RISK-3908

Risk Analysis and Contingency Estimating for Class 10 Estimates

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Abstract–The AACE® International (AACE) cost estimate classification system recommended practice (RP) series is likely its most recognized RPs. In 2021, a new Unclassified/Class 10 estimate type was introduced in AACE RP 111R-20, *Estimating for Long-Range Planning – As Applied for the Public Sector*. However, there is no AACE RP for quantitative risk analysis (QRA) methods for estimating contingency or management reserve allowances for Unclassified/Class 10 estimates.

A goal of the paper is to lay the groundwork for a potential QRA RP for Unclassified/Class 10 QRA recommended practice. It starts by reviewing the concepts of estimate classification in general and Unclassified/Class 10 estimates in particular. Next, it outlines various uses of these estimates such as for asset life cycle cost (LCC) estimating and analysis as part of strategic portfolio management or for surety (bonding) valuation. The paper also reviews scenario analysis and other decision analysis methods to identify potentially useful QRA concepts. It also reviews current contingency determination practices for long-range estimates and the limited research on long-range estimate cost growth. Finally, several proposed Unclassified/Class 10 QRA and contingency/reserve allowance determination methods, aligned with AACE QRA principles, are presented.

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Introduction

The AACE® International (AACE) cost estimate classification system series of recommended practices (RP) is outlined in the AACE Professional Guidance Document PGD-01, *Guide to Cost Estimate Classification Systems* [1]. These are likely the most widely used AACE RPs. Since the first such RP was published 25 years ago (RP 17R-97, *Cost Estimate Classification System* [2]), the classification system has included five classes that represent levels of project scope definition numbered from 1 to 5 with Class 5 being the least well defined.

In 2021, a new Unclassified/Class 10 estimate was added as documented in RP 111R-20, *Estimating for Long-Range Planning – As Applied for the Public Sector* [3]. The need for a pre-Class 5 designation for long-range planning uses (i.e., estimate prepared 10 or more years before project execution) was first described by Taylor, et.al. in 2018 [4]. This paper summarizes the purpose and definition of this new estimate classification and proposes fit-for-use quantitative risk analysis (QRA) and contingency/reserve allowance estimating practices that align with Unclassified/Class 10 estimating and AACE QRA principles.

The 2018 Taylor paper [4] was by a water treatment utility; an industry where long-range capital portfolio planning for a growing and evolving utility system has always been required. In recent years, low carbon initiatives have increased the stakes. For example, most energy firms have published 10 and 20 years plans for achieving lower carbon emissions. A specific example is Consumers Energy's *Clean Energy Plan* which includes retiring coal units and replacing power supply with wind and solar renewables (renewables are planned to increase from the current 11% to 42% in 2030 and 56% in 2040 [5]). From conception through start-up, it is not unusual for a major project to take 10 years to complete, so most projects in 10-year plans have already entered a company's phase-gate estimating and funding approval process. It is for the asset life cycle and portfolio or system management plans that extend beyond 10 years (outside of traditional, shorter-term, phase-gate processes) where the Unclassified/Class 10 classification comes into play.

Background/Basis

This section discusses a number of definitions, concepts and practices related to Unclassified/Class 10 estimates that will help establish the basis of proposed QRA methods. It starts with explaining the general concept of estimate classification, moving on to the concepts of asset life cycle and life cycle cost (LCC) in long-range planning, and then to the use of Unclassified/Class 10 estimates in various long-range analysis methods.

Estimate Classification, Phase-Gate and Quantitative Risk Analysis (QRA)

The estimate classification system was developed to tie cost estimating practice to the phase-gate project scope development processes that have become ubiquitous in most industries. Phase-gate is a project system governance and risk management process wherein project funds are approved at decision "gates" or milestones in a stepped fashion. Each definition *phase* adds more scope definition detail, thus reducing the definition-driven risk. And, each *gate* approves additional funds (or recycles project for further definition) until full funding can be prudently sanctioned, typically at AACE Class 3 or 2 [6]. The risk is usually communicated as a cost estimate accuracy range which is determined through QRA (refer to RP 104R-19, *Communicating Expected Estimate Accuracy* for more information on accuracy ranges [7]).

