

# A Concept Model to Scale the Impact of Safety Risk in a Construction Project Using a Semi Quantitative Method

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**Abstract** The success of a construction project is influenced by variables including time, cost, quality, scope, safety and the environment. These variables all have associated risks. These risks can be managed through the stages of risk identification, risk analysis to determine priority, the risk response itself and risk control. Qualitative and quantitative methods are generally used in the risk analysis stage. A probability-impact (P-I) risk matrix is used for qualitative risk analysis. The weakness of a qualitative risk analysis is that it is not able to provide integrated information on the impact of risks on the project variables, whereas semi-quantitative analysis can alternatively be conducted. The current semi-quantitative description and measurement scale is limited to the P-probability and I-impact for variable cost, quality, time and the scope of the project. The integration of the project constraint variables found is usually a triple constraint which integrates the cost, quality and time variables. The accommodation of global issues in the safety aspects of the project then allows for the development of a diamond model that integrates the variables of cost, quality, time and safety. The development of a semi-quantitative risk analysis is limited by integrating the triple constraint variable where the diamond constraint variable has not been found. This is due to the unavailability of a semi-quantitative safety impact scale. This paper specifically formulates the impact of risk on the safety aspects in a semi-quantitative manner. A descriptive methodology was used for this research. The variance in the safety impact scale was identified from a literature review and the expert judgement method was analyzed through brainstorming with experts. The results of the

analysis for the formulation of the safety risk impact scale model using the semi-quantitative method were obtained through the use of a hybrid formulation between the Project Management Body of Knowledge (PMBOK) guidelines and the Standard Australian / Standard New Zealand (AS / NZS) 4360 with a scale of 1 to 5 and a description of the impact starting from very low through to low, moderate, high and very high. It has numeric values of 0.05, 0.1, 0.2, 0.4 and 0.8 adopted from the PMBOK while the detailed descriptions were adopted from the AS / AZS 4360 guidelines. This obtained safety scale can be used in integrated risk analysis with semi-quantitative methods and a constraint diamond model with the variables of cost, quality, time and safety.

**Keywords** Analysis, Semi Quantitative, Impact of Safety Risks, Integration, Construction Projects

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## 1. Introduction

Infrastructure projects are intended to enhance the community's economy. However, during the construction implementation period, there are risks to the stakeholders and the environment [1, 2]. These risks are related to time, cost, quality, scope, resources, safety technologies and the environment. The risk analysis that is commonly used today is either a qualitative or quantitative method of analysis. The qualitative method provides a descriptive description of the impact of the risk using an ordinal

measurement scale and the quantitative method uses a numerical value measurement scale. The description of the results of the risk analysis of the qualitative method is not yet able to show the priority of the risks. For this reason, a semi-quantitative method was developed. The semi-quantitative method is a hybrid of the qualitative and quantitative methods. At present, the semi-quantitative risk analysis used for risk assessment in construction projects is limited to the aspects of cost, quality, time and scope [3, 4]. Most project managers are familiar with the project management triangle of quality, cost and time. These three criteria involve project management risks. The combination or relationship between the integration of these risk variables indicates that the strategic risk management decisions are easier to make [5]. Incorporating the cost, quality and time aspects that can allow for more comprehensive strategic risk mitigation decisions to be made [6].

The safety performance in project management

becomes an important issue and an added baseline within the scope of project performance management. The integration of the 4 types of performance that have been studied includes the variables of cost, quality, time and safety [7]. The parameters for the impact of the risks related to the cost, quality and time aspects using semi-quantitative methods have been studied previously but the impact of the risks of safety has not been realized until now.

## 2. Materials and Methods

The research material is the parameters of the scale used to determine the impact of the safety aspect as the object of the case study of a National road improvement project. The descriptive methodology was used in this research. The research concept framework has been presented in Figure 1.

