




Risk and Uncertainty in the Cost Contingency of Transport Projects: Accommodating Bias or Heuristics, or Both?

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Abstract—Transport projects are regularly subjected to cost misperformance. The contingency set aside to cover any increases in cost due to risk and uncertainty issues is often insufficient. We review approaches that have been used to estimate a cost contingency. We show that some approaches such as reference class forecasting, which underpins the planning fallacy theory, take a biased view to formulate a contingency. Indeed, there is a perception that the risks and uncertainties that form the parts of a cost contingency cannot be accurately assessed using heuristics. The absence of an overarching theory to support the use of heuristics has resulted in them often being downplayed in a project's investment decision-making process. This article fills this void and provides the theoretical backdrop to support the use of heuristics to formulate a cost contingency. We make a clarion call to reconcile the duality of the bias and heuristic approaches, propose a balanced framework for developing a cost contingency, and suggest the use of uplifts to derisk cost estimates is redundant. We hope our advocacy for a balanced approach will stimulate debate and question the legitimacy of uplifts to solely debias cost estimates.

Index Terms—Bias, contingency, heuristics, probability, risk, transport projects, uncertainty.

I. INTRODUCTION

“Predictions are hard, especially about the future.”—Niels Bohr.

WORLDWIDE the costs of transport projects generally increase from their budget estimates and contract values [16], [17], [81], [94], [111], [113], [122]. Research has shown that the poor estimation of a project's cost contingency has

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contributed to higher construction costs than initially budgeted [44]–[48], [71]–[73], [78], [79], [89], [90]. Thus, we suggest that the contingency approaches used to mitigate the likelihood of cost increases in transport projects have been ineffective [81], [113].

The most common contingency approaches utilized in practice, be they deterministic like expert-judgment [7], [8], [21], [44], [72], [113] or probabilistic like the reference class forecasting (RCF) [23]–[25], have overlooked the distinction between risk and uncertainty [53]. In its simplest form, a contingency incorporates an exposure to risk and uncertainty, which provides the backdrop for our article [78]. Typically, a contingency refers to costs that will probably occur based on past experiences, often expressed in percentage terms as a proportion of an estimate. It is a reserve set aside over and above the base cost estimate by project clients and contractors for unforeseen circumstances [78]. We specifically deal with the cost contingency of a client in this article. This monetary amount will cover risk and uncertainties in the estimating process and minor errors or omission when the estimate is put together. However, a cost contingency is not intended to cover significant changes in scope, industrial action, inclement weather, price escalation (e.g., labor and materials), and changes in exchange rates.

When examining risk and uncertainty, two contexts come to mind [39]. In risk settings, we need to consider how we make decisions when all the relevant alternatives, consequences, and probabilities can be known (i.e., this requires statistical thinking) [39]. However, in uncertainty settings, we need to consider how we should make decisions when some of the alternatives, consequences, and probabilities are unknown (i.e., this requires heuristics¹ and intuition) [39]. Put differently, risk can be known in advance as its probabilities can be empirically assessed, but this is not the case for uncertainty as it is unknown. Thus, “by managing contingency funds in a more cost-effective way,” and accurately assessing risk and better accommodating uncertainty, we can improve the cost performance of transport projects [113: p.40], [128].

Against this contextual backdrop, we review the current approaches for determining a transport project's cost contingency. We acknowledge that the literature is replete with reviews of

¹A heuristic is “a strategy that ignores part of the information, with the goal of making decisions more quickly, frugally, and/or accurately than more complex methods” [41: p.454].

existing cost contingency methods and the proposal of new techniques [9], [48], [68]. However, the propagated methods, bar RCF, are not underpinned by a decision-making theory. This absence of theory contributes to them being unable to effectively accommodate risk and uncertainty and make decisions to ensure a transport project's cost accuracy. We aim to address this issue by reviewing the literature and suggesting a robust theoretical underpinning to use heuristics while also considering biases when formulating a cost contingency. We rely on our experience and in-depth knowledge of the transport cost performance literature to synthesize its content through qualitative analysis and interpretation.

Our review leads us to question the accuracy of RCF, which is commonly relied upon by governments worldwide to debias cost estimates for transport projects. Underpinning RCF is the planning fallacy theory [61], [62], [75]. However, it focuses solely on the risks of behavioral bias and strategic misbehavior when compiling a project's cost contingency (estimates) [53]. As a result, we call for a more balanced approach to developing a cost contingency by considering behavioral bias and the descriptive and prescriptive role of heuristics in the judgment and decision-making process. Indeed, when faced with uncertainty, not risk, "a heuristic can be better than optimization or complex strategies" [120: p.3].

Our article aims to contribute to improving the investment decision-making process of transport projects by providing a frame of reference to understand better the inherent risks and uncertainties associated with their delivery. Producing more accurate estimates of a transport project's final construction costs may help reduce taxpayers' financial burden and lower the probability that cost blowouts materialize.

We acknowledge that the production of a cost contingency may be subjected to Machiavellian behaviors (e.g., gaming) during the investment decision-making process. Uplifts to debias risk through the application of RCF are supposed to address such (mis)behaviors and the likelihood of a project experiencing cost blowouts (the planning fallacy). However, as we unequivocally point out in our article, the rationale for using uplifts over and above a cost contingency is questionable. Worse, we argue that RCF may paradoxically fall foul to the planning fallacy. While RCF aims to redress behavioral bias that may have manifested within a cost estimate, those using it for decision-making purposes can still "massage data" to suit their own needs and requirements. While RCF purports to reduce bias, it is also prone to bias² [53], [76].

We commence our article by providing a cursory look at the nature of project cost performance to provide the setting within which a cost contingency sits in Section II. Then, we review the approaches used to develop a cost contingency making specific reference to the bias and heuristics underpinning formulation in Section III. Next, we propose an alternative way to formulate a cost contingency by reconciling the duality of the bias and heuristic approaches making the use of uplifts to derisk cost estimates redundant in Section IV. Finally, Section V concludes this article.

²We would like to thank the reviewer for raising this issue.

II. PROJECT COST PERFORMANCE

The literature is replete with studies examining why transport projects capital costs increase across their life-cycle [43], [45], [79], [80], [83], [95], [111], [121], [122], [128]. Without a doubt, this literature is too vast to review here, but it would be fair to say that it is ambiguous and controversial in terms of practical recommendations, which stymies our ability to make headway toward improving the cost performance of large-scale transport projects. For instance, fundamental differences exist in the points of reference to determine a project's cost performance, the use of definitions, the format of the data, how causes are attributed, and risks and uncertainties assessed [19], [30], [43], [53], [76]–[83].

Terms such as cost overrun, cost growth, and cost escalation are used to describe increases in project costs, but from a theoretical and conceptual perspective, they have different meanings, though often treated to be synonymous [54]. For example, when using the term "cost overrun," it should not incorporate "scope changes," especially when a project's funder or client sanctions these, yet they are commonly incorporated into the reported figure. A scope change is a sanctioned addition to a project, and thus, the term that should be used is "cost growth." In the case of cost escalation, it "is an anticipated upsurge in the cost of construction as a result of time and market forces and not due to project content changes" [79: p.492]. Explicitly, using such terms interchangeably contributes to the quagmire surrounding the transport cost performance literature [54]. We, therefore, need to be explicit with our use of terminology and not use the term "overrun" simply, which often garners attention from the media who like to sensationalize issues that may arise during the delivery of a transport asset.

