UDC 69.05:658.155.5
DOI: 10.15587/1729-4061.2025.330351

DEVELOPMENT OF CONTINGENCY COST ANALYSIS MODEL IN CONSTRUCTION PROJECT WITH COST-TIME-QUALITY RISK INTEGRATION

I Nyoman Yudha Astana
Corresponding author
Doctor of Construction Management*
E-mail: astana_yudha@unud.ac.id
Dewa Ketut Sudarsana
Professor of Civil Engineering*
Ariany Frederika
Magister of Engineering*
Putu Ari Sanjaya
Magister of Engineering*
*Department of Civil Engineering
Udayana University
Kampus Bukit Jimbaran str., Badung, Bali, Indonesia, 80362

The object of this study is the contingency cost in the implementation of construction projects. The problem to be solved is the develop a contingency cost model in the implementation of construction projects, by integrating cost, quality, and time risks. The previously used models involve cost, quality, and time risks separately. It is still rare to find an analysis in construction project execution that incorporates these three risks into a contingency cost model. The formulation of this integration is crucial since every project is unique and carries varying degrees of risk. Data were investigated and collected from the Bali Province Regency Road Improvement Project, and the descriptive strategy analysis was employed. Using the probability (P) by impact (I) approach, which is the multiplication of (P) by (I) on a Likert scale of 5, triple constraint risks are included in the Expected Monetary Value (EMV) analysis. Moreover, monetary units are used to develop impact scale I, in which daily penalties and quality with rework costs are applied using the monetary unit approach of time effect. The simultaneous total of the PI from time, cost, and quality concerns is the EMV contingency cost formulation for the integration of these risks.

The study obtained that, a cost contingency model was created that incorporates the risk factors of cost, time, and quality. This model's cost contingency value was 9.61% of the total cost when it was applied to a case study. Specifically, this finding falls between 5% and 10%, which is adequate and consistent with the empirical approach. This contingency cost model is thought to be more rational since it accounts for project risks, including the likelihood of potential risks as well as their effects. The project team can use this approach to estimate contingency expenses

Keywords: construction project, risk integration, cost-time-quality, contingency cost, EMV

Received 02.04.2025
Received in revised form 21.05.2025
Accepted 09.06.2025
Published 30.06.2025

How to Cite: *Astana, I. N. Y., Sudarsana, D. K., Frederika, A., Sanjaya, P. A. (2025). Development of contingency cost analysis model in construction project with cost-time-quality risk integration. Eastern-European Journal of Enterprise Technologies, 3 (3 (135)), 49–56. https://doi.org/10.15587/1729-4061.2025.330351*

1. Introduction

When managing a building project, it's critical to ascertain the amount of unexpected expenses. In construction projects, these unexpected costs are often referred to as contingency costs. The number of contingency expenses is not only crucial during project execution, but it is also crucial during the bidding construction phase [1]. A contractor must thoroughly comprehend the hazards that are anticipated to arise during the project's later implementation before submitting a bid. These risks must therefore be considered when determining how much markup should be placed during the bid. Typically, contractors just use the project's percentage cost to account for contingency expenses; they do not take the project's degree of risk into account. As every project is unique and has varying degrees of risk, so too should the way contingency expenses are distributed. If the number of contingency costs is too high, being inaccurate in estimating them will prevent from winning the competition; if it is too low, it will make field execution challenging. Given the significance of these contingency expenses, contingency costs must be developed based on time, cost, and quality risks.

Therefore, research on contingency costs integrated with cost, time, and quality risks is relevant to carry out. Furthermore, this will help practitioners manage construction projects both during the bid and during implementation, maximizing project performance.

2. Literature review and problem statement

Risk analysis in construction projects has developed significantly to date because it is able to mitigate the risks contained in the project performance success variables. Risk analysis generally uses qualitative, quantitative, and semi-quantitative analysis methods. Risk analysis can be used to calculate contingency cost allocation with a semi-quantitative method with a risk impact scale in monetary units.

Paper [2] finds that construction projects are high-risk occupations. Up to 10–30% of risk management emphasizes how crucial it is to recognize and manage possible risks as soon as possible to guarantee project success, but no one has yet discovered how to carry out risk analysis. Paper [3] found that inadequate risk management might result in schedule delays. Numerous factors, such as the extent of the job, time, cost, quality, resources, technology, safety, and others, affect how well a construction project functions, but an in-depth risk analysis has not been carried out. Paper [4] investigates project performance variables containing risks, such as the risk of time delays which have an impact on costs. Sources of risk that have an impact on project performance such as politics, costs, time, legality, and safety. Possible risks can be managed with risk management, and the stages of risk management begin with risk analysis, risk response and control, and risk monitoring.

