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Cost Contingency and Cost Evolvement of Construction Projects in the Preconstruction Phase

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Abstract: The current literature discusses the methods to estimate the costs and cost contingency. The literature also distinguishes "known unknowns" and "unknown unknowns" contingencies. Little is written, however, about the evolvement of total project cost estimates during the preconstruction phase of construction projects. Moreover, not many studies are investigating the "known unknowns" and "unknown unknowns" contingencies in real construction projects. Practice expressed the need for getting more insight into the development of the estimated costs of the projects in the preconstruction phase. This paper, therefore, discusses the estimate of the total project costs (and cost contingency) in the preconstruction phases of 29 Dutch flood defense projects using a case study approach. Altogether, the projects have experienced an 11.51% increase in the estimated costs compared to the initial estimates, which is low compared to previous studies. This increase in the cost estimates of the flood defense projects can be explained by "technical" reasons. The investigation of "known unknowns" and "unknown unknowns" contingencies shows that the percentage of the "unknown unknowns" contingency has increased in the preconstruction phase while a reduction was expected. This increase suggests that the projects were not confident about their estimates and the increase can be explained by a lack of experience, organizations' culture, or the phenomenon of "pessimistic bias." Practitioners can avoid "pessimistic bias" behavior by asking for opinions about their estimates and using historical project data. Further research is suggested into realized cost contingency after project execution. **DOI: 10.1061/(ASCE)CO.1943-7862.0001842.**

Author keywords: Risk management; Cost contingency; Cost estimate; Construction projects; Unknown unknowns.

Introduction

The literature on risk management acknowledges that projects of all types of industries are bounded with uncertainties. Uncertainty can be defined as the difficulty in predicting the final outcomes of a project in terms of time, cost, client satisfaction, and technical performance (Böhle et al. 2016; Turner 2016). Uncertainty, introduced by different factors, can jeopardize the objectives of projects (Hillson 2012; Schwindt and Zimmermann 2015). As an approach to deal with the uncertainties, projects employ a contingency to cater for unforeseen circumstances (De Marco et al. 2015; Mak and Picken 2000). This way, the projects have more confidence to finish within the allocated budget (or scheduled time). The objective of cost contingency allocation is to ensure that the budget that is set aside for the project execution is sufficient to cover the uncertainties. Cost contingency should, therefore, be calculated properly, assigned in the budget estimation process, and controlled wisely during project execution (Baccarini 2004; Barraza and Bueno 2007).

A cost contingency in a project caters for "known unknowns" and "unknown unknowns" events. "Unknown unknowns," in the context of projects, are unforeseeable situations within the scope of the project (PMI 2013). "Known unknowns," or risks, are the events that can be identified and may or may not occur in a project (Baccarini and Love 2014).

The challenge of cost (contingency) estimation is that an estimate is a forecast to be incurred in the future and the future is uncertain (Yeo 1990). The literature on project risk management endorses the development of numerous methods and techniques to determine the cost contingency of projects (Baccarini and Love 2014; Barraza and Bueno 2007; Hammad et al. 2016; Mak and Picken 2000; Marco et al. 2016; Yeo 1990). Maintaining a realistic amount of cost contingency, however, is still a mystery. Even the development of extensive cost contingency estimation methods has not improved the estimation of cost contingency in construction projects (Baccarini and Love 2014; De Marco et al. 2015; Flyvbjerg et al. 2002; Gharaibeh 2013; Hollmann 2012; Khamooshi and Cioffi 2012; Lovallo and Kahneman 2003).

Many construction projects fail to adequately recognize that any estimate of cost (or schedule) involves uncertainty, and that this uncertainty should be incorporated in an estimate (Reilly et al. 2004). For example, an investigation in UK construction projects revealed that insufficient consideration is given to the assessment, placement and management of contingency, and risk budgets (Treasury 2010). Likewise, a review of 50 years of empirical cost estimate accuracy research by Hollmann (2012) reveals a continuous failure to effectively address the project cost contingency. The inaccurate cost estimations are usually a result of poor cost estimation practices, poor project management practices, and poor communication between design and construction personnel, and the stakeholders (Shane et al. 2015).

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Available literature regarding cost estimates addresses either the development of a method to improve the accuracy of estimates or discusses the performance of estimated contingency (i.e., comparing the estimated costs with the realized costs) (Baccarini and Love 2014; Flyvbjerg et al. 2002). In this context, there are not many studies regarding the evolvement of the total project cost (and cost contingency) estimates in the preconstruction phase of the construction projects. This research contributes to the current body of knowledge by investigating the evolvement of the total project cost (and cost contingency) estimates in the early phases of the projects.

Risks that matter to the stability of a firm are often unidentifiable ("unknown unknowns") and simply focusing on managing the identifiable risks ("known unknowns") is inadequate (Ganegoda and Evans 2014). While it is common for projects to assign contingencies to address the "known unknowns" and "unknown unknowns," there is not much insight and knowledge about the proportion of "known unknowns" and "unknown unknowns" contingencies in practice. This is highlighted as a second contribution: this research investigates the evolvement of "known unknowns" and "unknown unknowns" contingencies in real construction projects.

The research focuses on flood defense projects in the Netherlands performed under the flood defense program known as Hoogwaterbeschermingsprogramma (HWBP). There is a need from the flood defense program to get a better insight into the estimated costs of the projects in the preconstruction phase. This research addresses this need from practice and the obtained knowledge can be applied for improving cost estimates in future projects.

To summarize, the research objective is to investigate the evolvement of the total project cost and cost contingency estimates in the preconstruction phase of construction projects. In this research, the preconstruction phase includes Exploration, Plan Development, and Tender and Award. The following research question is formulated:

How Do the Total Project Cost and Cost Contingency Estimates Evolve in the Preconstruction Phase of a Construction Project?

This paper is structured as follows. It starts with a review of relevant literature in the next section, followed by a description of the methods used. Next, results are presented and analyzed in three parts. First, the total project cost contingency development over time in the preconstruction phase is discussed. Second, the development of the total project cost estimates in the preconstruction phase is investigated. Finally, the relation between "known unknowns" and "unknown unknowns" contingencies is examined. In the discussion section, the results are discussed elaborating on the possible reasons for the fluctuations of cost and cost contingency estimates in the preconstruction phase and the possible consequences of these fluctuations. Subsequently, conclusions are drawn, research implications are explained, and recommendations for future research are given. Finally, acknowledgments are listed.

Literature Review

A cost estimate is a quantitative assessment, based on the available information, at a given point in time, of the likely costs for resources required to complete a project. The cost estimate includes the identification and consideration of cost alternatives to initiate and complete a project (PMI 2013). A cost estimate process generally includes five main steps: determining the estimate basis, preparing a base estimate, determining risk and setting contingency, reviewing the total estimate, and finally communicating the estimate (Anderson et al. 2007). An accurate cost estimate is crucial in deciding on whether to proceed with a project, and it serves as a baseline for project control (Baccarini and Love 2014; Hammad et al. 2016; Mak and Picken 2000; Uzzafer 2013; Yeo 1990).

The result of a cost estimate is comprised of two components: (1) the base cost (BC) (recognized also as "known knowns") and (2) the cost contingency.

The BC is the likely risk-free cost of the project developed using historical data and cost-estimating techniques. Cost contingency is, however, a provision to mitigate cost risk (PMI 2013). According to PMI (2009), cost contingency is the amount of needed budget, above the estimated budget, to reduce the risk of overruns of project objectives to a level acceptable to the organization (PMI 2009). Likewise, the American Association of Cost Engineers defines contingency as: "An amount of money or time (or other resources) added to the base estimated amount to (1) achieve a specific confidence level, or (2) allow for changes which, based on experience, will likely be required" (AACE 2000, p. 28). Cost contingency is decided based on a list of uncertainties with their estimated financial implications to cope with the uncertainties in a project (Anderson et al. 2007; Baccarini and Love 2014; Mak and Picken 2000; Molenaar 2010). In short, the cost contingency is allocated to handle the uncertainties in a project (De Marco et al. 2015; Mak and Picken 2000).

Literature on cost contingency distinguishes two categories of contingency: "known unknowns" (known as contingency reserve) and "unknown unknowns" (Lee et al. 2017; PMI 2013; Walker et al. 2017). The "known unknowns" contingency is determined by the risk identification step within the risk management process, focusing on the assessment of event uncertainty (Chapman and Ward 2011; PMI 2013). The "known unknowns" contingency is thus dependent on the number of identified risks, with specific consideration of the post-mitigated risks rather than the premitigated risks. The "unknown unknowns" contingency is, however, intended to address the unforeseen situations within the scope of the project (Eldosouky et al. 2014; PMI 2013). Despite its role and importance, there is no specific rule on how to determine the right amount of the "unknown unknowns" contingency. It is often estimated just as a percentage, which is typically derived from intuition and experience (Lee et al. 2017).

