project managers would be satisfied with this target. They would definitely want the work to be completed with 100% confidence level. This however, would require extra budgeting and would not be practical. A more practical approach would be to determine this confidence level from the view point of the riskiness of the work package and apportion the budget accordingly. If the work package is found to be more risky, it would require more allocation of the fund to get completed successfully. This extra allocation of fund above the base cost estimate gives the contingency required for the work package.

For instance, one of the respondents for Nyadi Hydropower Project perceived that the overall risk for the headrace tunnel construction was 35%. The probability that the cost will lie within targeted cost is proportional to the summation of even chance of success (50%) and the overall percentage risk of work package, 35% in this case. So, from the cumulative distribution curve obtained from Monte Carlo Simulation as shown in Figure 4, target cost corresponding to 85% (50%+35%) is determined. This targeted cost for this example was USD 2,908,951 which is USD 451,313 more than the base cost. This extra cost is the contingency to be allocated for the construction of headrace tunnel for Nyadi Hydropower Project.

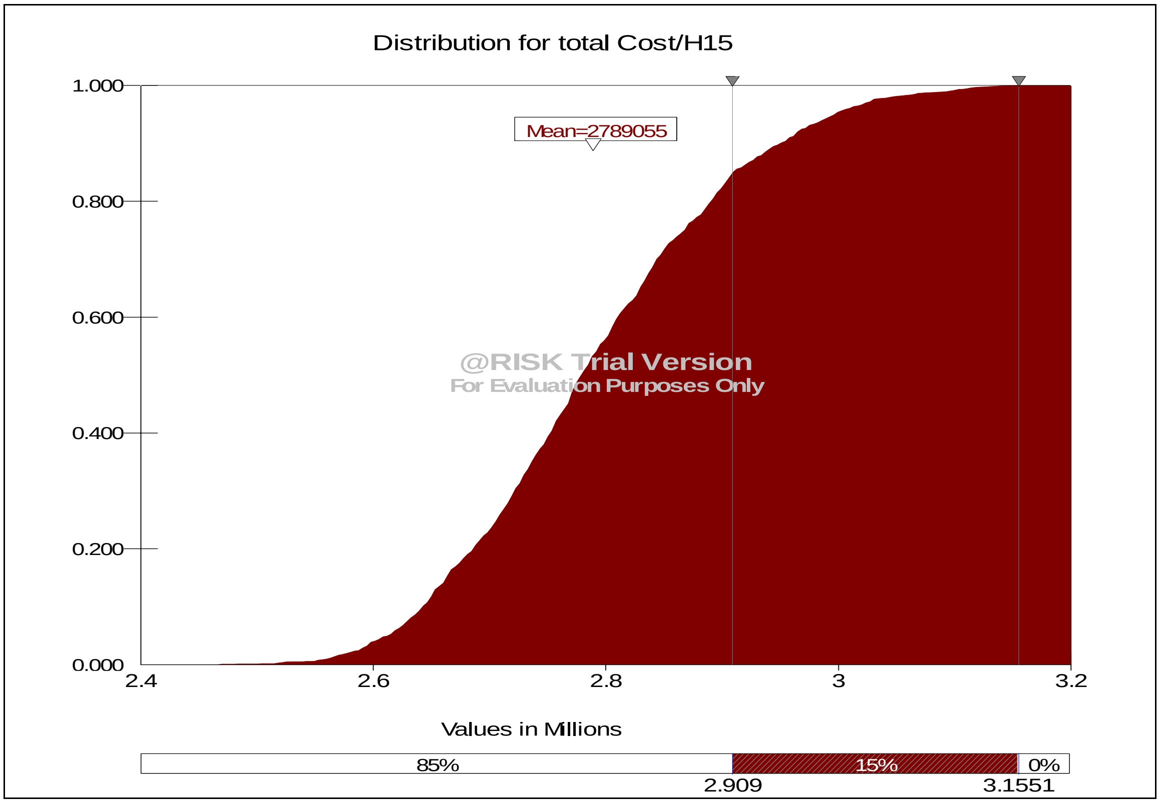


Figure 4: Cumulative distribution curve obtained from Monte Carlo simulation

Similarly, Contingencies for other work packages and for other respondents can be determined in a similar manner and the average is taken as the final contingency. Contingency allocated for Nyadi Hydropower Project based on this methodology is shown in Figure 5.