The research from [5] mentions, that the risk response priority uses the AHP method, in which risk analysis and response steps prioritize major risks. Systematic guidelines for risk monitoring and control using detailed risk analysis, response, and risk control methods, but not yet continued with contingency cost analysis. Paper [6] uses risk assessment analysis using qualitative and quantitative methods, while paper [7] uses semi-quantitative methods. All sources explain that the ordinal scale is used in the qualitative analysis method. For risk probability and impact, the Likert Scale is typically used. It could be said that risk management is mostly carried out qualitatively, focusing more on expert opinion, which still contains subjectivity, so the qualifications of respondents must be determined very carefully. In paper [6, 7] no semi-quantitative method has been found that can be used for contingency cost analysis.

Papers [4, 7] describes how the PI (probability-impact) matrix methodology is used mostly for qualitative and semi-quantitative risk management, and how it is used to analyze risk in all construction project research. Risk priorities can be established by analyzing the magnitude of the PI results. Probability multiplication with risk impact is frequently used in risk assessment, which is semi-quantitative. Although the quantitative analysis method states the level of risk likelihood and impact using a numerical measuring scale. Research from [8] describes that qualitative risk assessment analysis primarily identified partial risk sources, including risks related to time, quality, cost, safety, and other project performance factors. All these studies do not explore how risk is managed in an integrated manner into a model. In actuality, the successful completion of a building project depends on the mutual integration of the performance variables. In the papers [9, 10], integrated risk analysis was discovered along with two risk variables: cost and time aspects. However, quality risk the risk resulting from the triple constraint project was not included.

Paper [11] developed an integrated risk analysis method to determine risk priorities with three variables, cost, time, and quality aspects, but has not been continued for contingency cost analysis. Contingency costs can be estimated using the PI approach, which is sometimes referred to as the Expected Monetary Value (EMV) method and generally uses risk impact calculated in monetary units. Paper [12] determines the contingency cost of 5–10% of the whole project value with an average approach, but the work breakdown structure (WBS) method is not explained, which makes it difficult to analyze for construction projects. Papers [13–16] develops a contingency cost analysis model on construction projects with limited integration of two risks, namely cost and quality risks, and uses the method of describing project work risks using the WBS. While three variables, cost, time, and quality aspects, were found to be integrated, without further analyzing contingency costs [17]. In the paper [13], this risk analysis uses a semi-quantitative method for risk probability taken from PMBOK [18]. The risk impact uses a quantitative scale of monetary units describing the level of risk impact. The monetary scale of cost impact uses PMBOK, the monetary impact scale for time risk is developed in this paper. In the paper [13] it is suggested to develop a contingency cost analysis method with the integration of the triple constraint project, namely cost, time, and quality risks, by first developing the impact of quality risks in monetary units.

Given these unresolved issues, it is clear that further research is needed to develop a contingency cost model that integrates cost, time, and quality risks into the model. Such a solution must take into account the complexity of the project, geographical conditions, climate, weather, and even other aspects such as socio-cultural, political, and economic, which have an impact on the impact of risk. All this allows to assert that it is expedient to conduct a study on minimize the losses arising from inaccurate contingency cost calculations, by integrally incorporating cost, time, and quality risks into the model. The main goal is to improve project performance so that the results can be enjoyed by the community. The problem's background and several cost contingency references can be used to formulate the following issues:

– how to develop a cost contingency model that integrates cost, time and quality;

– how it might be applied to realistically applicable building projects.

3. The aim and objectives of the study

This study aims to develop an analysis model and calculate the amount of contingency costs from the risk of a construction project that is restricted to the risk variables of quality, time, and cost in an integrated way. Using the created model, the project team may calculate the amount of contingency cost for the risk factors of quality, time, and cost.

To achieve these aims, the following objectives are fulfilled:

– to determine the project work breakdown structure including its costs and duration, based on a contract of the project;

– to find the probability and impact of each task name, using the opinions of the respondents involved;

– to determine risk category (L – low, M – medium, and H – high) for each task name, based on the multiplication of probability and impact;

– to determine cost contingency of cost, time, quality, and integration risk.

4. Materials and methods of research

4. 1. Object and hypothesis of the study

The object of this study is the contingency cost in the implementation of construction projects.

The research hypothesis assumed the possibility of developing a contingency cost model in the implementation of construction projects, by integrating cost, quality, and time risks.

The study employs the descriptive technique [6].

Table 1 defines the probability scale of cost (*Pc*), time (*Pt*) and quality (*Pq*), which categorized into very low (VL), low (L), Moderate (M), high (H) and very high (VH).

Table 2 displays the quantitative scale of monetary units for cost risk effect (*Icm*), whereas Table 3 displays time risk effect (*Itm*) and Table 4 displays quality risk effect (*Iqm*).