Cost contingency can be determined employing deterministic and probabilistic approaches. Both approaches are applicable to discretely decide the costs and time contingencies (Bakhshi and Touran 2014; Eldosouky et al. 2014; Pawan and Lorterapong 2015; Purnus and Bodea 2013), or the combination of time and cost (Purnus and Bodea 2013). The biggest difference between the two approaches is that the deterministic approach is based on deterministic and point-estimate values, whereas the probabilistic approach is based on stochastic values. The former cannot mathematically incorporate uncertainty, whereas the latter can (Xenidis and Stavrakas 2013). In the deterministic approach, a certain percentage of the total project costs is simply added to the project as the cost contingency (Shane et al. 2015). This method is criticized due to its oversimplicity and dependency on the estimator (Mak and Picken 2000; Yeo 1990). Probabilistic models also suffer from limitations (e.g., unavailability of detailed quantitative information) (Panthi et al. 2009).

The available literature about cost estimation can be divided in two categories: (1) scholars who discuss the development of the methods to improve the cost (contingency) estimates, and (2) scholars who discuss the cost performance of projects by comparing estimated costs (early in the beginning of a project) and realized costs (after the project completion) and investigating the reasons for the poor cost performance of the projects. A summary of references in each category is provided in Table 1.

Table 1. Two different categories of literature discussing cost and cost contingency estimates

ID	Description	Scholars	Scope of the research
First category	Development of new methods to improve cost and cost contingency estimates	Mak and Picken (2000), Thal et al. (2010), Lee et al. (2017), Panthi et al. (2009), Lhee et al. (2011), and Khamooshi and Cioffi (2009)	Developing quantitative methods to estimate cost contingency in the preconstruction phase
		Xie et al. (2011), and Barraza and Bueno (2007)	Developing quantitative methods to manage cost contingency throughout the project execution phase
		Hammad et al. (2016) and De Marco et al. (2015)	Developing methods to estimate and manage the cost contingency in both preconstruction and execution phases of a project
Second category	Investigating the cost performance in the projects	Flyvbjerg et al. (2002), Cantarelli et al. (2012), Baccarini (2004), and Hollmann (2012)	Comparing the realized and estimated costs and discussing the reasons for deviation

Next to these two categories, there is a possible but missing third category: the evolvement of the total project cost (contingency) estimates (i.e., evolvement of BC and cost contingency and the relation between "known unknowns" and "unknown unknowns" contingencies in the preconstruction phase of construction projects. To the knowledge of authors, few researches are reported that address this third category. This research contributes to this third category by investigating the evolvement of the total project cost and cost contingency in the preconstruction phase of construction projects.

Methods

To investigate the cost contingency of projects in the preconstruction phase, the research benefits from a case study approach. Yin (2014) explains that the first and most important condition for selecting a research strategy is to identify the type of research question. The research question in this research is a "how" question, which aims to explore the cost contingency evolvement in different phases prior to the start of the execution phase. For this research question, the cost contingency needs to be traced over time. Yin (2014) states that in this situation, the case study approach is a suitable approach. The case study places more emphasis on the full analysis of a limited number of events or conditions and is, thus, an intensive exploration of the particular unit under consideration (Kothari 2004; Yin 2014).

The research investigates the flood defense projects (such as improvement of the dikes, locks, pumps, and so on) executed under the Hoogwaterbeschermingsprogramma (HWBP) in the Netherlands as cases. The HWBP has a budget of about €5 billion and has the objective to improve the flood defense facilities in the Netherlands that do not meet the safety norms. The program inspects the flood defense facilities every 5 years. Each flood defense facility that does not satisfy the safety norms will be improved in a project. Urgent flood defense facilities will receive priority to improve. Each batch of the projects is governed under a program of projects. The HWBP is responsible for approving the subsidy required for the execution of these projects. The regional public organizations, known as Waterboards, responsible for the flood defense facilities, have to submit their estimated budgets to the program. The program provides the Waterboards with the required funding after approval of the estimates. The projects (cases) for this research are selected from a program of projects known as HWBP-2, as most of the projects in this program are finished.

This study focuses on the cost estimates made by the Waterboards in the preconstruction phase. Each project goes through each of the phases of Exploration, Plan Development, and Tender and Award. A short explanation of these phases is given here:

- Exploration (EXP): In this phase, the possible alternatives and solutions are investigated. These alternatives are further elaborated and the best alternative would be selected.
- Plan Development (PD): the selected alternative of the previous phase is further elaborated and the project plan and design are created.
- Tender and Award (T&A): In this phase, the project follows the tendering process and is awarded to a contractor.

The EXP is the first official phase in which the project organizations submit the first cost estimate of the projects. In each of the aforementioned phases, projects provide an estimate of project costs containing both BC and the required cost contingency for the whole project execution. Going through the phases, the design and scope and consequently the cost estimate might change. By finishing the T&A phase, the cost estimation is finalized. After this phase, the contract is awarded and the contractor starts the execution of the project.

The total budget of a project in each phase is a summation of the costs of work packages: Construction (i.e., the costs of project execution by the contractor who wins the project through tendering), Engineering (i.e., costs of consultancy and design), Real Estate (i.e., cost of ground expropriation), Other Costs, and the cost contingency. The summation of the Construction, Engineering, Real Estate, and Other Costs composes the project BC.

The projects in this study determine the cost contingency based on similar methods as mentioned by Yeo (1990) and Shane et al. (2015). This research acknowledges that there are different methods to calculate the cost contingency of projects (e.g., using probability distribution of estimated costs). In our research, the method for calculating cost contingency is determined by the projects that were examined. As previously mentioned in this paper, the "known unknowns" contingency addresses the identifiable risks and the "unknown unknowns" contingency addresses the uncertainties that cannot be identified upfront (Böhle et al. 2016). In the examined projects, the "known unknowns" contingency is determined based on the most important identified risks from the risk analysis step. The risks are quantified and the summation of risks' impact (probability $\times$ consequence) forms the "known unknowns" contingency. The "unknown unknowns" contingency is determined on a percentage of BC depending on the risk profile of each project (to cater for unforeseen events and the ambiguities and the variability

Table 2. Example of the cost estimate composition of a project

Different work packages	Explanation	Amount (in euro)
Construction costs	—	€12,066,206.95
Real estate costs	—	€0
Engineering costs	—	€1,603,164.00
Other costs	—	€697,813.80
Base costs	The summation of above cost components	€14,367,184.74
"Known unknowns" contingency	The summation of the impact of the most important risks	€1,596,250.00
"Unknown unknowns" contingency	5% of base costs	€718,359.24
Total cost contingency	The summation of the "known unknowns" contingency and the "unknown unknowns" contingency	€2,314,609.24

in the estimated amounts.) The percentages that the projects in this research typically use to account for "unknown unknowns" are between 5% and 10% of the BC. Note that these percentages are defined by the projects, based on their experience. The authors do not justify these percentages and neither indicate that these percentages should be generalized to other projects. The authors just explain the percentages used by the projects. The summation of the "known unknowns" and the "unknown unknowns" contingencies is the total cost contingency of the projects. Project total cost (TC) is the summation of the BC and the cost contingency. These explanations are clarified by an example from a real project shown in Table 2. The base cost (BC) (= €14,367,184.74) is calculated based on the summation of the costs of the work packages Construction, Engineering, and Other Costs (the project in this example has no costs for the work package Real Estate). The amount of "unknown unknowns" contingency (= €718,359.24) is 5% of the BC and the total cost contingency is equal to the summation of "known unknowns" and "unknown unknowns" contingencies (= €2,314,609.24). Eqs. (1)–(3) explain how each part of the cost contingency in the examined projects is calculated.

Formula for the "known unknowns" contingency where n represents the number of risks

$$Known\,unknown\,contingency = \sum_{i=1}^{n}(Probability_i \times Consequence_i) \quad (1)$$

Formula for the "unknown unknowns" contingency, where x is a number between 5 and 10

$$Unknown\,unknowns\,contingency = x\% \times Base\,Cost \quad (2)$$

Calculating the total cost contingency

$$Cost\,Contingency = Known\,unknown\,contingency + Unknown\,unknowns\,contingency \quad (3)$$

To examine the cost contingency in practice, construction projects from different Waterboards were selected. These projects were selected based on the following criteria:

- The project has passed the preconstruction phase (so the project is either in the execution phase or the execution is already finished).
- The cost estimation document(s) in at least one of the preconstruction phases is available.