There are essentially three phases of a project where cost performance needs to be controlled and managed [77]: (1) precontract; (2) postcontract; and (3) operations. Our article focuses on pre-and-post contract phases, as only a handful of studies have examined cost performance during a transport project's operation [1], [15], [74]. We define cost performance as "deviations (+/-) from the budget estimate (i.e., decision to build)" or "deviations (+/-) from the contracted value" in the precontract and postcontract phases, respectively. When projects experience cost reductions, as in the case of the Pacific Motorway in Brisbane, Australia (−14%), the unused contingency can be "funnelled into scope increases and other projects" [113: p.42].

Different guidelines for estimating³ the costs of infrastructure projects and programmes provide a robust approach for establishing an early cost estimate and others across a project's subsequent stages. The Infrastructure and Projects Authority [51] explicitly states that a "cost estimate is not a single figure that is determined at the start of a project" (p.1). An estimate

³Cost estimates are characterized by the varying levels of accuracy and the phases of a project where they are undertaken. For example, Class 5 estimate (lowest level of accuracy) is performed during the initial phase of a project to screen and evaluate different projects and cost concepts (judgment and parametric estimating are used). In the case of Class 1 (highest accuracy level), it is performed when a project plan is mature and helps verify cost estimates or design compelling bids. For further details, refer to Association for the Advancement of Cost Engineering Cost Estimate Classification System [4].

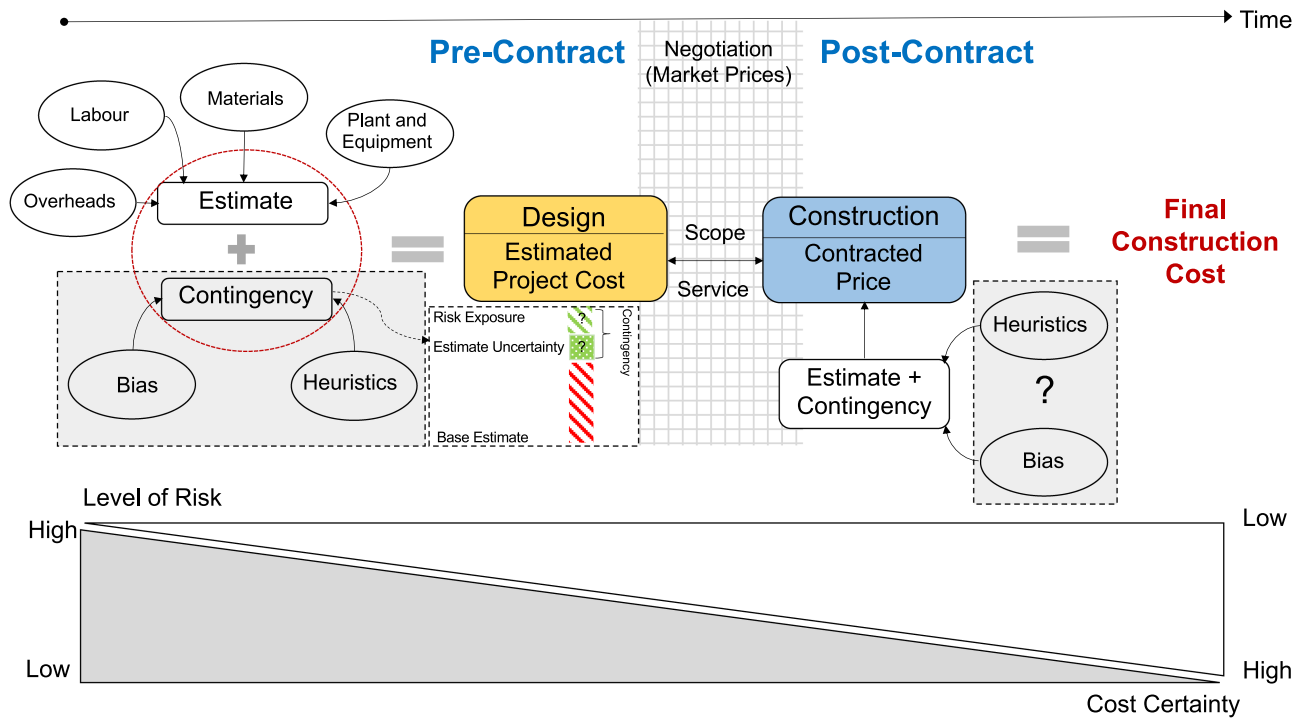


Fig. 1. Simplified (traditional) view of the transport project procurement process.

evolves over time as the scope and schedule of a project develop (i.e., information becomes available). Therefore, a cost estimate should be presented as a range to accommodate risk and uncertainty as a project develops [47]. Yet, quantifying the level of risk and the degree of uncertainty to include in a cost estimate is typically insufficient in transport projects [78]. The next section of our article presents a cursory examination of the meaning and methods used to determine a cost contingency.

III. CONTINGENCY

In the world of project execution, “contingency is probably the most misunderstood, misinterpreted, and misapplied word” [98: p.115]. Despite the considerable amount of effort that has been undertaken to understand and develop estimation methods to determine a transport project’s exposure to risk and uncertainty, increases in costs and schedules, as well as poor quality, remain natural features of practice [43], [69], [70], [74], [85], [86], [121], [122].

A. Definition and Meaning

The AACE [2], for example, defines a 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 that experience shows will likely be required” (p.28). In a similar vein, a contingency can be defined as “an amount of funds added to the base estimate to cover estimate uncertainty and risk exposure” [21]. Accordingly, a contingency considers unplanned events or identifiable risks that may arise during a project’s execution.

Two major categories of contingency are [18]: (1) design, which accommodates incomplete scope and inaccuracies of estimates and data during a project’s precontract phase; and (2) construction, which typically sets a sum aside for change-orders, errors and omissions in a project’s documentation. Both clients and contractors/consortiums will customarily determine their cost contingencies (Fig. 1). However, in the case of Alliances/Integrated Project Delivery (IPD), there will be a single contingency for the project, which is developed by the project owner (PO, i.e., client) and nonowner participants (NoP, i.e., project team). Notably, Alliances have provided large-scale transport projects with higher cost certainty due to their collaborative cost estimating and planning [127].

Fig. 1 presents a simplified (traditional) view of a project’s estimation and contingency process. Decision-making during a project’s precontract phase, which forms part of its front-end management, has been identified as a key determinant of its success [128], [130]. As a project’s scope develops and design progresses, the extent of risk exposure becomes known (though levels may fluctuate), and cost estimates become more accurate. But it is only during the tender process that we can determine the accuracy of an estimate as the market will then determine the price to be paid to deliver a project. Indeed, the procurement approach and contract type (e.g., private participation in Infrastructure versus conventional forms such as design-bid-build and design and construct), which allocate risk, will influence the price a public sector client will need to pay. Naturally, the public sector client and the contractor/consortium will amend their respective contingencies according to their risk appetite and exposure.