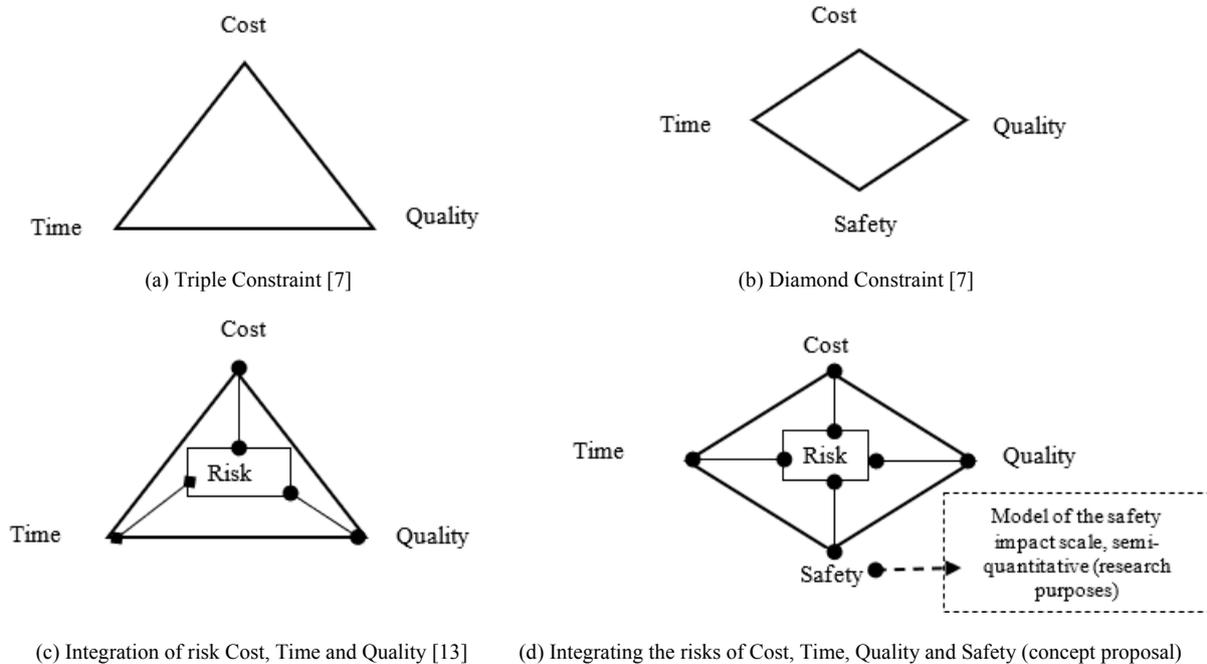


Figure 1. Research Concept Framework

The research steps and methods used to obtain a safety impact model using a semi-quantitative method were as follows:

- 1) The conducting of a literature review regarding the impact of ordinal scale hazards and the aspects of different numerical scale categories.
- 2) Establishing a brainstorming team using a non-probability sampling method [8] to determine the expert team. The designated team of experts consisted of two supervisory advisors, two directors, two entrepreneurs and an academic.
- 3) Analysis of the dominant category scale from the category scales found by the expert’s judgements (3).
- 4) Brainstorming of the variants of the descriptions for the dominant categories in Step 3) to determine the category descriptions [3].
- 5) Evaluation of the numerical scale of the predetermined category scale as in Step 4) and then brainstorming the numerical scale using the expert judgement method [3].

The scales used for measuring impact (I) with categories 1 - 3 were found in up to 4 reference sources [4, 9-11]. The impact scale with categories 1 - 3 has been described in Table 1.

2) Impact scale (I) categories 1 - 4.

The measurement impact scale I with 4 categories of 1 - 4 was found in a single reference source [12]. The degree of impact described in Scale 4 is catastrophic, Scale 3 is critical, Scale 2 is marginal and Scale 1 is insignificant. This can be seen in Table 2.

**Table 2.** Impact scale with categories 1 - 4

Category scale	Description severity
(a)	(b)
4	Catastrophic
3	Critical
2	Marginal
1	Negligible

Source: [12]

### 3. Results and Discussion

#### 3.1. Risk Impact Categorization Scale

The results of the literature review of Risk Impact Categories (I) found four groups of categories on a scale of 1 - 3, 1 - 4, 1 - 5 and 1 - 6.