Based on these criteria, out of 79 HWBP-2 projects, 29 recent projects from 10 Waterboards were considered suitable for the study and all were included. From these 29 projects, 22 are dike reinforcement projects, 2 are dune reinforcement projects, and 5 are coast reinforcement projects. The Appendix provides the total costs of the projects in the T&A phase. In the T&A phase, the estimated project execution costs range between €0.6 million and €140 million. All these projects had their start and finish between 2011 and 2016. For the 29 projects, the cost estimation documents from the three phases were collected. For each phase, different numbers of cost estimate documents were found:

- In the EXP phase, 28 out of 29 projects have an appropriate cost document.
- In the PD phase, 26 out of 29 projects have an appropriate cost document.
- In the T&A phase, 29 out of 29 projects have an appropriate cost document.

The amount of the total cost contingency, "known unknowns," and "unknown unknowns" contingencies [as explained in Eqs. (1)–(3)] were calculated for each project in each specific phase. Next, the results were checked by an expert. The purpose of this step was to check the accuracy of the method and results. The expert has more than 10 years of experience and works at HWBP, the overarching program. This expert is responsible for drawing periodic financial reports and is familiar with the working methods and financing strategy of the projects.

The collected data were quantitatively analyzed and compared in order to understand the evolvement of the total project cost contingency in the preconstruction phase. The significance of the results in each part is statistically tested. Based on the analysis, possible reasons for the evolvement of the cost contingency in the preconstruction phase are given. These reasons are also explained from a more theoretical point of view in the Discussion section of this paper. The authors' knowledge and experience with the HWBP projects helped explain the possible reasons for the changes in the estimate.

Results and Analysis

In this section, the development of estimates over time is discussed. First, the changes in the estimates are elaborated. The quantitative analysis of cost contingency, BC, and percentage of cost contingency in the three phases of EXP, PD, and T&A are discussed. Next, the cost evolvement of the projects in the preconstruction phase is explained. Finally, the relation between the "known unknowns" and "unknown unknowns" contingencies of the projects is investigated.

Changes in the Estimates over Time

Table 3 shows that the mean and the standard deviation (SD) for cost contingency, BC, and the percentage of cost contingency have

Table 3. Descriptive statistics of cost contingency (in million euro), BC (in million euro), and calculated percentage of cost contingency per project phase (28 projects in the EXP phase, 26 projects in the PD phase, and 29 projects in the T&A phase)

Statistical parameter	Cost contingency			BC			% cost contingency		
	EXP	PD	T&A	EXP	PD	T&A	EXP	PD	T&A
Mean (M)	6.69	5.57	5.08	32.45	32.34	30.62	20.28%	17.67%	14.93%
Standard deviation	7.89	6.54	6	40.70	35.81	36.56	6.71	5.69	4.61
Number of projects	28	26	29	28	26	29	28	26	29

reduced over time. Comparing the cost contingency in the EXP and T&A phase shows indeed a reduction in the uncertainty of the projects as the projects progressed ($p = 0.001$, independent sample t-test). The changes in the estimated cost contingency and BC of the projects are provided in the Appendix.

As shown in Table 3, the largest uncertainty, as expected, is in the EXP phase. In the EXP phase, the scope of the work is based on the requirements and wishes without any clear design. In this phase, different alternatives and solutions are provided. Eventually, one alternative is selected in this phase, which will be further developed in the next phases. Hence, cost estimation at each successive stage progresses toward a smaller number of options, since more detailed designs, more accuracy of quantities, and better information about unit prices are available (Flyvbjerg et al. 2002). This generally leads to reduction of the uncertainty and a lower cost contingency. Another reason for the reduction in the cost contingency could be that some risks, identified in the early phases, did not occur or are not applicable anymore. For example, in later project phases, a project has acquired the necessary work permits, and has performed research for the (under)ground conditions.

The histogram of estimated cost contingency (percentages) for each phase is presented in Figs. 1–3. As shown in the histograms, the percentage of cost contingency is shifted over time to the left, confirming the reduction of the uncertainties in the projects.

Further, three distributions are fitted to the histogram of the percentage of cost contingency in each phase to check which distribution better reflects the empirical data. The cumulative frequency of the empirical data is compared to the cumulative distribution function (CDF) of the theoretical distribution to accept the best distribution. A probability paper, as explained by Ang and Tang (2007), checks which distribution best fits the empirical data.

To construct a probability paper, a transformed probability scale should be used in such a way to obtain a linear graph between the cumulative probabilities of the underlying distribution and the values of the random variable (Ang and Tang 2007). Using the procedure explained by Ang and Tang (2007), three distributions were selected: beta, lognormal, and gamma distribution. Figs. 4–6 show the probability density function (PDF) for the percentage of cost contingency in each phase.

The goodness-of-fit for each of the distribution models are checked by performing a Chi-square test. The Chi-square goodness-of-fit checks the observed frequency of k variables with the corresponding theoretical frequencies calculated from the assumed theoretical distribution model (Ang and Tang 2007). Table 4 presents the results of the Chi-square goodness-of-fit for the percentage of the cost contingency in the three phases (where x_f^2 = chi-square, f is the degrees-of-freedom, and $C_{1\text{-}\alpha,f}$ is the critical value of the Chi-square as explained in Ang and Tang (2007). As shown in Table 4, the lognormal distribution best fits the percentage of cost contingency in the three phases. Table 5 presents the parameters of all the distribution per phase. Fig. 7 presents the changes in the lognormal distribution in the three phases of EXP, PD, and T&A, confirming a reduction in the percentages of cost contingency as the project progresses.

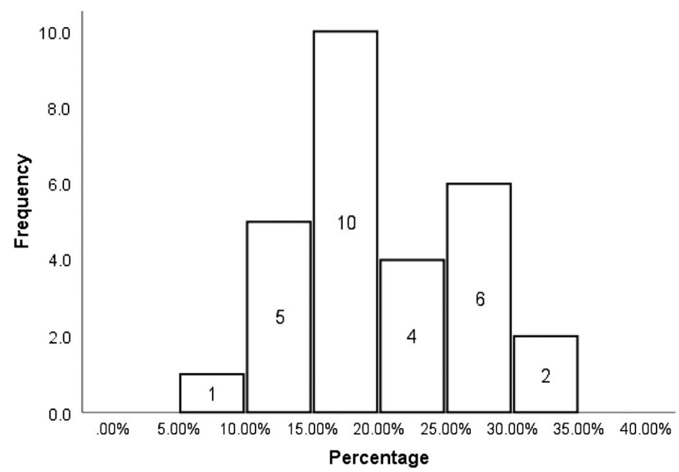


Fig. 1. Histogram of cost contingency of the projects in the Exploration (EXP) phase (N = 28).

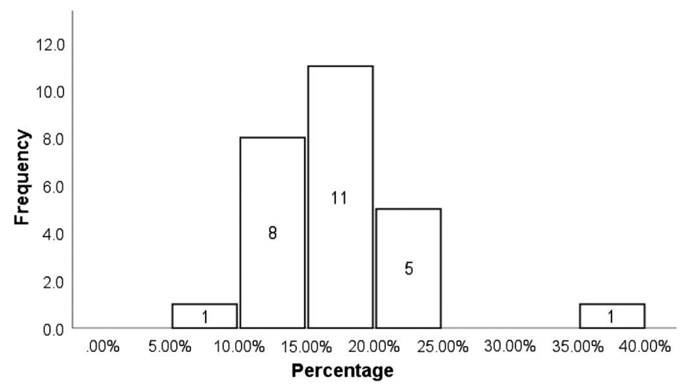


Fig. 2. Histogram of cost contingency of the projects in the Plan Development (PD) phase (N = 26).

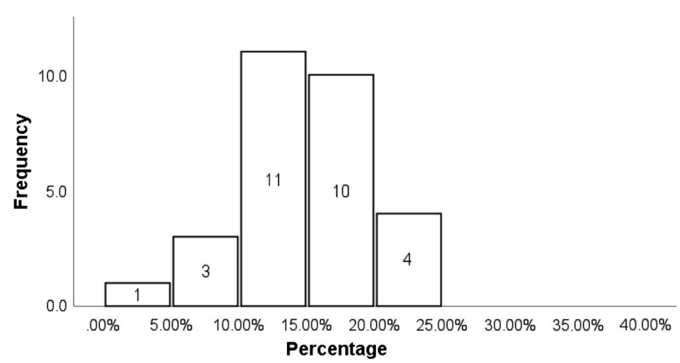


Fig. 3. Histogram of cost contingency of the projects in the Tender and Award (T&A) phase (N = 29).