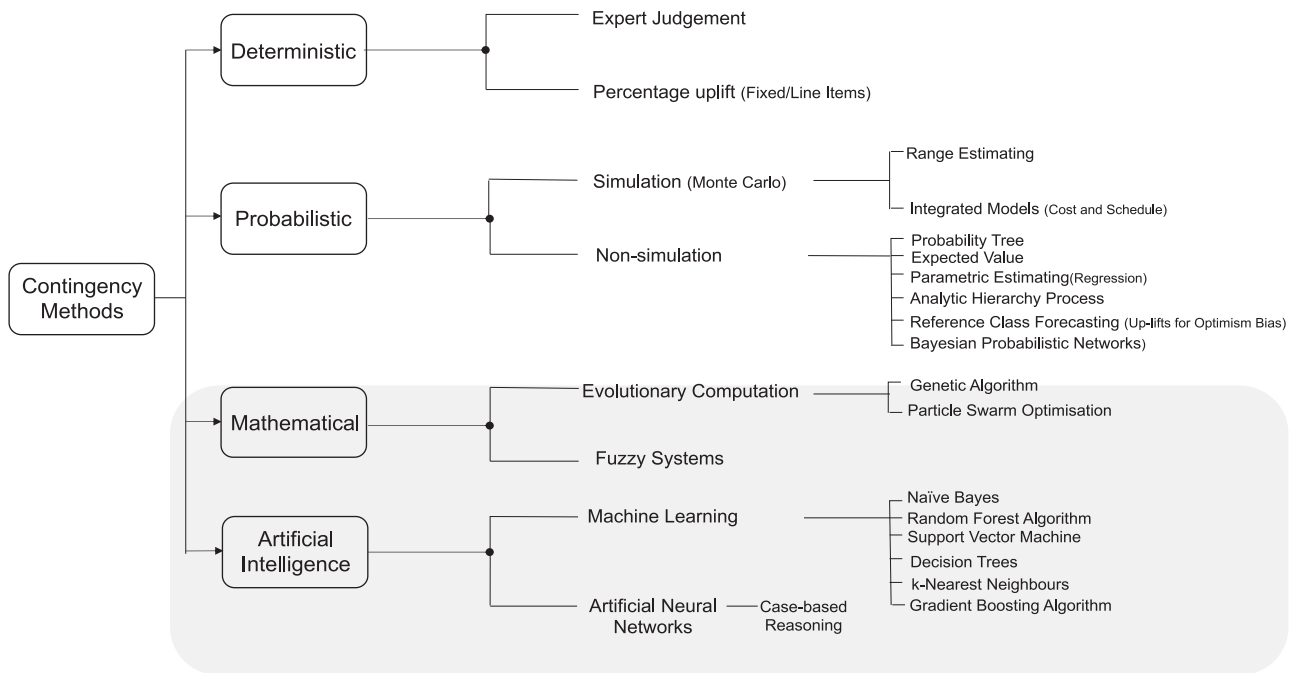


Fig. 2. Categorization of cost contingency approaches. Note: The shaded area denotes areas under development. No empirical-based models have been developed that demonstrate the validity and reliability of a transport project’s cost contingency accuracy. Sources: [7], [28], [50], [65]–[67], [96].

B. Contingency Approaches

In Fig. 2, we can see numerous computational algorithms and statistical methods have been proposed to estimate a project’s contingency, such as Monte Carlo simulation, artificial neural networks (ANNs), analytical hierarchy process (AHP), regression, and RCF⁴ [7], [10], [23], [47], [65], [66], [89]–[91], [97], [113], [132]. The methods we identify in Fig. 2 do not explicitly contain an estimate for uncertainty, but they can be used independently or combined to assess risk. For example, AHP with Monte Carlo [97], case-based reasoning with genetic algorithms (GAs [66], particle swarm optimisation with ANNs [68], RCF and Monte Carlo [104], and earned value management with RCF [10], [11].

1) *Historical Data and Expert Judgment (Heuristics)*: A plethora of contingency approaches have come to the fore due to the recurring inability to provide cost certainty in transport projects. Yet, these approaches’ accuracy (i.e., ability to provide a degree of cost certainty) has been questioned [8]. The common techniques used to determine a cost contingency are deterministic and probabilistic methods (Fig. 2). Notably, mathematical and AI methods are nascent and have yet to be empirically examined in the literature (Fig. 2).

While the deterministic approach is simple and most commonly used, it is arbitrary and unscientific [44]. Moreover, using a single-figure percentage uplift of estimated cost implies a degree of certainty that cannot be justified, particularly for large-scale transport projects. Additional features of a deterministic cost contingency approach include the following.

- 1) A tendency to double count risk as estimators may include contingencies in the formulation of the base estimate [117]. In this instance, we see “an inflated buffer” occurring [91: p.131] as a consequence of personal bias and differences in risk attitudes [103]. In other words, estimators are subject to “conservatism” [101: p.392], “structural overestimation⁵” [10: p.49], or “pessimism bias” [81: p.2]. We will address this issue in more detail below.
- 2) Overlooking time, performance, and quality risks (e.g., rework) as the percentage allowance is only for risks associated with cost [117]. Seldom are the risks of having to perform rework, and those associated with it (e.g., safety and environmental) included within the contingencies of public sector clients and their contractors/consortiums [9], [31], [85].
- 3) Discouraging creativity in estimating practice, allowing it to become routine and mundane, resulting in errors and oversights being made [117].

The Monte Carlo method is often used to overcome the issues associated with the deterministic approach. It enables

⁵When examining the formulation of base estimates from an “inside view,” that is from the perspective of the project team, Batselier and Vanhoucke [10] observed the structural overestimation of costs and duration. Batselier and Vanhoucke [10] state that this observation “cannot be explained by the existence of an unintended “negativism bias” (i.e., seeing future events in a more negative light than warranted by actual experience (p.49). Instead, they interpret the overestimation as being attributable to strategic misrepresentation (i.e., lying). However, “a lie is a false statement that is deliberately created by someone to intentionally deceive others; deception requires justification. There needs to be a motivation to enact the lie” [76: p.365]. The grounds for producing deceitful cost estimates in Batselier and Vanhoucke [10] are simply assumed and not empirically examined.

⁴RCF is not a traditional contingency method as it provides an uplift on top a project’s estimate, which includes a contingency.

quantitative analysis of risk for decision-making by providing a range of outcomes and the probabilities that they will occur for any choice of action [97], [124]. However, though flexible, the Monte Carlo method has significant limitations. For example, like most probabilistic approaches, the Monte Carlo method “is data-intensive” and unable to produce results without a “considerable body of empirical information, or unless an analyst is willing to make several assumptions” based on their expert judgment [22: p. 990]. Moreover, even though the Monte Carlo method can handle “variability and stochasticity”, it “cannot be used to propagate partial ignorance under any frequentist interpretation of probability” [22: p. 990].

Nonsimulation methods also abound. The use of parametric estimating to determine cost contingency relies heavily on historical data and techniques such as regression and ANNs [7]. Safeguards need to be put in place to identify risk factors (technical) considered to have a predictable influence on a project’s cost performance. We also need to be cautious when using parametric models of cost contingency as “empirical models, until validated with new data or analysis cannot be assumed directly applicable to projects beyond the scope of those that form their empirical basis” [3: p.1].

The creation of a cost contingency (and estimates) using expert judgment (i.e., intuition and heuristics) and decision-making has been the subject of intense criticism as psychological and political-economic issues are overlooked [25]–[30]. According to Flyvbjerg [25], these psychological and political-economic issues are always ignored when an estimate and contingency are formulated. To reiterate, we are only concerned with contingency in this article but note the points also raised apply to the preparation of cost estimates.