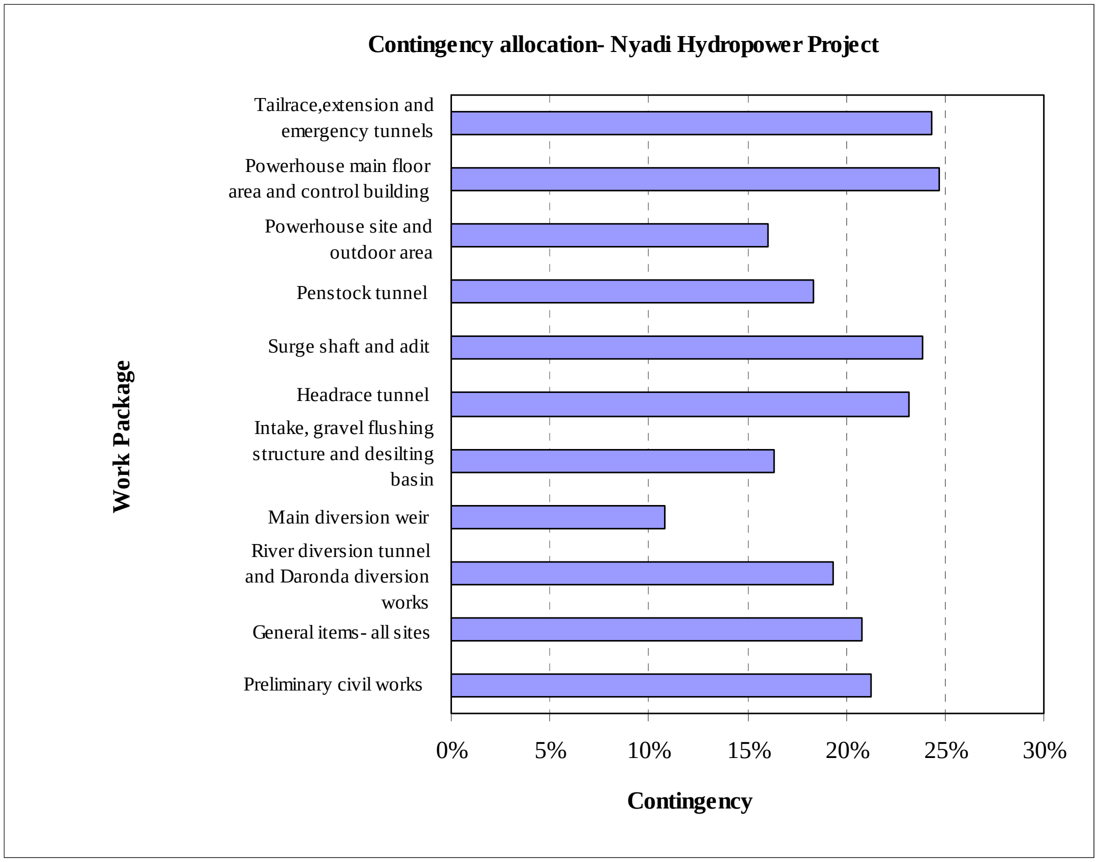


Figure 5: Contingency Allocation for Different Work Packages of NHP

6. Conclusions and recommendations

Following conclusions and recommendations based on the results could be made from the risk analysis:

- Risk identification done for project shows that quantity related risks are major causes of concern. Unknown geological and underground conditions and overbreak in tunnels were risk sources most likely to increase the cost of the project. For Nyadi Hydropower Project, security concerns were significantly high too. This is due to the worsening security situation in Nepal which can greatly impact the schedule of the project assuming the situation does not improve in the near future. Equipment breakdown and unavailability of these equipment and other resources on time has a substantial impact on the schedule of the project. This is quite understandable with regard to the remote location of the project considering the time it would require to replace the damaged equipment and supply other resources. The risk sources having greatest impact are summarized as follows in order of decreasing importance:

- Overbreak in tunnel excavation
- Unknown subsurface conditions of geology/ ground contours
- Civil disorder/ terrorism
- Equipment failure
- Unavailability of resources/ equipment on time

- Work packages involving tunneling works possessed higher relative risks. These included construction of headrace tunnel, tailrace tunnel, penstock tunnel and underground powerhouse for the project. This is because of the fact that tunneling projects are sensitive to disturbances. Tunneling process is a serial type of production system. Therefore, in such a system the possibility for changing the workplace location is limited, except when there are many tunnel adits.

- Overall contingency percentage determined from the risk analysis for Nyadi Hydropower Project was 20.20%. However, contingency allocated for the project for the civil works at the time of preparation of detailed feasibility study report is 13.59%. Final cost overrun, however, is not available as the construction of the project has not started yet. Although the projected contingency from the risk analysis performed is higher by about 7% than that of the actual contingency allocated at the time of preparation of the detailed feasibility study report, such increase in cost is possible. It should be noted here that the contingency allocated for Nyadi Hydropower Project during the detailed feasibility study is an arbitrary one followed on the basis of normal trend for the past construction projects.

However, for Nyadi Hydropower Project, the results obtained from the risk analysis could be used to allocate contingency accordingly rather than assigning the contingency arbitrarily. To avoid the chance of the project being overrun, contingency of 20.20% should be allocated for Nyadi Hydropower Project. The project management should be cautious of the high ranking risk work packages and the potential risks identified so that they can apply necessary risk management approaches early on the project stage. This will avoid any complicated situation arising at the later stage of the project. Although the risk analysis methodology developed is tested only for the above project, it could equally apply to other projects of similar nature. The sources of risk, however, should be identified specifically for each project whose risk analysis is to be done. It is recommended here that whoever is doing the cost estimation of the project should incorporate risk analysis in the cost estimate process to allocate contingency based on the risk analysis.

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