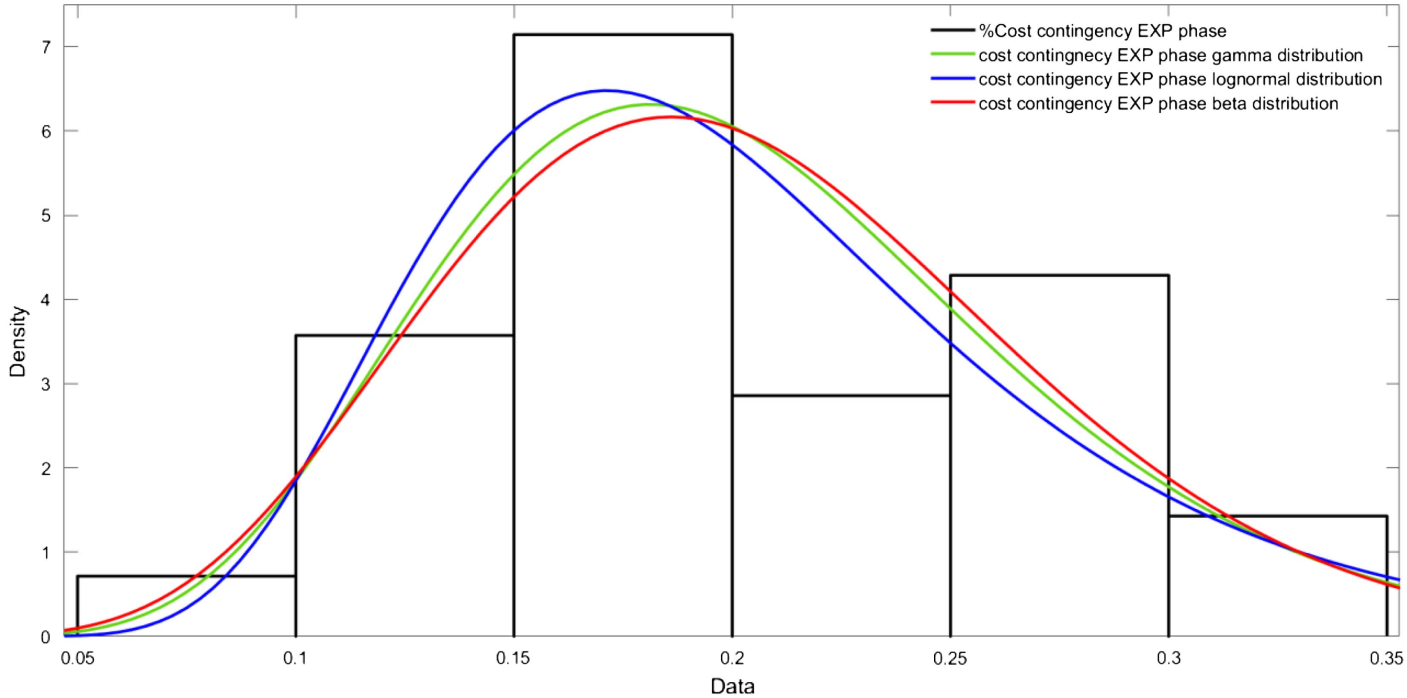


Fig. 4. Histogram and PDF fitting distributions for the percentage of cost contingency in the EXP phase.

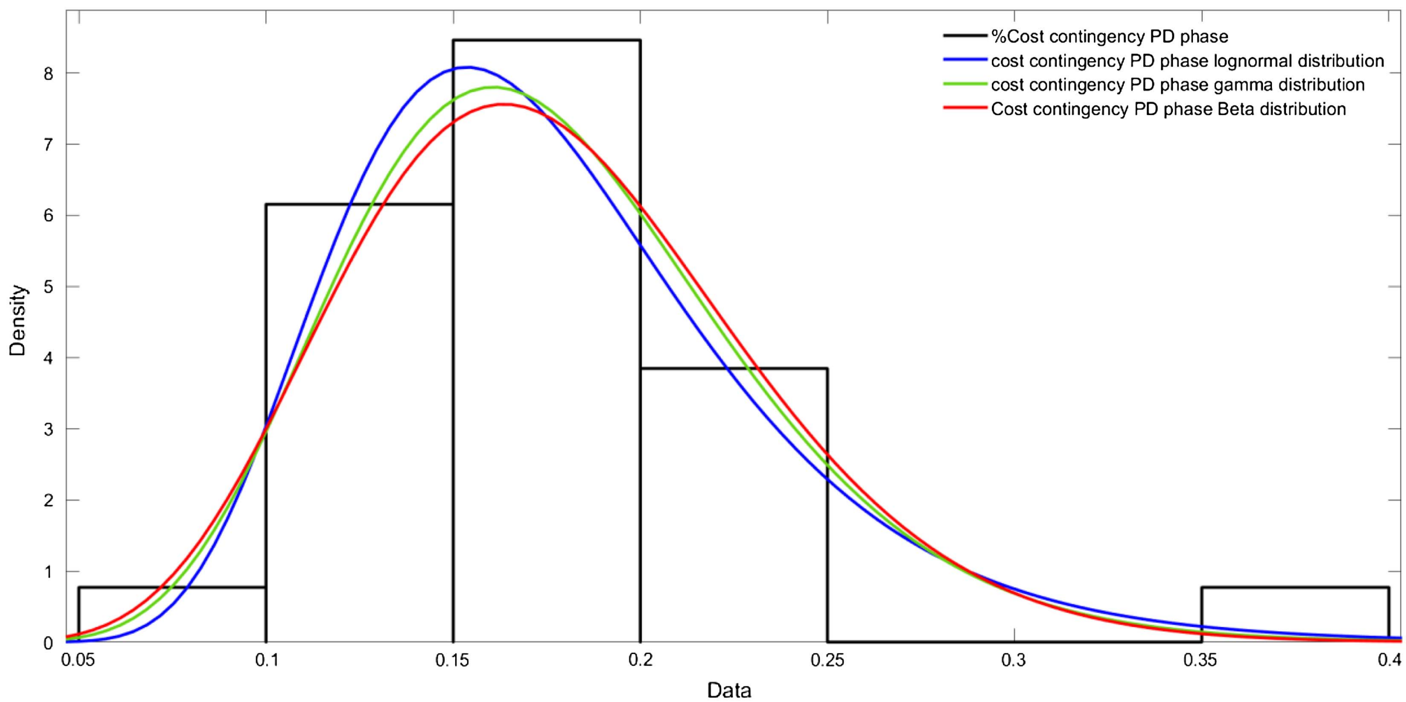


Fig. 5. Histogram and PDF fitting distributions for the percentage of cost contingency in the PD phase.

Cost Evolvement in the Preparation Phase

Cost evolvement of the projects in the preparation phase was calculated by comparing the TC in two moments: EXP and T&A. Data from 28 projects were used, as data was required for both EXP and T&A. The delta of the cost estimates (TC estimate at T&A phase—TC estimate at EXP phase) in these two phases is used to calculate the amount of cost evolvement. Figs. 8 and 9 present the distribution of percentage and the amount of cost evolvement, respectively. An accurate estimate means that the delta is zero or around zero.