2) *From an Inside to an Outside View of Contingency Estimation*: Flyvbjerg’s [25] aforementioned critique is drawn from the planning fallacy phenomenon [61], [62]. In this instance, there is a tendency to underestimate the times, costs, and risks of future actions and simultaneously overestimate their benefits [62]. Thus, optimism bias leads to time and cost overruns and benefit shortfalls. At this point, we refer readers to Flyvbjerg’s [29] “Iron Law,” which is derived from the perceived optimism bias that may prevail when determining a project’s cost, schedule, and benefits.

Traditionally, the estimation of cost contingency (and estimate) has taken an “inside view” [24], which Kahneman and Lovallo [62] suggest is akin to “intuitive forecasting⁶” (p.26). In this case, estimates of cost and risk are based on knowledge (e.g., heuristics) of a project’s scope, the details of its overall plan, “some ideas about likely obstacles and how they might be overcome. In an extreme form, the inside view involves an attempt to sketch a representative scenario that captures the essential elements of the history of the future” [62: p.25]. That is to say, the inside view focuses on probabilities akin to degrees of belief on the part of estimators, which are intersubjective, and often based on anything from experience to personal impression [32]–[34].

⁶Kahneman and Lovallo [62] refer to forecasters making forecasts, but in the context of this article they are deemed to be synonymous to estimators (e.g., cost planners and engineers) that estimate construction costs.

The “inside view” is, therefore, “susceptible to the fallacies of scenario thinking and anchoring of estimates on present values or extrapolations of current trends” [62: p.27]. The upshot, purportedly juxtaposed with strategic misbehavior, is developing a ridiculously optimistic cost contingency (estimate), which causes transport projects to experience cost overruns [24], [25], [29]. Estimators or forecasters taking this view have been the subject of intense criticism from scholars such as Taleb [112] and Makridakis *et al.* [92], with Flyvbjerg [27] lamenting most are “fools and liars” (p.772).

According to Kahneman and Lovallo [62], the mitigation of optimism bias needs estimators and decision-makers to take the “outside view” when considering risk. So, when an estimator, for example, is preparing their estimate and cost contingency for a new rail project, they need to “ignore the details of the case at hand” and make “no attempt at detailed forecasting of the future history of the project” [62: p.25]. By taking an “outside view,” the estimator needs to focus on the statistics of a comparable class of rail projects, for example, “chosen to be similar in relevant respects to the present one” [62: p.25]. The rail project under consideration would also be compared to others within its respective class to determine its position in the distribution of outcomes, and hence, the so-called “reference class” [61]. Put differently, the outside view focuses on intersubjective probabilities that are measurable frequencies based on large amounts of data [32]–[34], [36], [38].

Drawing inspiration from the work of Kahneman and Tversky [60], [61] and Kahneman and Lovallo [62], Flyvbjerg and COWI [23] cogently developed procedures for dealing with optimism bias and strategic misbehavior⁷ in transport projects using RCF. It has been asserted by Flyvbjerg [25] that RCF not only “bypasses” the optimism bias and strategic misrepresentation that are (supposedly) contained in transport project’s cost estimate and contingency, but it can improve its accuracy (p.5).

Disillusioned and frustrated with transport projects experiencing cost increases and with contingencies not being able to accommodate their risk exposure adequately, we have seen governments worldwide (e.g., Denmark, Ireland, The Netherlands, and the U.K., to name but a few) embracing RCF in an attempt “to produce more realistic forecasts for [an] individual project’s capital expenditure” [23: p.2]. But, as a method that seeks to produce a realistic forecast of capital expenditure, RCF simply adds an uplift to overcome possible shortfalls in a project’s contingency, as illustrated in Fig. 3. As such, RCF is akin to a contingency on a contingency. This position is confirmed by Flyvbjerg and COWI [23] as they state an “upward adjustment must be applied on top of a standard budget including standard contingencies” (p.28). In this instance, the estimate of project cost is grossly inflated through a process of “simplification” based on the assumption of potential bias [30: p.185]. While there is a rationale for uplifts to compensate for behavioral bias and strategic behaviors, no empirical evidence has been

⁷The term strategic misrepresentation is not used in Flyvbjerg and COWI [23]; instead reference is made to strategic behavior. In this document, the guidelines stress that there is a need to consider the deliberate attempt by actors to keep budgets low, ignore unforeseen costs, and emphasize benefits [23: p.50].

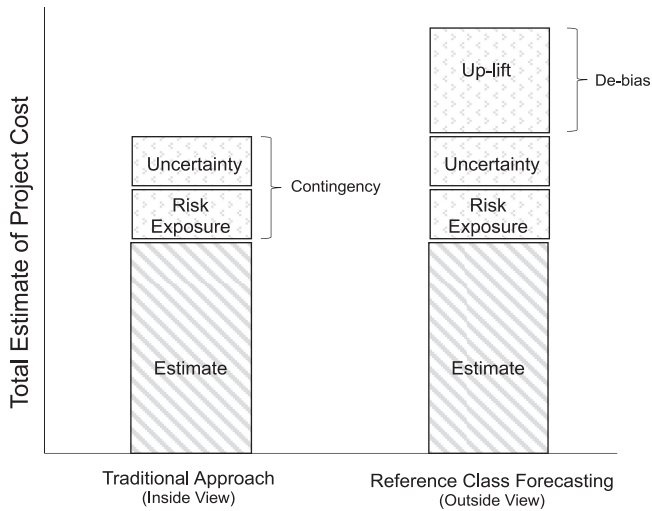


Fig. 3. Risk exposure, uncertainty, and uplifts.

forthcoming to demonstrate its presence within an estimate and quantify its effects on final construction costs [81], [82].

As a matter of fact, Mak and Raftery's [89] study of risk attitude and systematic bias in the estimating and forecasting of construction costs concluded that "there is little significant support for the existence of severe and systematic bias in this study" (p. 320). Thus, estimators' skill, training, and expert judgment may markedly influence a cost contingency (and estimates) accuracy and not necessarily bias [89].

We do not discount the presence of optimism bias, quite the contrary. Other behavioral biases (e.g., availability and confirmation bias) influencing a cost contingency (and estimate) have not been considered. We also need to note that most research on bias and heuristics, decision-making under risk and individual risk attitudes have been heavily reliant on experiments in a laboratory environment [37], [46], [60], [61]. Experiments are often unable to mimic reality as the "conditions of making judgments may be dissimilar to the real-world equivalent" [89: p.319].

Despite the widespread adoption of RCF, except perhaps the work of Batselier and Vanhoucke [10], [11], there is limited empirical evidence about its accuracy and how it compares to other dominant cost estimation methods⁸ [20], [71], [72], [102]. Batselier and Vanhoucke [10], for example, found that "RCF only outperforms the other techniques when the degree of similarity between the considered project and the projects in the reference class is sufficiently high" (p.49). However, large-scale projects tend to be unique and complex undertakings in idiosyncratic contexts, and carbon copy replication of their cost and risk patterns is prone to failure [77]. Thus, a significant barrier to applying RCF is accumulating a sample of similar projects with a large enough sample size and accurate cost information, including comparable practices and risk profiles

⁸RCF is not a cost estimation method per se as noted by Li and Napier [71] Li *et al.* [72]. It is an approach to validate an estimate by benchmarking against historical experience and/or past estimates.

[67], [71]. Moreover, past and similar projects are relatively rare in some instances, and a reference class reliability of RCF [71], especially in conditions of uncertainty [53].