Table 1

Probability scale (*P*) for cost (*Pc*), time (*Pt*), and quality (*Pq*)

Scale	Probability *Pc/Pt/Pq*		Numeric *Pc/Pt/Pq*
1	The likelihood of an event < 20% (very low)	VL	0.10
2	The likelihood of an event is 20–40% (Low)	L	0.30
3	The likelihood of an event is 40–60% (moderate)	M	0.50
4	The likelihood of an event is 60–80% (high)	H	0.70
5	The likelihood of an event > 80% (very high)	VH	0.90

Source: [18].

Table 2

Impact cost scale *Ic* and *Icm*

Scale	Cost Impact (*Ic*)			*Icm* (IDR or USD)
	Qualitative		Numeric (*Ic*)	
1	Not sig. (very low)	VL	0.05	0
2	Cost increased < 10% (low)	L	0.1	5% Cc
3	Cost increased 10–20% (moderate)	M	0.2	15% Cc
4	Cost increased 20–40% (high)	H	0.4	30% Cc
5	Cost increased > 40% (very high)	VH	0.8	45% Cc

Source: [18].

Table 3

Time impact *It* and *Itm*

Scale	Time impact (*It*)		Numeric	*Itm* (IDR or USD)
	Qualitative			
1	Not sig. (very low)	VL	0.05	0
2	Time increased < 5% (low)	L	0.1	2.5%. Cc. D. F
3	Time increased 5–10% (moderate)	M	0.2	7.5%. Cc. D. F
4	Time increased 10–20% (high)	H	0.4	15%. Cc. D. F
5	Time increased > 20% (very high)	VH	0.8	25%. Cc. D. F

Source: [13, 18].

Table 4

Impact of quality *Iq* and *Iqm*

Scale	Quality impact (*Iq*)			*Iqm* (IDR or USD)
	Qualitative		Numeric	
1	The degradation of quality is barely noticeable	VL	0.05	4.57% Cc
2	Only influential applications are very in demand	L	0.1	6.81% Cc
3	Requires sponsor approval in quality reduction	M	0.2	11.29% Cc
4	Unacceptable by the sponsor for quality reduction	H	0.4	16.77% Cc
5	The project end item is uselessly ineffectively	VH	0.8	18.01% Cc

Source: [18, 19].

4. 2. Research methodology

This research seeks to achieve two objectives: to develop a contingency cost model by integrating cost, time, and quality risks, and to implement it in construction activities in a more practical way. The procedure for carrying out these activities is illustrated in Fig. 1.

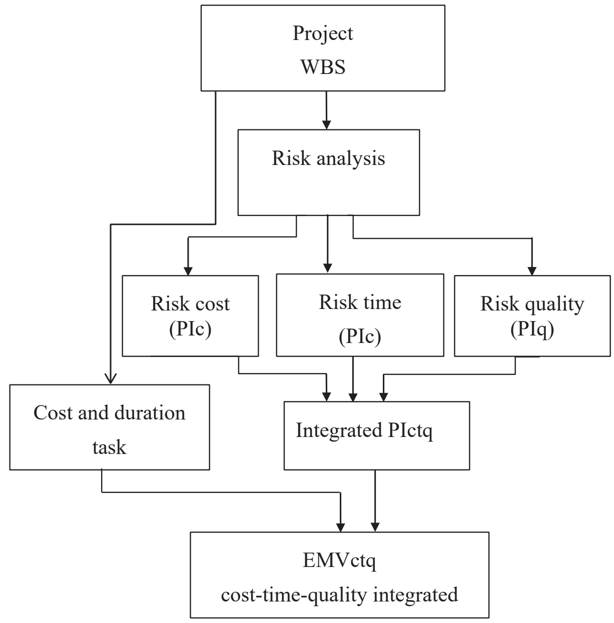

Fig. 1. Research framework

Fig. 1 displays that the WBS approach is used to identify the risks associated with the construction phase. A risk breakdown structure (RBS) is then created to characterize the possible risks associated with this WBS. Regarding the EMV analysis, if the risk analysis results fall into the moderate (M) or high (H) categories, the task component of the WBS is investigated; if the risk impact is not considerable, the low (L) category is not explored.

The probability-impact (*P-I*) risk matrix approach, which includes two factors, is used in the risk assessment analysis: the risk impact (*I*), or the consequences of risk, and the chance of a risk occurring (*P*), or the potential of occurring (likelihood). The EMV is then calculated using the findings of the *PI* matrix analysis. Cost, time, and quality concerns are all integrated into the development of EMV. The *P* and *I* scales employ quantitative analysis to determine cost dependencies and semi-quantitative measures (both qualitative and numerical) to identify risk categories.