The histogram in Fig. 8 shows that 13 out of 28 projects experienced a decrease in the costs (cost underrun) in the preconstruction phase. Two projects show no differences in the estimates. For the projects with an increase in the estimated costs, the average cost estimate increase is about 45.52% (SD = 55.14). For the projects with a cost estimate decrease, the average percentage is −20.73%

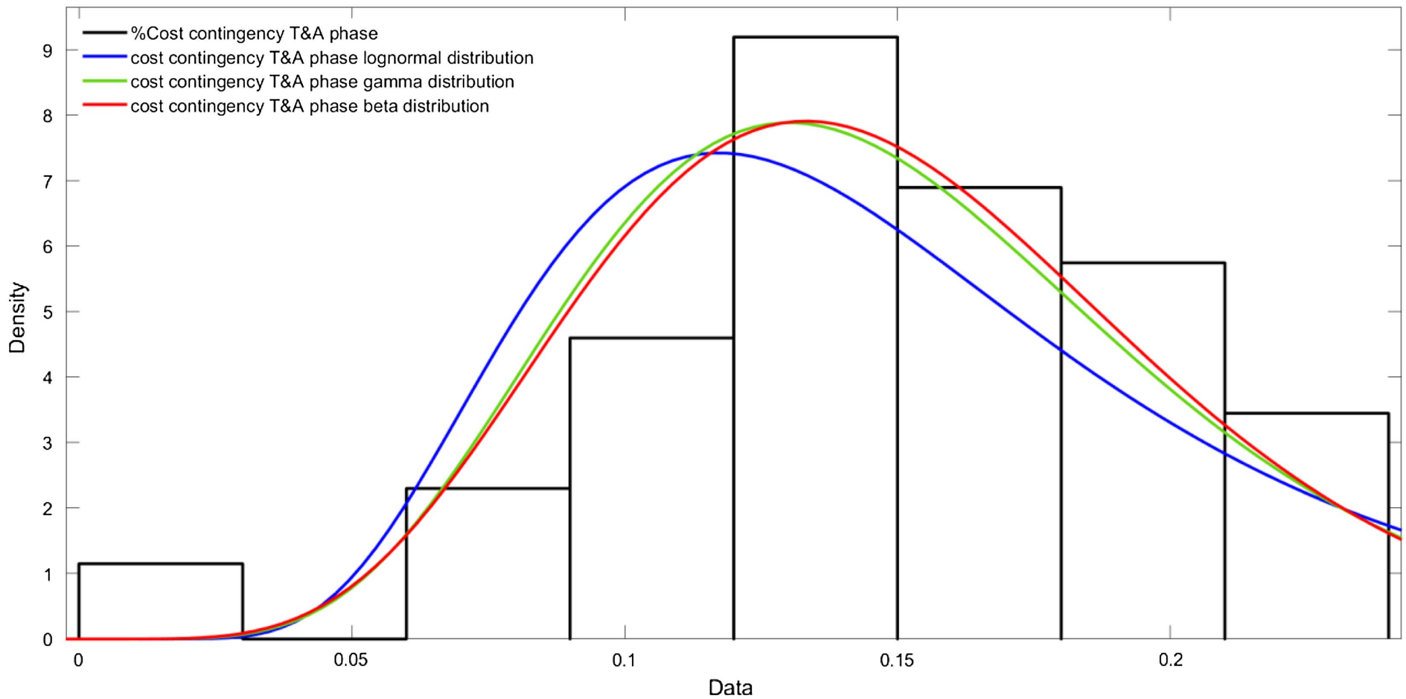


Fig. 6. Histogram and PDF fitting distributions for the percentage of cost contingency in the T&A phase.

Table 4. Chi-square goodness-of-fit test for the percentages of cost contingency in the EXP, PD, and T&A phases

	EXP phase			PD phase			T&A phase		
Distribution	Chi-square x_f^2	$f = k$-1	$C_{1-\alpha,f}$ ($\alpha = 0.05$)	Chi-square x_f^2	$f = k$-1	$C_{1-\alpha,f}$ ($\alpha = 0.05$)	Chi-square x_f^2	$f = k$-1	$C_{1-\alpha,f}$ ($\alpha = 0.05$)
Gamma	5.72	5	11.07	13.35	6	12.59	2.03	4	9.48
Lognormal	6.46	5	11.07	10.03	6	12.59	0.86	4	9.48
Beta	6.44	5	11.07	15.79	6	12.59	2.31	4	9.48

Table 5. Distribution parameters derived from the gamma, lognormal, and beta distributions per phase

	Gamma		Lognormal		Beta	
Distribution parameters	α	β	μ	σ	α	β
EXP phase	9.39	0.02	−1.65	0.34	7.53	29.58
PD phase	11.04	0.02	−1.78	0.31	8.88	41.32
T&A phase	7.79	0.02	−1.96	0.42	6.95	39.75

(SD = 20.91). The magnitude of the percentage of cost estimate increase in the preconstruction phase (45.52%) is higher than of the cost estimate decrease in the preconstruction phase (20.73%) ($p = 0.001$, independent samples t-test).

Fig. 9 shows the amounts rather than the percentage. About half of the projects have experienced cost underrun in the preconstruction phase (13 projects). Projects with a cost estimate increase mostly have an increase of up to €10 million (13 projects), which is small compared to the total amount of estimated cost in the T&A phase (see the Appendix). As shown in Fig. 9, looking at only projects with a cost estimate increase, the average cost estimate increase is €6.76 million (SD = 9.87). The average of cost estimate decrease for the projects with a cost estimate decrease is −€11.6 million (SD = 15.28). The magnitude of the amount of cost estimate increase is higher than the cost estimate decrease in the preconstruction phase ($p = 0001$, independent samples t-test).

The descriptive statistics of cost evolvement in the preconstruction phase for all projects are presented in Table 6.

The percentage of cost estimate increase in the preconstruction phases is 11.51% (SD = 51.12) and the amount of cost estimate increase is −€2.25 million (SD = 14.85).

The research by Cantarelli et al. (2012) about the cost overrun in the preconstruction phase of transport infrastructure projects in the Netherlands reveals that projects become more expensive in the planning phase (at least in the case of the Netherlands), and once the construction phase has started, cost overruns are less common. Please consider that the results of Cantarelli et al. (2012) (in the preconstruction phases) and the results of this research are in fact referring to cost evolution in the preconstruction phase, not cost overrun as such. Table 7 compares the cost evolution in the preconstruction phase of flood defense projects (this study) and transport infrastructure projects by Cantarelli et al. (2012). The amount of cost estimate increase in the preconstruction phase of transport infrastructure projects is 19.7%, which is higher than the cost estimate increase in flood defense projects (11.5%). The percentage of cost estimate increase for the projects with a cost estimate increase, however, is higher in flood defense projects compared to transport infrastructure projects (45.5% for flood defense projects against 30.8% for the transport projects). There is less cost estimate increase in flood defense projects; however, if there is, it has a higher magnitude. The percentage of cost estimate decrease for the projects with a cost estimate decrease is higher in flood defense