Rarely is reliable information made available about the influence of political-economic issues on a transport project's cost estimate and contingency (e.g., strategic misrepresentation and pork-barrelling⁹) [81]. However, High Speed Two (HS2)¹⁰ in the U.K. offers a befitting example where "strategic misrepresentation and optimism bias" have undermined the public's confidence in the project. An inquiry by The Committee of Public Accounts [115] concluded that the HS2 Ltd. and the Department for Transport deliberately lied as they knew HS2 could not be delivered on time, within budget or scope, and withheld information that would have informed parliament and the public about the true nature of the project's challenges. Thus, notwithstanding the usefulness of the aforementioned cost contingency approaches, they remain by and large inaccurate in the face of the risks and uncertainties associated with delivering large-scale projects.

C. Exposure to Risk and Uncertainty

It can be concluded, based upon the discussion above, that our ability to effectively determine the cost contingency of transport projects (i.e., exposure to risk and uncertainty) has fallen short due to [49: p.17].

- 1) An inability to measure and validate methods in practice: There exists no verifiable evidence demonstrating that the methods used to improve the assessment and mitigation of risk are accurate. Hubbard [49] explicitly puts forward that "for a critical issue like risk management, we should require positive proof that it works—not just the lack of proof it doesn't" (p.17).
- 2) Using components that are known not to work: Human judgment has often been used to assess risk, but experimental evidence highlights the inevitable presence of human errors and biases [59], where only individual judgment is relied upon, it has been shown that people can systematically underestimate risks [60]–[62], and there is a likelihood that the duty of sound risk assessment will be abrogated.

As a result of the work of Tversky and Kahneman [125] and Kahneman and Tversky [60], which challenges the assumption of human rationality and provides a theory for decision-making under uncertainty to mitigate risk, Todd and Gigerenzer [118] observe: "the demise of the dream of certainty and the rise of a calculus of uncertainty–probability theory" [p.728]. Thus, as a consequence of Flyvbjerg and COWI's [23] advocacy for the use

⁹The utilization of government funds for projects designed to please voters or legislators and win votes.

¹⁰The High Speed Two programme aims to construct a new high-speed, high-capacity railway between London, Leeds, and Manchester, via the West Midlands. This will join with the existing rail network to enable journeys to Liverpool, Newcastle, Edinburgh, and Glasgow. With an original budget of £55.7 billion set in 2015, it is the Government's largest infrastructure programme by value" [115: p.4]. Estimated costs of the project have skyrocketed and are estimated to be in the vicinity of £106 billion [116].

of RCF, buttressed by Kahneman's Nobel winning theories of decision-making under uncertainty, we have seen the increasing reliance on the use of probability to derisk cost contingencies (estimates). The underlying assumption is that risk exposure estimation is riddled with irrational cognitive biases as estimators (forecasters) seek to maximize their utility function [64].

Risk mitigation only forms part of the equation when determining a cost contingency as we also need to consider uncertainty, which probability theory cannot accommodate [118]. Even though decision-makers in the public sector are utilizing RCF, cost underestimation in transport projects remains problematic [81], particularly in the face of uncertainty, which RCF does not accommodate [53].

Previously documented in Love and Ahiaga-Dagbui [76: p.366], a case in point is the infamous Edinburgh Tram and Airport Link project (U.K.), which utilized RCF. The project was initially estimated to cost £320 million, including a risk contingency-based estimate [6]. Taking all the available distributional information into account, considering a reference class of similar rail projects (e.g., London Docklands Light Rail), the reference class estimated an 80th percentile value of £400 million. The project was completed three years late in 2014 at a reported construction cost of £776 million. Considering claims and contractual disputes, which partly occurred due to errors and omissions in contract documentation, a revised estimated final cost of over £1 billion was forecasted, including £228 million in interest payments on a 30-year loan to cover the funding shortfall [12]. As noted by Li *et al.* [72], "the main challenge for applying the RCF method is the accumulation of a sample of similar projects with a large enough sample size and accurate cost information. It may take a long time to develop such a database. For some types of projects that are relatively rare in a country, it may never be possible to have a sample size large enough for statistical analysis." (p.232).

While probability theory has a valuable role to play in mitigating risk, Todd and Gigerenzer [118] do not see this to be the case as they suggest "replacing the image of an omniscient mind computing intricate probabilities and utilities with that of a bounded mind reaching into an adaptive toolbox¹¹ filled with fast and frugal heuristics" (p.729). This rather different biases-and-heuristics¹² (i.e., human reasoning and judgment) approach to statistical reasoning undertaken by Gigerenzer and his colleagues have been largely ignored in the planning and transport literature and other fields such as construction and

project management [32]–[42], [53], [109]. The prominence of probability theory and erroneous beliefs about heuristics results in them being treated as "second-best strategies" that we use due to "cognitive limitations, and that logic or probability is always the best way to solve a problem" [34: p.2]. In Table I, we identify six common erroneous beliefs about heuristics.

Often the information needed to make accurate assessments of a cost contingency required to ensure transport projects are delivered on budget is unavailable. Thus, we need to rely on heuristics due to their useful frugality in the face of uncertainty. Models of heuristic cognition can therefore be drawn upon as "the probabilities or utilities are unknown" and "ill-defined problems prevent logic or probability theory from finding the optimal solutions" [34: p.20]. If we rely on heuristics to accommodate the absence of information, then the "mind resembles an adaptive toolbox with various heuristics tailored for specific classes of problems—much like the hammers and screwdrivers in a handyman's toolbox [34: p.20]. Contrary to popular belief held by protagonists of the "outside view" grounded in probability theory [23]–[30], empirical evidence demonstrates that less information processing and reduced computation time can improve decision-making accuracy [40]. This observation has also been affirmed within the context of estimating construction costs by Mak and Raftery [89].

IV. DUALITY OF BIAS AND HEURISTICS

Our minds can apply logic/statistics or heuristics to make decisions. However, each of these "mental tools are not treated equally" and each is suited to a particular problem [41: p.452]. For example, in Kahneman's view [56], [58], rules of logic and statistics marry with rational reasoning, whereas heuristics are linked to error-prone intuitions and irrational thinking. Therefore, when deviations from statistical principles occur and projects experience cost increases over their expected budget, Flyvbjerg *et al.* [30] conveniently interpret this upsurge to be due to behavioral biases, which are "attributed to cognitive heuristics" [41: p.452]. To this end, Flyvbjerg *et al.* [30] believe that if estimators (forecasters) ignore heuristics, then a more accurate assessment of a project's risk and uncertainty can be made irrespective of its context, and cost overruns mitigated. That said, Marewski and Gigerenzer [88] demonstrate that heuristics are more accurate than biased in some contexts, particularly under conditions of uncertainty. In other words, we can use heuristics as they can be fast and correct in specific and evolving contexts and adequately accommodate risks and uncertainties.

Despite the extensive contradictory research that has examined "judgment under uncertainty" [33], [56], [63], [93], [99], [110], [118], the framing of bias and heuristics as a dualism or an "either/or" approach does not necessarily improve the accuracy of a project's cost contingency [53], [84], [89]–[91]. As we mentioned above, the research on "judgment under uncertainty" predominantly focuses on the individual under experimental conditions in a laboratory setting with students who have limited understanding and knowledge of real-life settings. Thus, extrapolation of the conclusions presented in Tversky and Kahneman [125], Kahneman and Tversky [61], and Kahneman and Lovallo

¹¹An adaptive toolbox focuses on an individual's or organization's repertoire of heuristics.