From Fig. 1 it can be explained that risk identification in terms of cost, time, and quality is obtained from the work breakdown structure, based on the cost and duration of every tasks, it is then integrated with cost, time and quality risks to obtain a cost-time-quality integrated formulation (EMVctq). This formulation can apply to numerous projects with varying levels of risk and impact.

5. Research results of cost contingency integration

5. 1. Work breakdown structure

Table 5 shows that The Buleleng Regency's District Road Improvement Package for 2024 serves as an example. WBS includes task charges (*Cc*) in IDR and task duration (*D*) in days.

Table 5

Work description (WBS) of district road improvement project

WBS level 1	WBS Task level 2	Cost (*Cc*) (IDR)	Duration (*D*) (day)
Drainage	R1. Masonry with mortar	197,570,685	42
	R2. Reinforce concrete box culverts	25,443,360	7
Earthworks	R3. Ordinary digging	25,223,024	42
	R4. Ordinary stockpiles from excavations	19,000,000	42
	R5. Road body preparation	16,042,500	42
Granular pavements	R6. Class A aggregate foundation layer	595,444,740	42
Asphalt pavements	R7. Binder absorbent asphalt layer	133,982,400	14
	R8. Binder absorbent asphalt layer	42,895,125	14
	R9. Laston wear layer (AC-WC)	1,503,759,360	14
Structures	R10. Concrete, fc′15 Mpa	449,301,270	28
	R11. Stone pair	200,740,140	42
Performance maintenance works	R12. Hot mix asphalt repair	34,909,475	7
Amount (IDR)		3,244,312,079	

Table 5 explains a project with a contract value IDR 3,244,312,079 for which a WBS has been prepared complete with costs and duration for each task activity. The largest volume is granular pavements with a duration of forty-two days, and the smallest task duration is seven days.

5. 2. Project task probability (*P*) and impact (*I*)

The probability (*P*) and impact (*I*) of each risk aspect of the cost (*Pc*, *Ic*), time (*Pt*, *It*), and quality (*Pq*, *Iq*) were collected using an instrument with a Likert scale level 1–5. The qualitative scale mode value obtained was then expressed in a semi-quantitative (numerical) scale for risk analysis. The numerical values of the probability of *Pc*, *Pt*, and *Pq* were also used for EMV analysis.

Table 6 displays the outcomes of the semi-quantitative scale brainstorming for impact and probability.

In Table 6, the probability of cost ranges between 0.1–0.5, followed by the probability of time and quality between 0.1–0.7. While the impact of cost, time, and quality ranges between 0.05–0.4.

Table 6

Probability and impact values

Task name	*P-I* Cost		*P-I* Time		*P-I* Quality	
	Pc	*Ic*	*Pt*	*It*	*Pq*	*Iq*
R1. Masonry with mortar	0.50	0.20	0.30	0.10	0.70	0.40
R2. Reinforced concrete box culverts	0.30	0.40	0.30	0.10	0.30	0.10
R3. Ordinary digging	0.10	0.05	0.10	0.05	0.10	0.10
R4. Ordinary stockpiles from excavations	0.10	0.05	0.10	0.05	0.10	0.05
R5. Road body preparation	0.30	0.40	0.30	0.10	0.10	0.05
R6. Class A aggregate foundation layer	0.50	0.40	0.70	0.40	0.70	0.40
R7. Binder absorbent asphalt layer	0.10	0.20	0.10	0.05	0.10	0.05
R8. Binder absorbent asphalt layer	0.10	0.05	0.10	0.05	0.70	0.40
R9. Laston wear layer (AC-WC)	0.30	0.20	0.70	0.40	0.10	0.20
R10. Concrete, fc′15 MPa	0.50	0.20	0.50	0.20	0.30	0.10
R11. Stone pair	0.50	0.20	0.30	0.10	0.70	0.40
R12. Hot mix asphalt repair	0.50	0.10	0.30	0.10	0.30	0.10

5. 3. Risk categories of projects task

The results of the risk analysis and risk categories can be seen in Table 7, column (b) for cost risk (*PIc*), column (c) for time risk (*PIt*), and *PIq* quality risk in column (d).