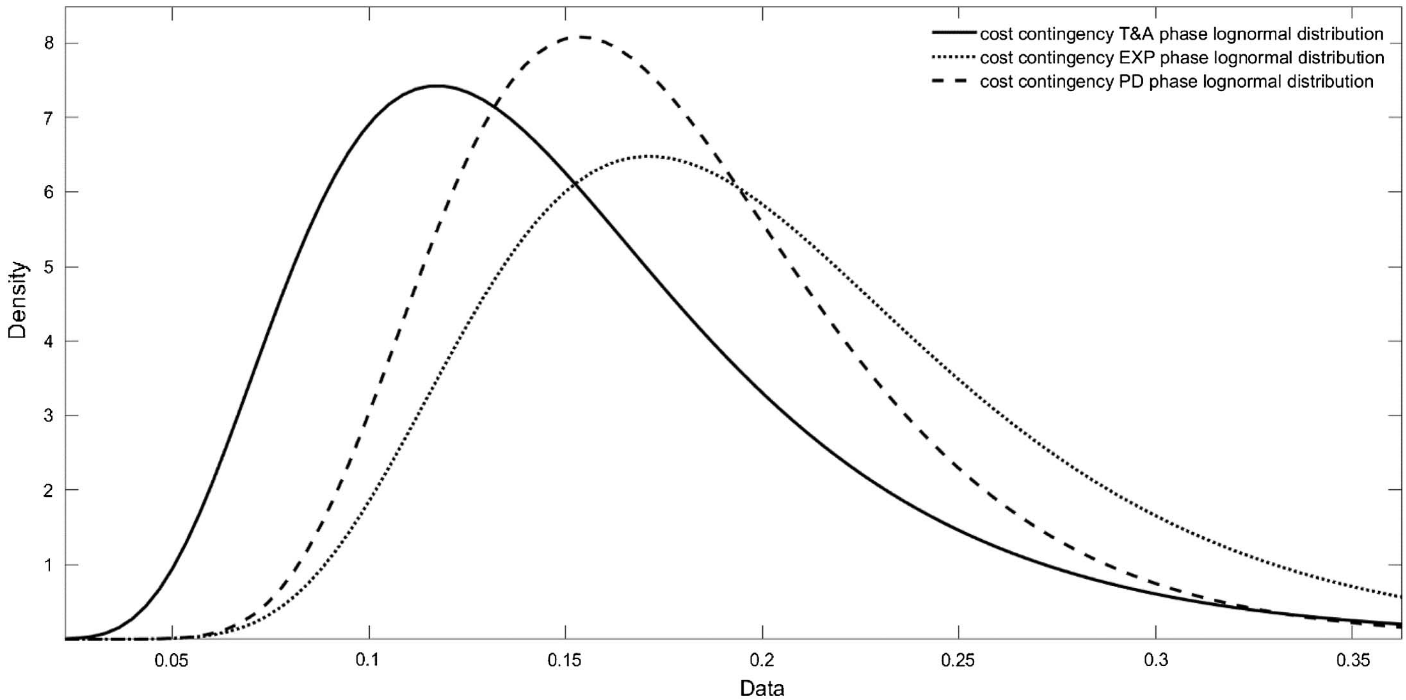
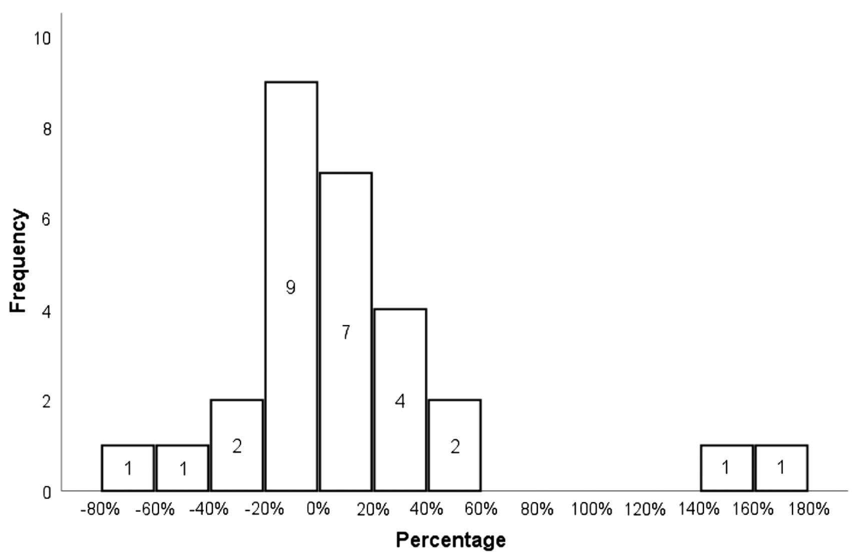
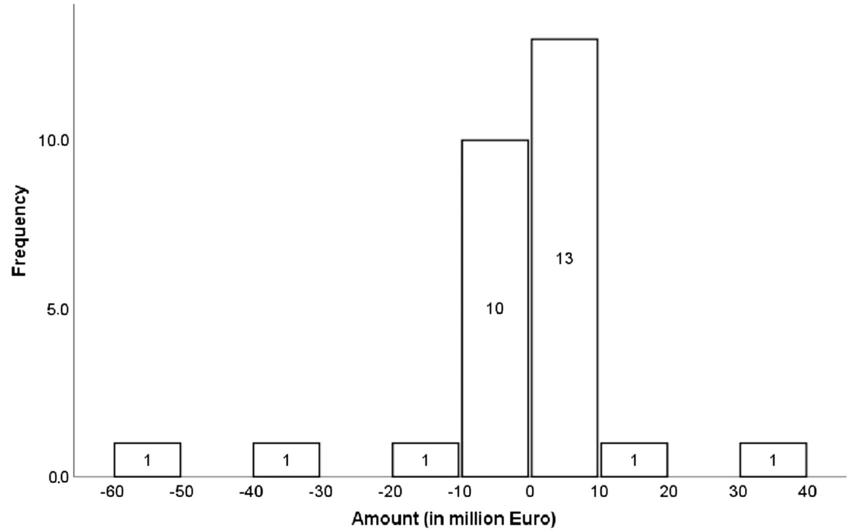


Fig. 7. Changes in the distribution in the three phases.



	Statistical analysis of percentage of cost estimate increase	Statistical analysis of percentage of cost estimate decrease	Number of projects without changes in the estimates	Overall results
Mean	45.5%	-20.73%	-	11.51%
Median	26.44%	-13.41%	-	0.13%
Standard Deviation	55.14	20.91	-	51.12
Minimum	2.1%	-65%	-	-64.86%
Maximum	169.4%	-1.8%	-	169.42%
Count	13	13	2	28

Fig. 8. Distribution of percentage of cost estimate increase and cost estimate decrease in the preparation phases of Dutch flood defense projects (N = 28).



	Statistical analysis of amount of cost estimate increase	Statistical analysis of amount of cost estimate decrease	Number of projects without changes in the estimates	Overall results
Mean	6.76	-11.60	-	-2.25
Standard Deviation	9.87	15.28	-	14.85
Minimum	0.03	-52.80	-	-52.8
Maximum	37.10	-0.13	-	37.10
Sum	87.87	-150.86	-	-62.99
Number of projects	13	13	2	28

Fig. 9. Distribution of amount of cost estimate increase and cost estimate decrease (in million euro) in the preconstruction phase of the Dutch flood defense projects (N = 28).

Table 6. Descriptive statistics of the amount of cost evolvement in the preconstruction phase for all projects

Statistical parameter	Statistical analysis of amount of cost estimate increase (in million euro)	Statistical analysis of % cost estimate increase
Mean	−2.25	11.51%
Standard deviation	14.85	51.12
Minimum	−52.8	−64.86%
Maximum	37.10	169.42%
Number of projects	28	28

Table 7. Comparing the cost overrun in flood defense projects with transport infrastructure projects in the preconstruction phase

Measure	Flood defense projects (this research) (%)	Transport infrastructure projects by Cantarelli et al. (2012) (%)
% cost estimate decrease for the projects with a cost underrun	18	6.5
% cost estimate increase for the projects with a cost overrun	45.5	30.8
Total cost estimate increase (%)	11.5	19.7

projects (18%) than in transport infrastructure projects (6.5%). In both studies, the overall (average) results show a cost estimate increase.

Relation between "Known Unknowns" and "Unknown Unknowns" Contingencies

The proportion of "known unknowns" and "unknown unknowns" contingencies are further investigated based on the explanation provided in Eqs. (1) and (2). Table 8 presents the descriptive statistic of the "known unknowns" and "unknown unknowns" contingencies in three phases. In all phases, the percentage of the "unknown unknowns" contingency is higher than the percentage of the "known unknowns" contingency.

Molenaar (2005) explains that the amount of "known unknowns" and "unknown unknowns" contingencies should decrease during the course of a project (Fig. 10).

The reduction in estimated cost is a result of better defining cost variables and eliminating uncertainty as cost factors are finally incorporated into the project plan. By further developing a project, the design and scope become clear (causing less ambiguity uncertainty), the cost variables are better defined (causing less inherent uncertainty), and some risks are not applicable anymore. As a result, both "known unknowns" and "unknown unknowns" contingencies reduce (Fig. 10). The results of this research, however, do not fully confirm this. As shown in Table 8, the mean value of the "unknown unknowns" contingency shows an increase in

Table 8. Comparing "known unknowns" and "unknown unknowns" contingencies in different phases

Statistical parameter	EXP phase		PD phase		T&A phase	
	Known unknowns	Unknown unknowns	Known unknowns	Unknown unknowns	Known unknowns	Unknown unknowns
Mean	18.61%	81.39%	30.54%	69.46%	27.52%	72.48%
Standard deviation	18.63	18.63	23.38 %	23.38	23.42	23.42
Minimum	0%	36.88%	0%	7.89%	0%	0%
Maximum	63.12%	100%	92.11%	100%	100%	100%
Number of projects in dataset	28	28	26	26	29	29

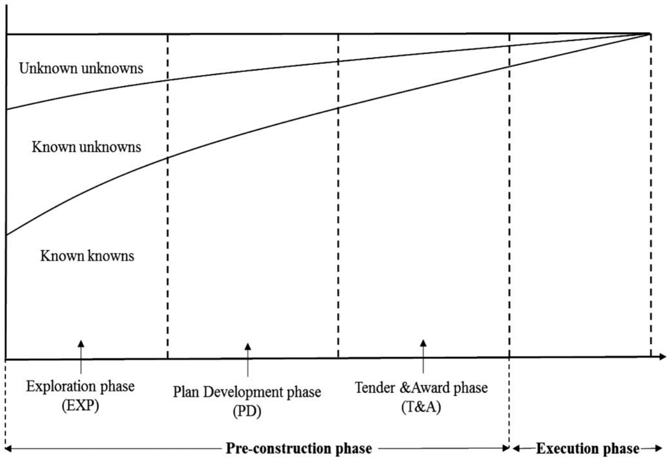


Fig. 10. Relation between "known knowns," "known unknowns," and "unknown unknowns" during the project life cycle. (Adapted from Molenaar 2005.)