1) Impact scale (I) with categories 1 - 3.

**Table 1.** Risk impact scale (I) with categories 1 - 3

Category scale	Description			
	[4]	[9]	[10]	[11]
(a)	(b)	(c)	(d)	(e)
1	Low	Slight accident	Light	Slight injury
2	Medium	Severe accident	Moderate	Severe injury
3	High	Fatal accident	Weight	Fatal injury

3) Scale of impact (I) categories 1 - 5.

The scale of the impact of measurement I with 5 categories 1 - 5 was presented in 10 reference sources [3, 12-20]. The varying descriptions of the category scale of 1 - 5 can be seen in Table 3. In the columns of Table 3 (k\*), there are 5 class descriptions but there are differences in the ordinal scales from 0 - 4 [20]. Some authors have developed a category scale from 1 - 5 in detail. A detailed description of the five categories under AS/NZS 4360 is shown in Table 4. Several sources complement the description of the impact of the category 1 - 5 scale with linear and non-linear cardinal numerical scales [3, 4] which can be seen in Table 5 based on the PMBOK guidelines [3]. In Table 5, impact I may already be reported in semi-quantitative parameters since the scale 1 - 5 is a combination of qualitative and quantitative data. The qualitative description is always very short. This makes it more difficult for the respondents to understand.

**Table 3.** Description of the impact scale (I) with 5 categories of 1 - 5

Category scale	Description				
	[3]	[12]	[13]	[14]	[15]
(a)	(b)	I	(d)	I	(f)
1	Very Low	Negligible	Very Low	Insignificant	Single fatality
2	Low	Minor	Low	Minor	2-10 Fatalities
3	Moderate	Serious	Moderate	Moderate	11-50 Fatalities
4	High	Fatal	High	Major	51-100 Fatalities
5	Very High	Catastrophic	Very High	Severe	100+ Fatalities

**Table 3.** Description of the impact scale (I) with 5 categories of 1 - 5 (continued)

Category scale	Description				
	[16]	[17]	[3]	[12]	[13]
(a)	(g)	(h)	(i)	(j)	(k*)
1	Insignificant	Insignificant	Level 1	Very Low	Negligible
2	Minor	Minor	Level 2	Low	Marginal
3	Moderate	Moderate	Level 3	Moderate	Serious
4	Major	Major	Level 4	High	Critical
5	Catastrophic	Catastrophic	Level 5	Very High	Catastrophic

**Table 4.** Detailed description of the impact (I) in accordance with AS/ NZS 4360

Category scale	Description	Detailed description
1	Insignificant	No injuries, low financial loss
2	Minor	First aid treatment, on site release immediately contained, medium financial loss
3	Moderate	First aid treatment required, on site release contained with outside assistance, high financial loss
4	Major	Extensive injuries, loss of production capability, off-site release with no detrimental effects, major financial loss
5	Catastrophic	Death, toxic release off-site with detrimental effect, huge financial loss

Source: [3]

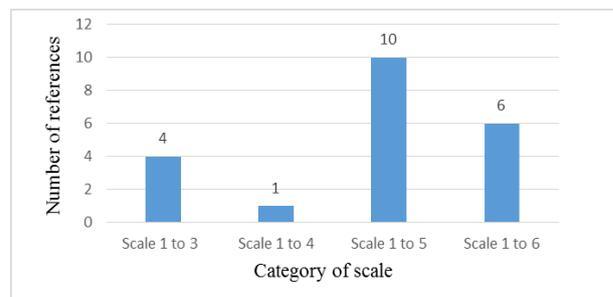
**Table 6.** Description of impact scale I on a scale of 1 - 6.