Cost estimate classification practices are related to QRA methods in that fit-for-use QRA methods vary with the level of project scope definition. For example, at Class 5, having little scope definition, QRA is often done using parametric risk analysis [8], while at Class 3, with more detailed scope definition, a critical path schedule method with Monte Carlo simulation (MCS) is often used for major projects [9]. The AACE PGD-02, *Guide to Quantitative Risk Analysis* describes these and other QRA methods and their relationship to estimate classification [10]. What has not been addressed in AACE RPs or PGDs to date are QRA methods for Unclassified/Class 10 estimates; the topic of this paper.

Base Estimates, Unclassified/Class 10/Class 5, and Contingency/Reserve Allowance

The focus of this paper is on the QRA and contingency/reserve allowance, not the "base" cost estimate (defined in RP 10S-90 *Cost Engineering Terminology*, as the "*estimate excluding escalation, foreign currency exchange, contingency, and management reserves*" [11]). Class 10 base estimates are prepared in the same way as Class 5 base estimates; the difference between Class 10 and Class 5 is mainly in the use of the estimates (e.g., Class 10 for life cycle costs estimates (LCCE) or determining surety requirements) and the greater risk of Class 10 due to potential scope change and increasing uncertainty over time.

Per RP 111R-20, the use of the Unclassified or the Class 10 designation is determined by the rigor and requirements of the entity's asset management and LCCE processes and practices as follows:

- Unclassified: performed as part of a process where scope change is not expected to be addressed in planned estimate updates over time (i.e., one-time, or more ad-hoc);
- Class 10: same as unclassified, but where a classification designation is required to meet organizational procedures (but also implies more documented requirements);

RP 111R-20 retains the use of the "Class 5" designation when a long-term estimate is part of a controlled, documented asset management process involving planned estimate updates to address scope and cost changes over time (e.g., often required for nuclear decommissioning, mine closure, and other regulated asset type projects). The difference between long-term and phase-gate Class 5 estimates is that the long-term estimate is done repeatedly over time (e.g., to assess current surety requirements), whereas the Class 5 estimate, as part of a phase-gate process, is expected to progress to Class 3 or 2 and an investment decision in a relatively short time (i.e., <10 years).

For Unclassified/Class 10 estimates, RP 111R-20 states that they "*are not associated with indicated expected accuracy ranges*". In respect to QRA, the RP further acknowledges that the "*estimate is unlikely to be accurate, and the original scope may not be representative of the final solution and associated costs. Unpredictable scope and risk challenges over the extended long-range planning timeframe include economics, technology, availability of resources, critical infrastructure, population dynamics, regulations, organizational and asset resiliency, climate, energy, and natural influences*."

In summary, the attribute of "*unpredictable scope and risk challenges*" is the driver of the need for specialized QRA and contingency/reserve allowance determination methods for Unclassified/Class 10 estimates. However, a terminology problem arises because "contingency", per RP 10S-90, specifically excludes scope change. Therefore, the expression "contingency/reserve allowance" is used for the remainder of this paper to describe the QRA end result [11]. One of the more complete treatments of long-range estimates found (in nuclear decommissioning) took this definition approach; "*in order to reduce possible ambiguity and confusion, instead of the term 'contingency', the terms 'estimating uncertainty' and 'funded risk' are used with funded risk being for 'out of scope' cost*". [12] In any case, this points out the need for those performing QRA to carefully define what risks are covered by any particular QRA analysis and any risk funding account.

The original Taylor paper that led to RP 111R-20 highlighted the words "cost communication" in its title, recognizing that the concepts of uncertainty/risk, accuracy, and contingency/reserves are more difficult to communicate for long-range planning estimating that is outside of a structured phase-gate process [4]. Other good references regarding communication are RP 104R-19 and the aforementioned nuclear decommissioning reference [12].

The Asset Life Cycle and Life Cycle Costs (LCC)

The scope of RP 111R-20 covers "*estimating as well as communicating needs and concepts that may pre-date the creation, existence, or emergence of an asset by many years, such as planning for future capacity/infrastructure. These estimates are prepared as planning-level predictions for facilities that may be constructed 10-50+ years in the future*." [3]. These estimates are often prepared as part of an asset life cycle cost (LCC) estimating or analysis (LCCE/A) process in which multiple projects are planned to be executed at various phases or points of time during the asset life cycle. This long-range process is often referred to as a capital portfolio management or long-term capital budgeting process [13] [14]. This is part of the strategic asset management sub-process of the AACE *Total Cost Management (TCM) Framework* [15] and is also the subject of the International Standards Organization (ISO) 55000 series standards [16].