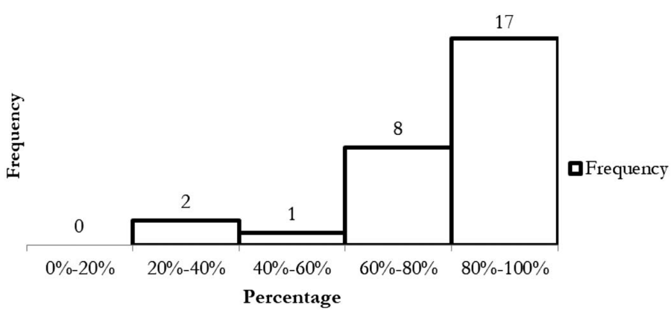


Fig. 11. Distribution of the "unknown unknowns" contingency in the EXP phase (28 projects).

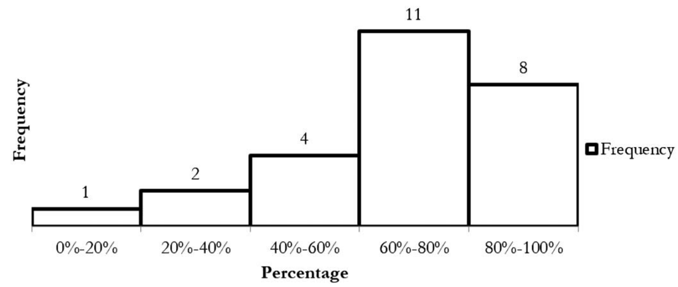


Fig. 12. Distribution of the "unknown unknowns" contingency in the PD phase (26 projects).

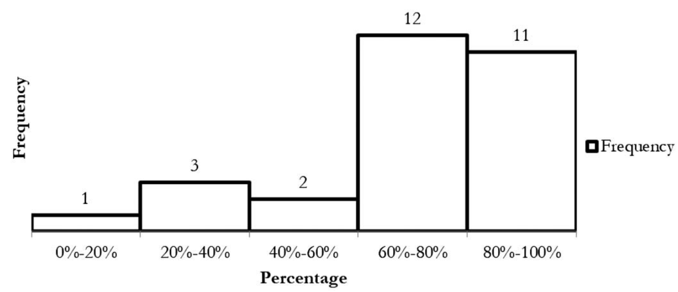


Fig. 13. Distribution of the "unknown unknowns" contingency in the T&A phase (29 projects).

the T&A phase compared to the EXP phase ($p = 0.047$, independent sample t-test).

Figs. 11–13 show the distribution of the percentage of the "unknown unknowns" contingency in the EXP phase, PD phase, and T&A phase, respectively. The histograms show a skewness to the right of the figures, meaning that most of the projects faced a higher "unknown unknowns" contingency than "known unknowns" (i.e., a project with an 80% "unknown unknowns" contingency means that it has only a 20% "known unknowns" contingency) (Figs. 11–13). Even in the T&A phase (Fig. 13) where a decrease in the "unknown unknowns" contingency was expected, some projects had large contingency to address "unknown unknowns." Overall, it is concluded that the projects in this research seem to be conservative in their estimates.

Discussion

The research investigates the cost evolvement of the Dutch flood protection projects in the preconstruction phase. The examined projects experienced on average 11.51% cost estimate increase in the preconstruction phase (Table 6), which is less than a similar study on the Dutch transport infrastructure projects (19.7%) (Cantarelli et al. 2012). Although the main reasons for the overruns cannot be concluded, several aspects might play a role.

Lovallo and Kahneman (2003) mention, among others, "anchoring" and "adjusting" as reasons for cost increase in projects. "Anchoring" means that the estimator makes initial estimates and "adjusts" their assessment to reach those estimates (Baccarini and Love 2014; Lovallo and Kahneman 2003). From the data in this research, it cannot be concluded whether any "adjusting" and "anchoring" has occurred in the cost (contingency) estimates. If it was the case, it would be expected that the cost (contingency) estimates in the T&A phase to be the same or close to the cost (contingency) estimate in the EXP phase. However, the results (Table 3) show that the cost contingency is reduced for most projects.

Another reason for poor cost performance mentioned in the literature is "optimism bias" and "strategic misrepresentation"

(Cantarelli et al. 2010; Flyvbjerg et al. 2003, 2002). "Optimism bias" means that promoters and forecasters are overly optimistic about project outcomes in the preparation phases (Flyvbjerg et al. 2002), and "strategic misrepresentation" refers to deliberate misrepresentation of project costs and risks for other gains such as political and economic gains (Flyvbjerg 2006). Due to the nature of the projects in our study, however, it is difficult to relate the cost increase in the preparation phase to these two phenomena. All the projects in this study are flood defense projects, which have failed the safety tests according to the norms, and therefore, they should be improved. All these projects, no matter what, will receive the required funding. As any budget left after the project execution should be given back to the HWBP, there are a few incentives for the projects to apply "optimism bias" or "strategic misrepresentation," such as proposing lower costs than actually expected. Therefore, in contrast to Cantarelli et al. (2012) who conclude that the cost increase in the Dutch transport projects can be explained by psychological and political-economic explanations, this study rejects these aspects as reasons of cost increase in the preconstruction phase of flood defense projects.

The cost estimate increase in projects in this research could be related to "technical" reasons such as imperfect forecasting techniques, inadequate data, and lack of experience, as also mentioned by Flyvbjerg et al. (2002, 2003). When the examined projects started, they were relatively new for the responsible Waterboards and they had limited experience with cost estimation of these types of projects. Mistakes caused by lack of historical data or lack of experience were unavoidable. It is expected, however, that such errors reduce as the Waterboards perform similar projects and gain more experience with these types of projects. Another possible reason for the cost increase in the preparation phase can simply be the result of more detailed design and more clear scope as the project progresses toward the execution phase. In the preconstruction phase, the scope is still not fixed, meaning that a project can change the design alternative, execution techniques, or materials. Consequently, the costs might deviate from the initial estimate. Therefore, an increase in cost estimates could be expected and acceptable.

Next to the investigation of the cost evolvement, the research shows that the projects have a tendency for a high "unknown unknowns" contingency (Figs. 11–13). One reason for the increase of the "unknown unknowns" contingency, from the EXP phase to the T&A phase (Table 8), could be the lack of certainty in the estimates. This increase in the "unknown unknowns" contingency is what the authors would call "pessimistic bias." This reveals that the projects were pessimistic; not confident in their estimates and despite the reduction in the total cost contingency (Table 3), the "unknown unknowns" contingency has increased. For the studied projects, a shortcoming in the budget means bureaucratic and administrating work to get the extra funding. To avoid these hassles, the project might have increased the "unknown unknowns" contingency upfront. It is generally observed that the estimator's assessment of range estimates tends to be conservatively biased for the upper-bound value assigned (Yeo 1990). Mak and Picken (2000) mention that estimators usually tend to include an inflated buffer in the contingency estimate.

An organizations' culture may have also played a role in increasing the "unknown unknowns" contingency. The examined organizations are public. In order to overcome reputation damage and public critics, their attitude is risk avoidant. Estimating a higher cost contingency gives them more certainty to finish the project within the assigned budget. The "unknown unknowns" contingency is calculated simply based on a percentage of BC. In the T&A phase, the design and scope are almost fixed and the changes in the BC and the "known unknowns" contingency is less possible. Therefore, to achieve a higher cost contingency, it would be easier for the projects to adjust the "unknown unknowns" contingency. This way, the projects have more confidence in their estimations. One possible pitfall of increasing the "unknown unknowns" contingency is that this amount becomes exaggerated, meaning that the projects have extra reservations. If there are fewer needs on the cost contingency, budgets could be seriously underspent. This remaining budget should be used in other projects, but, as the budget was already reserved, "gold plating" could also happen, leading to unnecessary expenditures.

Conclusion and Implication for the Practice

This research investigated cost contingency and cost evolvement of construction projects in the preconstruction phase. It is concluded that the examined projects have mostly experienced an increase in the estimated costs in the preconstruction phase. The results show that the projects were conservative in their estimates.