Table 7

Cost (*PIc*), time (*PIt*), quality (*PIq*), and integrated (*PIctq*) risk categories

Task name	$Pic = Pc \times Ic$	$Pit = Pt \times It$	$PIq = PIq \times Iq$	PIctq
a	b	c	d	e
R1. Masonry with mortar	M 0.10	L 0.03	H 0.28	H
R2. Reinforced concrete box culverts	M 0.12	L 0.03	L 0.03	M
R3. Ordinary digging	L 0.01	L 0.01	L 0.01	L
R4. Ordinary stockpiles from excavations	L 0.01	L 0.01	L 0.01	L
R5. Road body preparation	M 0.12	L 0.03	L 0.01	M
R6. Class A aggregate foundation layer	H 0.20	H 0.28	H 0.28	H
R7. Binder absorbent asphalt layer	L 0.02	L 0.01	L 0.01	L
R8. Binder absorbent asphalt layer	L 0.01	L 0.01	H 0.28	H
R9. Laston wear layer (AC-WC)	M 0.06	H 0.28	L 0.02	H
R10. Concrete, fc′15 MPa	M 0.10	M 0.10	L 0.03	M
R11. Stone pair	M 0.10	L 0.03	H 0.28	H
R12. Hot mix asphalt repair	L 0.05	L 0.03	L 0.03	L

The risk categories of PI risk analysis results are categorized into three categories, namely the low category (L) with a *PI* value between 0.01 and 0.05, the moderate category (M) between 0.06 and 0.14, and the high category (H) between 0.15 and 0.72.

The risk category for integrated cost, time, and quality risk (PIctq) used is the risk from the task with a higher risk category.

The results of the integrated cost, time, and quality risk category are in Table 7 column (e).

In Table 7, column (e), the risk category of cost, time, and quality is integrated with the major risk categories, namely high (H) and moderate (M). The cost contingency is calculated using the formula model (5), namely EMVctq. The findings of the analysis are displayed.

5. 4. Integration cost contingency model

5. 4. 1. Development of an expected monetary value model based on integrated cost and time risk

EMVctq, or integrated cost, time, and quality (*ctq*) risk, is the foundation of the EMV model that was created. An integrated cost, time, and quality risk model served as the foundation for the development of this EMVctq model. As shown in equation (1), the cost and time integration-based EMV model is transformed into the EMVctq model [13]

$$\text{EMVct} = PIcm + PItm. \quad (1)$$

Formula (1) is then added to the contingency cost aspect of quality with the impact of the monetary unit quality being *Iqm* so that formula (1) for EMVct becomes EMVctq, which is formulated as in formula (2)

$$\text{EMVctq} = PIcm + PItm + PIqm, \quad (2)$$

or

$$\text{EMVctq} = Pc * Icm + Pt * Itm + Pq * Iqm, \quad (3)$$

where EMVct – expected monetary value calculated using integrated cost and temporal risk (USD, IDR, etc.); EMVctq – expected monetary value calculated using integrated cost, time, and quality risk (USD, IDR, etc.); *PIcm* – cost risk value in monetary units (USD or IDR, etc.); *PItm* – time risk value in monetary units (USD or IDR, etc.); *PIqm* – quality risk value in monetary units (USD or IDR, etc.); *Pc* – likelihood of cost risk occurring; *Pt* – The likelihood of time risk occurring; *Pq* – the likelihood of quality risk occurring; *Icm* – monetary unit cost risk impact (USD or IDR, etc.), Table 2; *Itm* – monetary unit time risk impact (USD or IDR, etc.), Table 3; *Iqm* – impact of monetary unit quality risk (USD or IDR, etc.), Table 4.

The monetary amount of the task according to the contract (*Cc*), the task time (*D*), and the amount of the delay penalty sanction according to the contract (*F*) are all contained in the coefficients of the *Icm*, *Itm*, and *Iqm* formulas in Table 2–4. One way to write formula (3) is as formula (4)

$$\text{EMVctq} = Pc * Cc * kc + Pt * Cc * kt * D * F + $$
$$+ Pq * Cc * kq, \quad (4)$$

or

$$\text{EMVctq} = Cc * \{Pc * kc + Pt * kt * D * F + Pq * kq\}, \quad (5)$$

where *Cc* – cost of task; *D* – duration of task; *F* – penalty due to delay in completing task; *kc*, *kt*, *kq* – cost, time, and quality coefficients, as in Table 8.

Table 8 explains the impacts caused by cost, time, and quality risks, categorized as very low (VL), low (L), moderate (M), high (H) and very high (VH). The cost impact ranges from 5% to 45%, the time impact between 2.5% to 25% and the quality impact ranges from 4.57% to 18.01%.

5. 4. 2. Application of EMQctq model

All activities that are classified as medium (M) and high-risk levels (H) are shown in Table 9, then the calculation of Expected Monetary Value is carried out including EMVc, EMVt, EMVq. While the integrated Expected Monetary Value EMVctq is calculated using equation (5).