¹²A balanced review of the differences between Kahneman and Tversky and Gigerenzer and his colleagues on the research on human reason and judgment can be found in Vranas [126] and Samuels *et al.* [107]. It is outside the scope of this article to theoretically and empirically examine the differences as we do not want to understand how readers may become victims of "inevitable illusions," that is, how mistakes of reason can rule our minds [100]. When asked whether humans are rational, Gigerenzer and colleagues understand the question as "Are human cognitive mechanisms fitted to the environment?" [107]. Contrastingly, Kahneman and Tversky understand this question as "Are human taking decisions that maximise their utility function?" [107]. Kahneman and Tversky study decisions and conclude they are irrational. Gigerenzer and associates instead study reasoning mechanisms (i.e., heuristics) and argue they produce rational results.

TABLE I
SIX COMMON ERRONEOUS BELIEFS ABOUT HEURISTICS

	Common Misconception	Clarifications
1	Heuristics produce second-best results; optimisation is always better	In many situations, optimisation is impossible (e.g., computationally intractable) or less accurate because of estimation errors (i.e., less robust).
2	Our minds rely on heuristics only because of our cognitive limitations.	Characteristics of the environment (e.g., computational intractability) and the mind make us rely on heuristics.
3	People rely on heuristics only in routine decisions of little importance	People rely on heuristics for decisions of both low and high importance.
4	People with higher cognitive capacities employ complex weighting and integration of information; those with lesser capacities use simple heuristics (related to Misconception 1).	Not supported by experimental evidence. Cognitive capacities seem to be linked to the adaptive selection of heuristics and less linked to the execution of a heuristic.
5	Affect, availability, causality, and representativeness are models of heuristics	These terms are mere labels, not formal models of heuristics. A model makes precise predictions and can be tested, such as in computer simulations.
6	More information and computation are always better.	In an uncertain world, good decisions require ignoring part of the available information (e.g., to foster robustness).

Source: Gigerenzer [34: p.21].

[62] to the production of a cost contingency (estimate) by a team of professionals who are academically and professionally qualified remains questionable. The cost estimate produced for a large-scale transport project is often vetted by an independent third party to check for bias and errors. However, even when the check-and-balances are put in place, cost misperformance can still occur for reasons beyond the control of estimators (forecasters) and project sponsors.

The planning fallacy provides a cohort of policy-makers, decision-makers, researchers, and the like with a theoretical basis to explain project cost misperformance (i.e., behavioral bias and strategic misbehavior) and subsequently apply RCF to derisk a cost estimate. Still, such a theoretical backdrop may not work well under conditions of uncertainty. However, practitioners and scholars who essentially attribute cost misperformance to specific project-related issues, rather than behavioral biases, have made little headway in combating this problem as there is an absence of an overarching theory to support their views and observations [52], [53]. Metaphorically speaking, as the planning fallacy paradigm mostly prevails in theory and practice [24]–[31], these dissenting protagonists reside in an “anechoic chamber,” where their voices are little heard, including in the media [76]. We make a clarion call to fill in this void and justify the relevance and application of heuristics when formulating a cost contingency (estimate) using ecological rationality’s theoretical lens [42].

A. Ecological Rationality

It is beyond the scope of this article to provide a detailed account of ecological rationality and the mechanisms of adaptive toolbox (i.e., a collection of heuristics rather than an optimizing calculus; refer to the examples in Table II) it champions, as they have been well documented, though not in engineering and project management literature [35], [39], [41], [42], [109], [120].

Ecological rationality is used “to bring environmental structure back to bounded rationality” by using heuristics in environments or circumstances where they can work well [120: p.13]. A heuristic is said to be “ecologically rational to the degree that it is adapted to the structure of an environment” [120: p.13]. The definition of ecological rationality stands in stark contrast to the classical view of rationality as it is based on bounded rationality and places a positive outlook on heuristics [41]. The classical definition of rationality considers human behavior to be rational when it conforms to the norms of logic, statistics, and probability theory. As mentioned above, this view underpins the work of Kahneman [56], [58] and Flyvbjerg *et al.* [23]–[30].

The principles of consistency and coherence are typically drawn upon when evaluating people’s preferences [105]. For example, if a person prefers option A to B and B to C, the preference of C to A “would be intransitive and violate consistency” [104: p.273]. As a consequence of violating the “logical consistency principle, the person’s preferences are perceived as a violation of rationality” [104: p.273]. So, when human behavior violates the basic norms of logic or probability theory, they are “labeled as biases and have been explained by the application of heuristics that also violate the classical norms of rationality” [104: p.274]. Thus, a violation of the consistency principle is deemed to be “irrational” behavior [105: p.631].

The view that rationality only refers to coherence and logical consistency has been widely criticized [32]–[42], [46], [88], [105], [109], [118]–[120]. What is more, the consistency principle has been identified as being insufficient for defining rationality [38], [41] as we adapt to our environment and corresponding structure of cues when “time, knowledge, or resources are scarce” [105: p.632]. In this instance, human reasoning and behavior become ecologically rational when they adapt to the environment in which humans act [39]–[42].

To this end, ecological rationality views human rationality in light of the adaptive fit between the human mind and the

TABLE II
SAMPLE HEURISTICS AND THE ENVIRONMENTAL STRUCTURES THAT MAKE THEM ECOLOGICALLY RATIONAL

Heuristics	Definition	Ecologically Rational if	Surprising Predictions
Recognition	To decide which two options are greater on some criterion, if only one option is recognized, chose one	Recognition is a valid cue (i.e., leads to correct decisions over half of the time)	Contradicting information about a recognized object is ignored; recognizing fewer options can lead to greater accuracy
Take The Best	As above, but if both options are recognized: 1. search through cues in order of validity 2. stop search on first discriminating cue 3. choose option favoured by this cue	Cue validities vary highly; moderate to high redundancy between cues	Can decide more accurately than multiple regression, neural networks and exemplar models when generalizing to new data
Tally (unit-weight linear model)	To estimate criterion for some object, count the number of cues	Cue validities vary little, low cue redundancy	Can decide accurately as multiple regression
Try-a-dozen (satisficing)	To select a high-valued option from an unknown sequence, set an aspiration level; at the highest value seen in the first 12 options, then chose an option that exceeds aspiration	Unknown distribution of option values; no returning to previously options	Near-optimal performance over a wide range of sequence lengths (i.e., number of available options matters little)

Source: Todd and Gigerenzer [119: p. 168].

environment. Thus, the decisions we make are not good or bad *per se* but can only be evaluated relative to the environment within which they occur. Table II provides an overview of the various strategies that differ in complexity (e.g., the amount of information considered) and the environments under which they work well. Conventional wisdom suggests that more information, knowledge, and computation should result in making better decisions, while cognitive limitations pose a liability [120]. However, in specific environments (projects), simple decision strategies can compete with those of a complex nature; thus, at times, less is more [34].

The existence of multiple decision environments and strategies poses a problem to decision-makers as they need to adaptively select an approach that fits the particular domain. Evidence indicates that people are generally adaptive decision-makers and can respond to task and environmental characteristics [38], [41]. By adopting the lens of ecological rationality, we can understand how and when people's reliance on simple decision heuristics can result in smart behavior in different contexts. Thus, heuristics, in this case, can be ecologically rational with respect to the environment and the goals of the decision-maker as they draw upon the adaptive toolbox at their disposal; that is, a set of evolved and learned rules that guide deliberate and intuitive decision-making [14], [39], [88].