The research has contributed to the available literature in three ways. First, until now, few studies were reported on the evolvement of the total project cost estimate in the preconstruction phase. Our research contributes to closing this gap. Second, the concept of "known unknowns" and "unknown unknowns" is a rather undiscovered and vague one in current literature and there is no example, to the knowledge of the authors, of the investigation of this concept in construction project practice. This research has contributed to the current body of knowledge by investigating the "known unknowns" and "unknown unknowns" contingencies and explaining the proportion of these contingencies compared to the total cost contingency of projects. Third, while some researchers conclude

Table 9. Total project costs at the T&A phase

Project ID	Total cost estimate at the T&A phase (in million euro)
1	€23.31
2	€140.17
3	€8.89
4	€6.95
5	€51.29
6	€2.37
7	€24.66
8	€56.45
9	€2.97
10	€13.96
11	€49.78
12	€23.83
13	€50.63
14	€3.73
15	€39.89
16	€29.27
17	€124.13
18	€0.60
19	€5.38
20	€38.73
21	€4.13
22	€10.40
23	€8.81
24	€1.89
25	€126.06
26	€123.01
27	€60.82
28	€0.74
29	€2.66
Total	1,0351.51

that "optimism bias" is one of the reasons of cost increase in projects, this research shows that a lack of confidence in the estimates or "pessimism bias" is another possible reason for cost increase. This third contribution also has practical implications. The practitioners could consider the results of this study to avoid "pessimism bias" behavior and, as a result, improve their cost estimate practices. Being aware of "pessimism bias" behavior, the organizations can define strategies to minimize this phenomenon in their cost estimate practices. One possible strategy to avoid "pessimism bias" is to ask for a second opinion on the estimates (external view). The projects can ask for opinions on their estimates by experts in similar projects, which would be very helpful in the case of HWBP. Another possible implication of the research is to use the data to better estimate the costs of future projects. The results show that the lognormal distribution fits well to the percentages of cost contingency in Table 4. This distribution can be used to improve the estimate of the percentage of cost contingency in future projects. Using the historical data to estimate the project costs (known as "outside view" (Kahneman and Tversky 1977; Lovallo and Kahneman 2003) provides a check on the estimate by comparing the estimate with available historical data.

In total, cost documents of 29 flood defense projects in the preconstruction phase are studied. The results in the first part show that the mean value and the standard deviation of the cost contingency percentage have reduced from the EXP phase to the T&A phase. This confirms that the risk profile of the projects in the preconstruction phase has decreased. The results in the second part of the analysis revealed on average an 11.51% increase in the total estimated costs of the projects in the preconstruction phase. This amount is smaller than the cost estimate increase in the preconstruction phase of the Dutch transport infrastructure projects (19.7%). The literature on cost estimation mentions that cost increase is as a result of one or more of the following factors: "adjusting," "anchoring," "optimism biases," and "strategic misrepresentation." Due to the financing method of the examined projects in this research, it could not be concluded that these factors have played a role in the cost estimate increase in the preparation phases of the projects. Technical reasons such as imperfect forecasting techniques, inadequate data, and lack of experience seem more logical reasons in this case.

Comparing the "known unknowns" and "unknown unknowns" contingencies revealed that the projects in our research showed a tendency to a higher "unknown unknowns" contingency when the

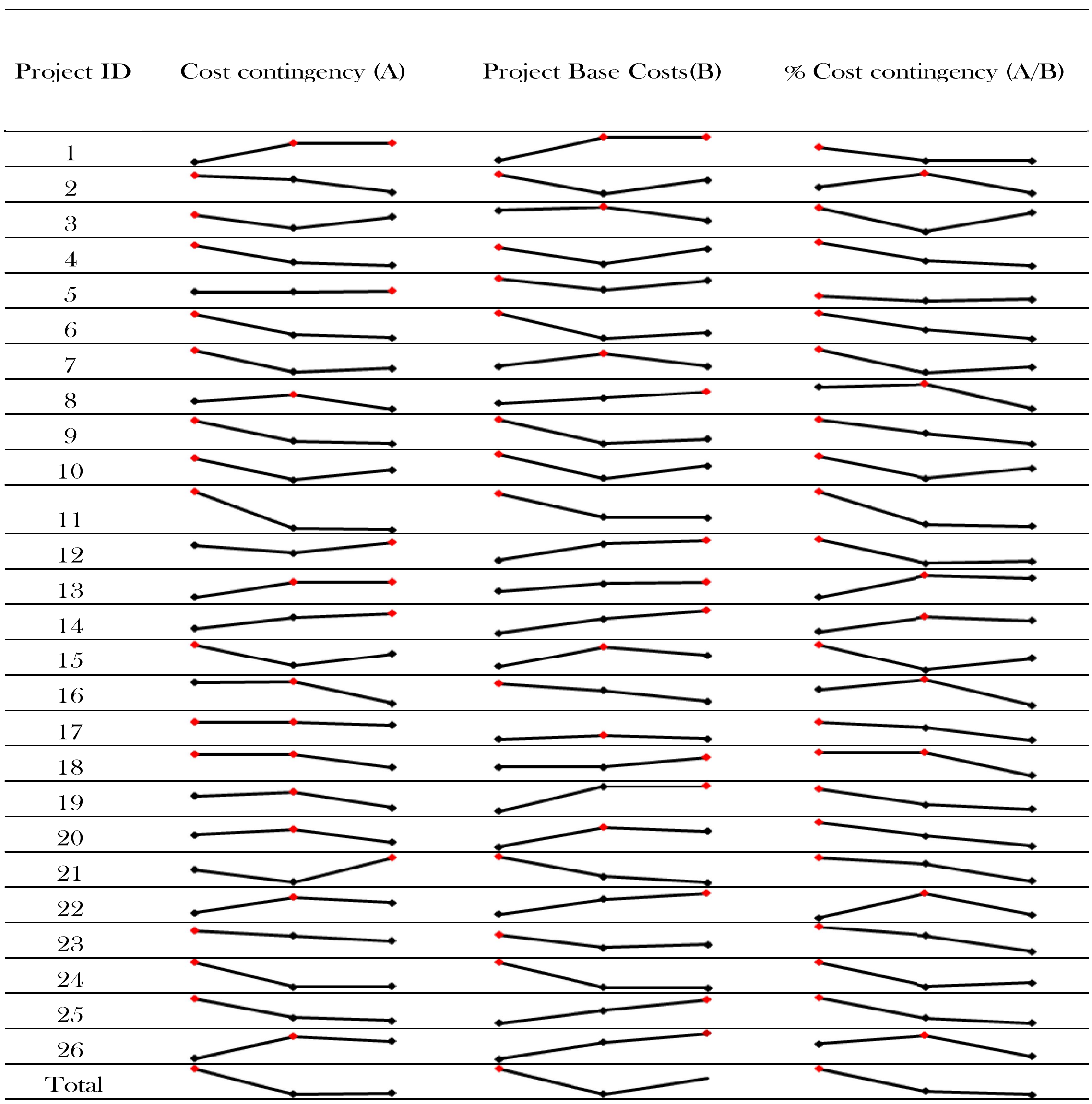


Fig. 14. Trends of base cost, cost contingency, and percentage of cost contingency.

project progresses. This would give the projects more confidence to finish within the budget. A higher "unknown unknowns" contingency can be a result of "pessimistic bias" where the projects are not confident with their estimates. In addition, it can be due to a lack of experience with the type of projects, to avoid the bureaucratic and administrative work to obtain an extra subsidy, or to overcome reputation damage and public criticism. However, overestimating the risks and reserving extra budget is an ineffective use of public money.

Research Limitation

The projects studied in this research make a border between the "known unknowns" and "unknown unknowns" contingencies and this border was used in the research in the data-gathering process. A clear border between the "known unknowns" and "unknown unknowns" events, however, might theoretically be impossible.

Recommendation for Future Research

This research has studied the cost contingency evolvement of Dutch flood defense projects. A possible area for future research could be investigating the cost contingency in the preconstruction phase of other types of projects in the Netherlands. It is also suggested that the same research is performed in other countries. This way, insight can be obtained in the cost contingency evolvement before the start of project execution in different countries.

Possible reasons for changes in the cost contingencies were theoretically explored in this research. These reasons, however, were not investigated in depth in the projects. This could be part of subsequent investigations.

As a next step, the current research could be expanded to later project phases (construction) and compare the estimated cost contingency and the actual cost contingency after execution.

The research showed that the lognormal distribution is a good fit for the percentage of cost contingency in the examined projects. Future research could investigate whether using this distribution can help in making more accurate estimates of cost contingency (development).

Appendix

Table 9 shows the total estimated cost of 29 projects in the Tender and Award (T&A) phase.

Fig. 14 shows the development of cost contingency in the three phases. Each dot on the lines represents a phase in which the left dot is the EXP phase, the middle dot is the PD phase, and the right dot is the T&A phase. The red dot indicates the highest amount in each trend.

Data Availability Statement

Some or all data, models, or code used during the study were provided by a third party. Direct requests for these materials may be made to the provider as indicated in the Acknowledgments.

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