As a specific example of a long-range capital budget, the San Francisco Municipal Transportation Agency published its 20-year (2023 to 2042) capital plan costing $31.3 billion in which every project and program is itemized including a brief basis statement such as "estimate based on past similar work" [17].

These estimates have become increasingly important as society focuses on the need for sustainability and low carbon. An example of its importance to cost engineering is the November

2021 3rd edition of the *International Cost Management Standard (ICMS)* that now covers not only life cycle cost as shown in Figure 1, but also carbon emissions [18].

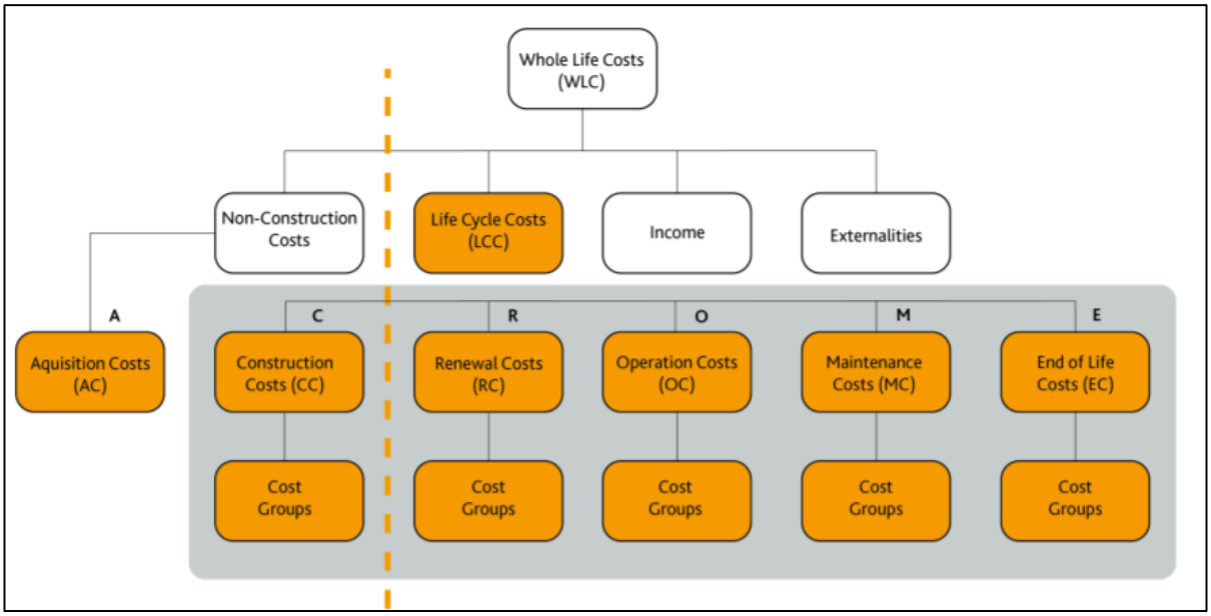

Figure 1–The relationship between ICMS, Life Cycle Costs and Whole Life Costs [18]

For utilities, transportation and similar industries, long-range planning also covers ongoing system management which, unlike for a given asset or project, has no identified end. System planning typically starts with forecasting long-range demand and other requirements, and then develops strategic plans for investments to meet those needs.

The concepts of Class 10 and of LCCE/A tend to go hand-in-hand. The literature on LCCE/A is extensive including in AACE *Transactions* (such as in Harbuck [19] and Gransberg et.al. [20]) and in government guidelines (such as in US Department of Energy [21] and US General Accounting Office guidelines [22]). These sources typically focus on either analyzing the cost (LCCAs) of alternative potential features within in one investment [23] or supporting alternative analysis using discounted LCCEs to derive alternative net present values (NPV) [19]. The focus in both cases is on the overall LCC, not the risk-adjusted cost of the various individual long-term projects within the total LCC (e.g., the individual input estimates for upgrades, expansions, replacements, closure and so on). For example, the sources often show each estimate within the LCC being assigned rule-of-thumb contingencies or uplifts without much regard for the estimate's long-term nature. The focus of this paper is on QRA methods to quantify the risk of *each* project within the overall asset LCC (or stand-alone long-term projects) in a fit-for-use and principled way.