In Table 9, it can be seen that the cost contingency risk value EMVc is 0.16%, the time risk EMVt is 0.10%, the quality risk EMVq is 9.34%, and the integrated risk EMVctq is 9.61% from the contract value. The lowest risk due to time (EMVt) is determined by taking the partial EMV ratio to the whole contract value. This is because the contract states that delays will only account for a minor portion of the ultimate value. For the remaining task, the daily fines in Indonesia are set at 1/1000. On the other hand, EMVq is the most expensive and requires careful consideration.

Table 8

Impact scale coefficient of cost (*kc*), time (*kt*), and quality (*kq*)

Scale	Impact	Cost coefficient (*kc*)	Time coefficient (*kt*)	Quality coefficient (*kq*)
1	Very low (VL)	0	0	4.57%
2	Low (L)	5%	2.5%	6.81%
3	Moderate (M)	15%	7.5%	11.29%
4	High (H)	30%	15%	16.77%

Table 9

Cost contingency of cost, time, quality, and integration risk (EMVctq)

Task name	Risk level	EMVc (IDR)	EMVt (IDR)	EMVq (IDR)	EMVctq (IDR)
R1. Masonry with mortar	H	29,636	290,429	23,192,823	23,512,887
R2. Reinforce concrete box culverts	M	519,808	16,029	519,808	1,055,645
R5. Road body preparation	M	2,406	30,320	73,314	106,041
R6. Class A aggregate foundation layer	H	1,250,434	1,875,651	69,899,258	73,025,343
R8. Binder absorbent asphalt layer	H	429	601	196,031	197,060
R9. Laston wear layer (AC-WC)	H	3,157,895	442,105	176,526,311	180,126,311
R10. Concrete, fc′15 MPa	M	336,976	440,315	9,179,225	9,956,516
R11. Stone pair	H	30,111	295,088	23,564,885	23,890,084
Amount (IDR)		5,327,694	3,390,539	303,151,655	311,869,888
Percentage		0.16%	0.10%	9.34%	9.61%

6. Discussion of results of cost contingency integration

As seen in Table 1, WBS has been prepared with the aim of breaking or dividing the work into smaller parts. WBS breaks down each work process into more detail so that the planning process has a better level. It can be seen in Table 1 six activities in WBS level 1 become twelve activities in WBS level 2. Drainage work which is classified as WBS level 1, is divided into two tasks, namely R1. Masonry with mortar and R2. Reinforce concrete box culverts which is classified as WBS level 2, each has a duration of 42 days and 7 days. While Earthworks WBS level 1 is divided into 3 items at level 2 such as R3. Ordinary digging, R4. Ordinary stockpiles from excavations, and R5. Road body preparation, with a duration of 42 days each. Asphalt Pavements work at WBS level 1 is also divided into three activities at level 2, such as R7. Binder absorbent asphalt layer, R8. Binder absorbent asphalt layer, and R9. Laston wear layer (AC-WC), with a duration of 14 days each. Structures work on WBS level 1 is divided into two at level 2 such as R10. Concrete, fc′15 MPa, and R11. Stone pair, with a duration of 28 days and 42 days. Activities are divided, which not only makes them smaller but also risk control and risk mitigation easier.

A questionnaire was used to gather qualitative data for *P*, and *I* to perform *P-I* analysis. Purposive non-probability sampling was used to choose respondents, and up to seven experts, two planning consultants, two contractor project managers, one project owner, and two supervisory consultants were involved in the construction project. As shown in Table 6 are the application of Table 1–4, which describe the probability and impact of each task, according to equation (2) or (3) EMVctq = $Pc * Icm + Pt * Itm + Pq * Iqm$. It can be seen that some activities have high *P-I* values, such as R1. Masonry with mortar, R6. Class A aggregate foundation layer, R8. Binder absorbent asphalt layer, R9. Laston wear layer (AC-WC), and R11. Stone pair.

The probability and impact of each task are then analyzed according to Table 7, following the formulation of equation (5) EMVctq = $Cc * \{Pc * kc + Pt * kt * D * F + Pq * kq\}$, so that the results are obtained as integrated probability impact cost time quality (*PIctq*), and can be categorized into high (H), moderate (M) and low (L) categories. R1. Masonry with mortar, R6. Class A aggregate foundation layer, R8. Binder absorbent asphalt layer, R9. Laston wear layer (AC-WC) and R11. Stone pair are category H. While R2. Reinforced concrete box culverts, R5. Road body preparation, and R10. Concrete, fc′15 MPa, are category M. Those included in the low category (L) are R3. Ordinary digging, R4. Ordinary stockpiles from excavations, R7. Binder absorbent asphalt layer and R12. Hot mix asphalt repair. For further analysis, tasks with category L will not be discussed because they are classified as minor risks.