B. Way Forward: A Balanced Approach—Considerations for Practice

A call for overcoming the dualism surrounding biases and heuristics in the cost estimation of infrastructure projects and reconciling them, not as opposites but complementary approaches, has arisen due to Ika *et al.*'s. [53] promulgation of a new principle of project behavior, namely the Fifth Hand. Thus, as noted in Fig. 4, this new principle seeks to promote an antidualistic approach to decision-making by bringing together the “bias and error, optimism bias and pessimism bias, risk

and uncertainty, statistical analysis and intuition, biases and heuristics, governance and project management paradigms for cost overruns and benefit shortfalls explanations” [53: p.10].

To simultaneously deal with risk and uncertainty requires people to “understand when to trust their guts, use statistical analysis or learned rules” [53: p.11]. A case in point is presented in Leleur *et al.* [67], who address overconfidence bias during the assessment of transport projects by using RCF to formulate the best reference pools and expert judgment to determine the adjustments to deal with uncertainties. Understanding the context of the reference pools and deriving simple rules garnered from experience help determine relevant uplifts. While our article recognizes the merits and drawbacks of using bias or heuristics in decision-making, we believe that if strides are to be made to produce more accurate cost contingency estimates, they should not be considered mutually exclusive. If we deem them complementary, then perhaps a robust cost contingency can be developed, and there would be no need to debias risks by adding uplift to a cost estimate. However, we need to be cognizant that many governments are conditioning their decision-makers to view project cost contingency through the lens of a cognitive illusion and Bayesian reasoning. Thus, the “systematic biases that separate the beliefs of people and the choices they make from optimal beliefs and choices are assumed in rational-agent models” [57: p.1449].

Alternatively, we may also ask decision-makers to embrace a mindset of ecological rationality where the emphasis is placed on describing how a judgment or decision is reached (i.e., the heuristic processes or proximal mechanisms) and the class of environments in which homo¹³ heuristics succeeds or fails [39]. In that case, they may succumb to the Einstellung Effect [87].

¹³Gigerenzer and Brighton [40] state that “homo heuristics has a biased mind and ignores part of the available information, yet a biased mind can handle uncertainty more efficiently and robustly than an unbiased mind relying on more resource-intensive and general-purpose processing strategies (p.107).

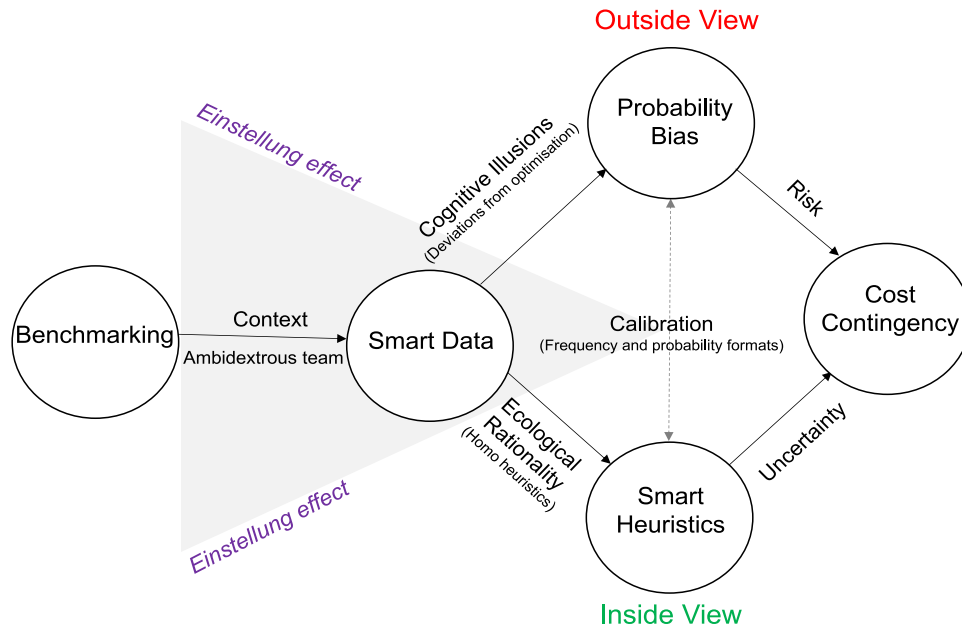


Fig. 4. Antidualistic approach to determine cost (estimate) contingency.

This situation occurs when pre-existing knowledge or experience prevents us from considering alternative possibilities to a problem. We become so fixated on one possible solution that we are cognitively unable to take a straightforward, unbiased approach to the current situation.

We can address the issues associated with Einstellung Effect (e.g., understanding a project's context) by creating an ambidextrous and diverse team (i.e., considering structural and contextual ambidexterity) to produce a cost estimate and contingency. Traditionally, little consideration is given to determining the accuracy of cost contingency when creating an estimate for a business case as deterministic approaches are applied with RCF being added to derisk bias by some governments.

The cost estimate and contingency approved at the business case is only indicative and will be subject to change, usually increasing, as a project's design and scope are developed. However, with the use of collaborative procurement methods such as Alliances/IPD to deliver transport projects, the benefits of an ambidextrous and diverse team can be acquired [77], [83], [127]. It can provide the "cognitive space" to arrive at novel solutions to problems (e.g., creative estimates) [55]. In this instance, team members can challenge one another's ideas and assumptions. Moreover, the team can draw on the project context, considering its complexity and how the cost contingency will adapt to any possible changing needs and demands in a project (e.g., scope). Questioning framed in accord to "how might we" can trigger new solutions and guide team members away from the seemingly obvious, which may not necessarily provide a satisfactory outcome to a problem. The team, in this case, would comprise the client and nonowner participants. They would jointly prepare an estimate and contingency enabling a realistic assessment of a project's target outturn cost. Thus, there would be no need to derisk a cost estimate for behavioral biases as they would be incorporated within the contingency.

While project teams need to be mindful of the Einstellung Effect, learning from best practices from previous projects also needs to be considered. Governments can create a database to benchmark the performance of their projects across their life-cycle (e.g., explicitly linking practices to outcomes through process benchmarking¹⁴). Indeed, several government agencies such as the Bureau of Infrastructure and Transport Research Economic (BITRE)¹⁵ in Australia do this already. Still, the data often contains considerable noise, is incomplete (e.g., unable to capture causes), and there is reluctance for agencies to share with others. More often than not, only final construction costs are benchmarked (i.e., contract award to final account), which only provides a snapshot of a cost contingency's accuracy and a project's performance throughout its life [1], [15], [52], [81].

We need to also benchmark cost contingency (estimates) from a project's business case to contract award and during a transport asset's operation. By enacting process benchmarking, we can improve decision-making and determine risks to improve project performance. The emphasis, however, should focus on acquiring smart data rather than collecting it *per se*. In this instance, the actual data needed for decision making and assessing risks is based on real-world facts rather than all the available data from a transport project [82]. As Love *et al.* [86] cogently note, "unless decision-making emerges from evidence, then large-scale transport projects will continue to be delivered over budget, thus eroding much of their intended benefits and public trust" (p.12).

¹⁴Process benchmarking focuses on identifying best practice processes and comparing actual processes that projects utilize. The goal of process benchmarking is to improve different project phases by learning from others.