Category scale	Description					
	[21]	[22]	[23]	[24]	[25]	[26]
(a)	(b)	I	(d)	I	(f)	(g)
1	Not Significant	None	Negligible	Noticeable	Minor injury	Negligible
2	Very Low	Very Low	Very Low	Important	No serious disabling injury	Very low
3	Low	Low	Low	Very serious	Extremely serious injury	Low
4	Medium	Medium	Medium	Serious	Fatality	Middle
5	High	High	High	Disaster	Multiple fatalities	High
6	Very High	Very High	Very High	Catastrophe	Catastrophe, numerous fatalities	Very high

4) Impact scale (I) categories 1 - 6.

Impact scale (I) with a class scale of 1 - 6 has been proposed with up to 6 reference sources [21-26]. A description of the scale for categories 1- 6 has been given in Table 6.

In Tables 1, 2, 3 and 4, it can be seen that the references related to risk impact (I) to date have been found. There are 4 references for the category scale of 1 - 3, 1 reference for the category scale of 1 - 4, 10 references for the scale of 1 - 5 and 6 references for the scale of 1 - 6 which graphically can be seen in Figure 2.



**Figure 2.** Reference Frequency Plot by Risk Impact Category Scale (I)

**3.2. Analysis of Impact Safety (I)**

The expert judgment method was performed through brainstorming with the chosen experts. This was used to analyze and determine the category scale, the operational descriptions of the category scale and to determine its numerical size. In Figure 2, it was determined that the category scale 1 to 5 is found to be at most 10 characters. The category scale of 1 - 6 is 6 references, a scale of 1 - 3 is 4 references and a scale of 1 - 4 is only 1 reference. If scale 1 is reached on a scale of 1 to 6 in Table 6, the ordinal scale in Category 1 explains that almost all of the descriptions indicate that the impact of the risk is insignificant or does not have any impact. If scale 1 is ignored on a scale of 1 - 6, the descriptions are equivalent to a scale of 1 - 5. The expert brainstorming results state that a scale of 1 - 5 was chosen as the impact scale based on the frequency of the most widely used scale of 1 - 5 (10 references). The description of the impact scale of 1 - 5 can be observed in Table 3, which indicates that the description of each class of ordinal scale varies greatly. The results of the brainstorming in the description formulation phase involve the selected 3 references used for the descriptions of the categories 1 - 5, namely the PMBOK guidelines [3], the AS / NSZ\_4360 [16] guidelines and BSN [17], as seen in Table 7.

The description of the impact of the risk on a scale of 1 to 5 among the 3 selected references as in Table 7 was followed by a more in-depth brainstorm. The description of the brainstorming results was used to formulate the category scale of 1 - 5 to combine the PMBOK guidelines'

[3] brief description as shown in Table 7 column (b) and the detailed descriptions of the AS / NZS 4360 guidelines [16] as in Table 7 column (d). The results of this brainstorming can be seen in Table 8.

In Table 8, the severity scale of the impact categories (I) is given qualitatively using an ordinal scale. The qualitative measure scale in Table 8 indicates that the scale becoming semi-quantitative, quantitative or numerical is required. The brainstorming results in the numerical scale formulation use a numerical scale referred to in the PMBOK guidelines [3] as shown in Table 5. In Table 5, there are 2 kinds of numerical value models, namely linear and non-linear cardinals. The brainstorming results of the experts formulated a numerical scale with a non-linear cardinal scale with the argument that the basis for implementing a construction project is the time schedule. Project timelines generally have a non-linear trend. Based on the time schedule, the project resources can be allocated. The allocation of project resources has an impact on the cost schedule with a non-linear trend as well. The formulation with a non-linear cardinal scale is in line with the scale found by other researchers for the impacts of cost, quality and time risk using a semi-quantitative scale [3, 13]. The safety risk impact parameter model (I) using the semi-quantitative method can be formulated using a scale of 1 to 5 with a brief description of the impact ranging from very low to very high. The numerical scale is non-linear cardinal with numerical values of 0.05, 0.1, 0.2, 0.4 and 0.8. This numerical scale can be seen in Table 9.