Furthermore, this model is simulated in a case study by taking Buleleng Regency's District Road Improvement Package for 2024, as an example case as shown in Table 9. All tasks in categories H and M are analyzed by referring to equation (5). The results obtained for EMVc is IDR 5,327,694 EMVt is IDR 3,390,539 and EMVq is IDR 303,151,655 or 0.16%; 0.10% and 9.34%. While the value of EMVctq is IDR 311,869,888 or 9.61%. This result is in accordance with research from [20], who allocated contingency costs of around 10%, and the research of [12] with a contingency cost allocation of between 5 to 10%. However, this study explains in detail how the composition and risk categories for each activity. For example, the Laston wear layer (AC-WC) activity has the largest EMVctq value of IDR 180,126,311 consisting of EMVc of IDR 3,157,895 EMVt of IDR 442,105 and EMVq of IDR 176,526,311. It can be interpreted that seen from all activities, the Laston wear layer (AC-WC) activity has the highest risk, especially regarding quality risk. Therefore, handling of this activity must be carried out seriously and with great care. Based on equation (5) EMVctq is obtained as IDR 311,869,888 or 9.61% of the project cost. This is in line with the research of [20], who allocated contingency costs around 10%, and the research of [12] with a contingency cost allocation between 5 to 10%.

The limitation of this study is that data collection and surveys were only conducted on road projects in Bali Province. It is certain to generate somewhat formulation will be modified if it is used on building project construction. Research on more specialized contingency costs, such as provincial roads, urban road projects, or even toll roads, is also required. It's the same with building project construction, whether they are basic or extremely complex.

The disadvantage of this study is that in qualitative assessment, a Likert assessment scale of 1 to 5 is used so that the results obtained are still relatively less detailed. To overcome this, an assessment with a scale of 1 to 10 needs to be carried out in the future. However, the difficulty experienced when using a wider scale is that a more detailed and measurable operational definition of the assessment is needed.

7. Conclusion

1. Preparing and developing a work breakdown structure requires consideration of the task's complexity, the interdependencies across activities, and the time required for each activity, which is determined by the volume of each task, work methods, and geographic conditions. WBS is the first step in making sure that risk impact and probability calculations can be completed more thoroughly and readily.

2. Risk probability and risk impact must be developed by referring to the opinions and experiences of respondents, using an instrument with a Likert scale assessment. The probability of cost ranges between 0.1–0.5, and the probability of time and quality between 0.1–0.7. While the impact of cost, time, and quality ranges between 0.05–0.4. Every task has a distinct P and I, which makes risk management easier to understand.

3. Risk categories are developed based on risk probability and risk impact, which are categorized into low-risk, medium-risk, and high-risk categories. Four activities are classified as low risk, with *Pic*, *Pit* and *Piq* 0.01. Three activities as medium risk, with *Pic*, *Pit* and *Piq* between 0.03–0.12, and five activities as high risk with *Pic*, *Pit* and *Piq* between 0.1–0.28. Activities in the medium and high categories are subject to further analysis.

4. The qualitative and quantitative analysis states that the EMVctq = $Cc * \{Pc * kc + Pt * kt * D * F + Pq * kq\}$. This cost contingency analysis model developed is quite adequate to accommodate the risks of the triple constraints of construction project performance, namely cost, time, and quality. This model comprehensively combines the risk elements in the project, and it can be seen simply that elements of activities such as project time, project costs, and contract provisions are taken into consideration. The implementation of the model with a case study obtained a cost contingency value of 9.61%. This result is quite adequate and in

line with the empirical approach found, namely between 5% and 10%. The developed cost contingency analysis method is more rational because it is based on a risk analysis of the project. The project team has a logical basis for estimating cost contingencies.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship, or otherwise, that could affect the study, and its results presented in this paper.

Financing

This study was funded by the Research and Community Service Institute (LPPM) of Udayana University based on non-tax state revenue funds in 2024.

Data availability

Data cannot be made available for reasons disclosed in the data availability statement.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Acknowledgments

We appreciate the time and assistance provided by the responders at the Bali Province Regency Road Improvement Project Agency with the data. Additionally, thanks to students Pande Putu Ray Nagata Semarabawa and Ni Putu Diana Putri Rastiti for their assistance with the survey. We also acknowledge the funding provided for this study from LPPM Udayana University.