¹⁵Details of BITRE can be found [Online]. Available: <https://www.bitre.gov.au/>. As an example, the Road Construction Cost and Infrastructure Procurement Benchmarking: 2017 update can be found [Online]. Available: https://www.bitre.gov.au/publications/2018/rr_148/.

Benchmarking provides a basis to establish a reference class for a pool of transport projects. Such pools can include various criteria such as their size (e.g., cost and schedule), procurement strategy, type of project (e.g., light and heavy rail and airports). Additionally, detailed information such as the estimated level, allocated cost contingency, scope change and quality issues should be captured and used as a reference source. With such data, we may use Bayesian analysis, regression or some other optimising strategy to estimate the probability of a deviation in project cost. However, decision-makers often face incomplete information about an epistemic situation due to each transport project's uniqueness and conditions. In situations like this, we tend to draw on rules of thumb, "which look like curiosities in the absence of an overarching theory" [41: p. 456].

The adaptive toolbox provides a basis for fast and frugal decision-making through the use of smart heuristics (i.e., those that people use to make good decisions) [42]. There are three building blocks that provide people with the ability to construct fast and frugal strategies in the face of risk and uncertainty [41]: "(1) search rules specify in what direction the search extends in the search space; (2) stopping rules specify when the search is stopped; and (3) decision rules specify how the final decision is reached" (p. 456).

Accurate probability judgments are central to estimating accuracy. To address the issues associated with bias, for example, Love *et al.* [81] draw on the recommendation of Hubbard [49], who suggests there is a need for a culture of calibration, which is a core feature of an ambidextrous team, particularly in transport projects procured by Alliances/IPD [127]. A calibrated culture is "one in which managers and subject matter experts know the prediction will be documented and reported and that good predictions will be incentivized" [49: p.25]. A method for generating incentives is the Brier Score [13], which can measure the accuracy of probabilistic estimates [49], [81]. The Brier score is used to evaluate the accuracy of an estimator's prediction by the probability they estimated for obtaining the right answer. Thus, it applies to tasks such as estimating, where forecasts for a set of mutually exclusive discrete outcomes are assigned probabilities.

The assertion that people's cognitive limitations make them poor Bayesians by Kahneman and Tversky [59], Thaler and Sunstein [114] and Kahneman [58], for example, is questionable [36], [37]. Such a claim only holds when information is presented in probabilities. However, when presented in a natural frequencies format, Bayesian performance substantially increases as biases can be made to disappear [32], [46], [47].

So, how we frame our question to determine the risk to be incorporated into a cost contingency needs consideration. Typically, public sector agencies require estimates to be presented as a P50 or P90¹⁶ using a probabilistic assessment of risk. In this case, the following question is considered: What is the probability that a rail project will exceed its budget? Alternatively, in the case of a frequency format, we should ask the following question: How many rail projects of this type using

¹⁶P50 (P90) represents the project cost with sufficient funding to provide a 50% (90%) level of confidence in the outcome; there is a 50% (90%) likelihood that the final project cost will not exceed the funding provided. A P90 is a conservative position and shows that funding allocation has only a 10% chance of being exceeded.

these practices exceed their funding and do you expect this to occur? The information format influences our risk perceptions and mental mechanisms for probabilistic reasoning [5]. While the frequency and probabilistic formats are antipodal, we suggest decision-makers and estimators (forecasters) make the best from a "project's evolving context" and learn from their use in practice to determine risk levels [53: p.12]. Indeed, combining developments in artificial intelligence with domain-knowledge Bayesian Networks provides decision-makers and estimators with robust tools to model and generate "what if" scenarios when considering risk and uncertainty during a cost contingency's production.

Our antidualistic approach presents a conceptualization of the process to develop a cost contingency. Practitioners are applying several aspects of our approach, such as benchmarking and statistical analysis, to create a cost contingency. Still, smart data and heuristics are not being given the credence they rightly deserve when dealing with uncertainty. Practitioners must draw on best practices and understand "what went right" by drawing on the experiences from projects that are delivered successfully rather than just focusing on "what goes wrong" and the "cost blowout" that is incurred. The technique of RCF ignores best practices, and thus, promotes mediocrity as it focuses on the distribution of projects that experience cost blowouts.

Concentrating on what can be learned, particularly through the enactment of process benchmarking, will enable practitioners to develop a portfolio of smart heuristics that can be incorporated into their adaptive toolbox, which can be used to assess risk and uncertainty in transport projects better. Collaborative procurement methods such as Alliances/IPD will provide an environment for an antidualistic contingency approach to be enacted as the emphasis is placed on "best-for-project" and sharing of risks. However, its operationalization to practice requires development, which we will focus on in our future research.

V. CONCLUSION

Our article set out to improve the investment decision-making process of transport projects by propagating a balanced approach where biases and heuristics are framed as a duality rather than a dualism or an "either/or" choice to help improve the cost estimation process. The rationale for this approach emerged due to a cost contingency being unable to accommodate the risks and uncertainties that can contribute to a project's cost misperformance.

We briefly reviewed the various approaches that have been developed to estimate a project's cost contingency. Despite numerous approaches for determining a project's cost contingency, we were none the wiser about determining its accuracy. Except for RCF that aimed to eliminate the behavioral bias in a cost estimate using statistical analysis, other developed methods for determining a cost contingency appeared to be curiosities that eschew a theoretical underpinning. If we can better assess risk and uncertainty and produce a more comprehensive cost contingency, then the use of uplifts for bias can be put aside. After all, there was no empirical evidence that has been able to demonstrate the presence of bias in an estimate and quantify its effect on project costs.

Different explanations as to why transport projects exceed their budgeted costs can be found in the literature. Many public

sector authorities succumb to the view that behavioral bias (e.g., optimism bias) and strategic misbehaviors were the causes of poor project cost performance. Consequently, we had seen increasing attention paid to RCF, underpinned by the planning fallacy, which was applied to debias a project's cost estimate and contingency. However, there was no empirical evidence to indicate that bias was present while estimating a cost contingency. Moreover, RCF only focused on debiasing cost estimates through probabilistic reasoning, which cannot account for uncertainty. Indeed, probabilistic reasoning played a role when formulating a cost contingency, but proponents of this approach were steadfast in their convictions that it was the only way to ensure its accuracy. In doing so, they have unfortunately cast aside the invaluable role cognitive heuristics can play in the uncertain world of project cost estimation.

No formal theory has been used to underpin and justify using heuristics to develop a cost contingency. In this article, we suggested that ecological rationality can be used to fill this void. In this sense, a heuristic was not considered good or bad, rational or irrational, but its accuracy depended on the structure of the project's environment. With sufficient experience, people can then learn to select appropriate heuristics from their adaptive toolbox. We acknowledged the importance of combining both the bias and heuristic approaches in the judgment and decision-making process. Therefore, emerging from our examination of the literature, we proposed a balanced framework for formulating a cost contingency for transport projects.

Our reconciliation of bias and heuristic views of judgment and decision-making formed the heart of our contribution for formulating a cost contingency. However, this reconciliation will undoubtedly irk "purists" on either side of the bias and heuristic camps fence. Estimates of risk and uncertainty were not undertaken by individuals in transport projects but by a highly differentiated team with varying experience, skills, and knowledge. Rationality and irrationality have meaning, and thus, need to be accommodated if headway is to be made in improving the accuracy of a transport project's cost contingency, thus eliminating the need to solely focus on the addition of artificial uplifts to an estimate.

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