**Table 7.** The formulas of the impact descriptions that were selected for the scale 1 - 5

Category scale	Impact and description			
	[3]		[16]	[17]
(a)	(b)	(c)	(d)	(e)
1	Very Low	Insignificant	No injuries, low financial loss	Insignificant
2	Low	Minor	First aid treatment, on site release immediately contained, medium financial loss	Minor
3	Moderate	Moderate	First aid treatment required, on site release contained with outside assistance, high financial loss	Moderate
4	High	Major	Extensive injuries, loss of production capability, off-site release with no detrimental effects, major financial loss	Major
5	Vey High	Catastrophic	Death, toxic release off-site with detrimental effect, huge financial loss	Catastrophic

**Table 8.** Hybrid of PMBOK and AS / NSZ 4360 used to construct a qualitative description of the impact of the safety risks using scale Categories of 1 - 5

Category Scale	Short description [3]	Detailed description [16]
1	Very Low	No injuries, low financial loss
2	Low	First aid treatment, on site release immediately contained, medium financial loss
3	Moderate	First aid treatment required, on site release contained with outside assistance, high financial loss
4	High	Extensive injuries, loss of production capability, off-site release with no detrimental effects, major financial loss
5	Very High	Death, toxic release off-site with detrimental effect, huge financial loss

**Table 9.** Formulation of the impact scale (I) using a semi-quantitative method for the safety aspects

Category Scale	Description		Numerical value scale
1	Very Low	No injuries, low financial loss	0.05
2	Low	First aid treatment, on site release immediately contained, medium financial loss	0.1
3	Moderate	First aid treatment required, on site release contained with outside assistance, high financial loss	0.2
4	High	Extensive injuries, loss of production capability, off-site release with no detrimental effects, major financial loss	0.4
5	Very High	Death, toxic release off-site with detrimental effect, huge financial loss	0.8

**Table 10.** Risk impacts on cost, quality, time and safety using a semi-quantitative scale.

Category Scale	Impact	Description of Impact				Numerical value scale
		Cost [13]	Time [3,13]	Quality [3,13]	Safety	
1	Very Low	Insignificant cost	Insignificant time increase	Quality degradation barely noticeable	No injuries, low financial loss	0.05
2	Low	< 10% cost increase	< 5% time increase	Only very demanding applications are affected	First aid treatment, on site release immediately contained, medium financial loss	0.1
3	Moderate	10–20% cost increase	5–10% time increase	Quality reduction requires sponsor approval	First aid treatment required, on site release contained with outside assistance, high financial loss	0.2
4	High	20–40% cost increase	10–20% time increase	Quality reduction unacceptable to sponsor	Extensive injuries, loss of production capability, off-site release with no detrimental effects, major financial loss	0.4
5	Very High	> 40% cost increase	> 20% time increase	Project end item is effectively useless	Death, toxic release off-site with detrimental effect, huge financial loss	0.8

The safety impact parameter model using the semi-quantitative method obtained from the research results as shown in Table 9 can be used in integrated project risk analysis in relation to cost, quality, time and safety. This is because it is aligned with the risk impact scale model using the semi-quantitative method for the variables of cost, quality and time [3, 13]. The semi-quantitative risk impact scale model with the variables of cost, quality and time from the related references and the safety variable obtained from the research results can be seen in Table 10.

#### 4. Conclusions

The semi-quantitative scale model on the impact of safety risks was obtained from a hybrid formulation between the Project Management Body of Knowledge (PMBOK) guidelines by the Project Management Institute and the Standard Australian / Standard New Zealand (AS / NZS) 4300 by Standard Australian / New Zealand. The qualitative scale model obtained uses an ordinal scale of 1 to 5 with a description of the impact ranging from 1 to 5 in order, namely very low, low, moderate, high and very high. The numerical scale uses the cardinal scale of the nonlinear model in order of 0.05, 0.1, 0.2, 0.4 and 0.8,

adopted from the PMBOK guidelines. The operational descriptions were adopted from the 4300 (AS / NZS) guidelines. The safety risk impact scale model obtained can be used to analyze the integrated risk of the diamond constraint model, inclusive of the integration of risks in terms of cost, quality, time and safety.

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