References

1. Barraza, G. A., Bueno, R. A. (2007). Cost Contingency Management. Journal of Management in Engineering, 23 (3), 140–146. https://doi.org/10.1061/(asce)0742-597x(2007)23:3(140)
2. Matějková, J. (2024). Assessing Public Works Procurement in the Czech Republic´s over-limit Regime: Survey Results and Recommendations for Contracting Authorities. Civil and Environmental Engineering Reports, 34 (2), 84–99. https://doi.org/10.59440/ceer/189313
3. Leśniak, A. (2023). Delays In Execution Of Building Projects And Their Financial Consequences For Contractors - Polish View. Civil and Environmental Engineering Reports, 33 (1), 99–108. https://doi.org/10.59440/ceer-2023-0007
4. Turskis, Z., Zavadskas, E. K., Antucheviciene, J., Kosareva, N. (2015). A Hybrid Model Based on Fuzzy AHP and Fuzzy WASPAS for Construction Site Selection. International Journal of Computers Communications & Control, 10 (6), 113. https://doi.org/10.15837/ijccc.2015.6.2078
5. Vaghela, V. N. (2020). Risk management in the construction industry. International Research Journal of Engineering and Technology (IRJET), 7, 584–588. Available at: https://www.irjet.net/archives/V7/i6/IRJET-V7I6107.pdf
6. Ziegel, E. R., Vose, D. (1999). Quantitative Risk Analysis. Technometrics, 41 (4), 381. https://doi.org/10.2307/1271374
7. Marco, A., Thaheem, M., Grimaldi, S., Rafele, C. (2014). A Framework Methodology for Selection of Risk Analysis Techniques in Construction Projects. Conference: Proceeedings of the Creative Construction Conference 2012. Available at: https://www.researchgate.net/publication/258506573_A_Framework_Methodology_for_Selection_of_Risk_Analysis_Techniques_in_Construction_Projects
8. Walke, R., Topkar, V., Kabiraj, S. (2010). Risk Quantification Using EMV Analysis - A Strategic Case of Ready Mix Concrete Plants. International Journal of Computer, 7 (5), 399–408. Available at: https://www.researchgate.net/publication/266214429_Risk_Quantification_Using_EMV_Analysis_-_A_Strategic_Case_of_Ready_Mix_Concrete_Plants
9. Purnus, A., Bodea, C.-N. (2014). Correlation between Time and Cost in a Quantitative Risk Analysis of Construction Projects. Procedia Engineering, 85, 436–445. https://doi.org/10.1016/j.proeng.2014.10.570
10. Rezaian, A. (2011). Time-Cost-Quality-Risk of Construction and Development Projects or Investment. Middle-East Journal of Scientific Research, 10 (2), 218–223.
11. Demir, S. T., Bryde, D. J., Fearon, D. J., Ochieng, E. G. (2014). A tool for integrating time, cost and quality perspectives in Probability Impact (P-I) Tables. International Journal of Project Organisation and Management, 6 (4), 303. https://doi.org/10.1504/ijpom.2014.066410
12. Idrus, A., Fadhil Nuruddin, M., Rohman, M. A. (2011). Development of project cost contingency estimation model using risk analysis and fuzzy expert system. Expert Systems with Applications, 38 (3), 1501–1508. https://doi.org/10.1016/j.eswa.2010.07.061
13. Jaya, N. M., Sudarsana, D. K. (2023). Development of Contingency Value Analysis Model Using Cost-Time Risk Integration and WBS-Pareto Hybrid in Construction Projects. International Journal on Engineering Applications (IREA), 11 (2), 121. https://doi.org/10.15866/irea.v11i2.23235
14. Aloko, M. N. (2018). Risk Assessment Process for Construction Projects in Afghanistan. International Journal of Advanced Engineering Research and Science, 5 (8), 211–217. https://doi.org/10.22161/ijaers.5.8.26
15. Simosa, F. (2024). Qualitative Risk Analysis Tools, Definition, Examples. Projectcubicle. Available at: https://www.projectcubicle.com/qualitative-risk-analysis-tools-definition-examples/

16. Singam, H. B., Chaudhari, P. S. (2016). Risk Analysis of Construction Project Using Sensitivity Analysis. International Journal of Modern Trends in Engineering and Research, 3(6).
17. Hulett, D. T., Nosbisch, M. R. (2018). Integrated Cost / Schedule Risk Analysis Using. Monte Carlo Simulation of CPM Model. Available at: http://www.projectrisk.com/white_papers/Presentation-Hulett-Nosbisch-rev2.pdf
18. A guide to the project management body of knowledge (2017). PMI.
19. Sudarsana, D. K., Astana, N. Y., Frederika, A., Sanjaya, P. A. (2024). Development of a Quantitative Scale for the Impact of Quality Risk on Construction Project. International Conference on Rehabilitation and Maintenance in Civil Engineering. Available at: https://icrmce06.ft.uns.ac.id/assets/doc/ICRMCE06Guidebook.pdf
20. Cooper, D., MacDonald, D., Chapman, C. (1985). Risk analysis of a construction cost estimate. International Journal of Project Management, 3 (3), 141–149. https://doi.org/10.1016/0263-7863(85)90065-1