Use Cases for Unclassified/Class 10

There are two typical high-level long-range planning use cases for Unclassified/Class 10 or repetitively updated Class 5 estimates. These include (but are not limited to):

1. Surety (Class 5): determine amounts for insurance reinstatement, bonding, escrow or other financial liability or assurance instruments to cover the future cost of required investments (e.g., typically asset or facility closure/decommissioning regulatory requirements) with estimates updated repeatedly over the asset life cycle.
2. Long Range Cost and Economic Studies (Unclassified/Class 10) including:
    - General Studies: to understand the cost and risk of potential future investments
    - Investment Economics and Sustainability (LCCEs/LCCAs): to support a current investment funding, loan, rate or other decision, or for portfolio or systems management, that consider current and future investments (e.g., additions, expansions, systems growth, technology evolution, rehabilitation, replacement, restoration, closure, etc.).

1. <u>Surety</u>

In surety use, traditional Class 5 estimates and QRA methods are typically used assuming fixed scope (albeit the defined scope attempts to address foreseeable conditions) with any scope change (e.g., regulation changes) addressed in later surety estimate updates as the asset life cycle progresses. In this use there is no expectation that a given estimate will cover the cost of project scope change (even though such change is expected in the long-range). These estimates are not used as the basis to approve or commit to an overall investment amount, but to support a narrower surety need, and in general to assure the current enterprise financial condition is sound until the next review (periodically or upon experiencing a major change).

There is a question as to whether the periodic surety Class 5 estimate updates are subject to greater risk than traditional Class 5 estimates. There is some evidence that they are not. For example, in 2016 the OECD published a study of the cost of decommissioning nuclear power plants that included case studies of periodic cost estimate updates. Most countries require operators to update their decommissioning plans and estimates periodically (e.g., every 5 to 10 years) over the plant life (e.g., 35 to 50 years) [16]. For example, a case study for a Finland nuclear plant included 6 repeated estimates from 1987 to 2012; there was a normalized cost increase of 17% over the 25-year period (mostly resulting from a regulation change addressed in the 2008 estimate). A case study for a multi-unit Swiss plant reviewed an estimate prepared in 2006 and updated in 2011; the normalized cost for decommissioning each of its 4 reactor units increased by 10 to 28% (much of the increase was for an increase in requirements to maintain operations during dismantling). Given the nuclear power industry's regulatory and environmental sensitivity, these example cost increases are quite sedate compared to general industry research of cost growth for Class 5 estimates, especially considering the relatively low contingency values used[1] [17].

[1] The Finnish estimates applied 10% contingency for each periodic estimate. After the 2011 Swiss estimate, the Swiss regulators imposed a requirement to apply 30% contingency because the 2006 and 2011 contingency allowances (not stated) were inadequate. Note that in both cases, contingency percentages were predetermined.

2. General studies and investment economics

General and economic studies are discussed because the estimates within the LCC or the unique future project estimate must cover all the future risks including potential project scope change (i.e., Unclassified/Class 10). For example, the Taylor paper describes in the following paragraph how a public wastewater treatment agency has to address scope change resulting from systems management and rate determination needs:

> "*Planning has determined that several decades in the future the volume of wastewater flows produced by the region is projected to be significantly greater than the utility's existing capacity. Expanding services to accommodate the increase in capacity will require significant public works projects. Despite the fact that these future capacity needs are decades away and the agency can only speculate as to what future solutions might ultimately entail, the agency must develop and publish scope and cost information to address the problem and place probable programs and projects into its capital improvement portfolio and rate*."

Figure 2 illustrates three typical cost and investment economic study types (stripped of their revenue, operating cost and other non-project input arrows) as follows:

- Single project: one-off study of a future project; not LCCE;
- Multiple projects, single investment LCCE across a given asset life cycle;
- Alternative selection with multiple project LCCEs.

The Figure shows the example project investments (vertical arrows) over the asset life cycle (time: blue arrow). The focus of this paper is on the QRA and contingency/reserve allowance determination (the red currency symbol) including potential scope change and strategic risk for each investment. The paper focus is not on the overall analysis outcome (e.g., NPV) except for the single project case which has a project cost outcome. These generalized study types will be referred to later in the paper in more specific discussions of analysis methods.

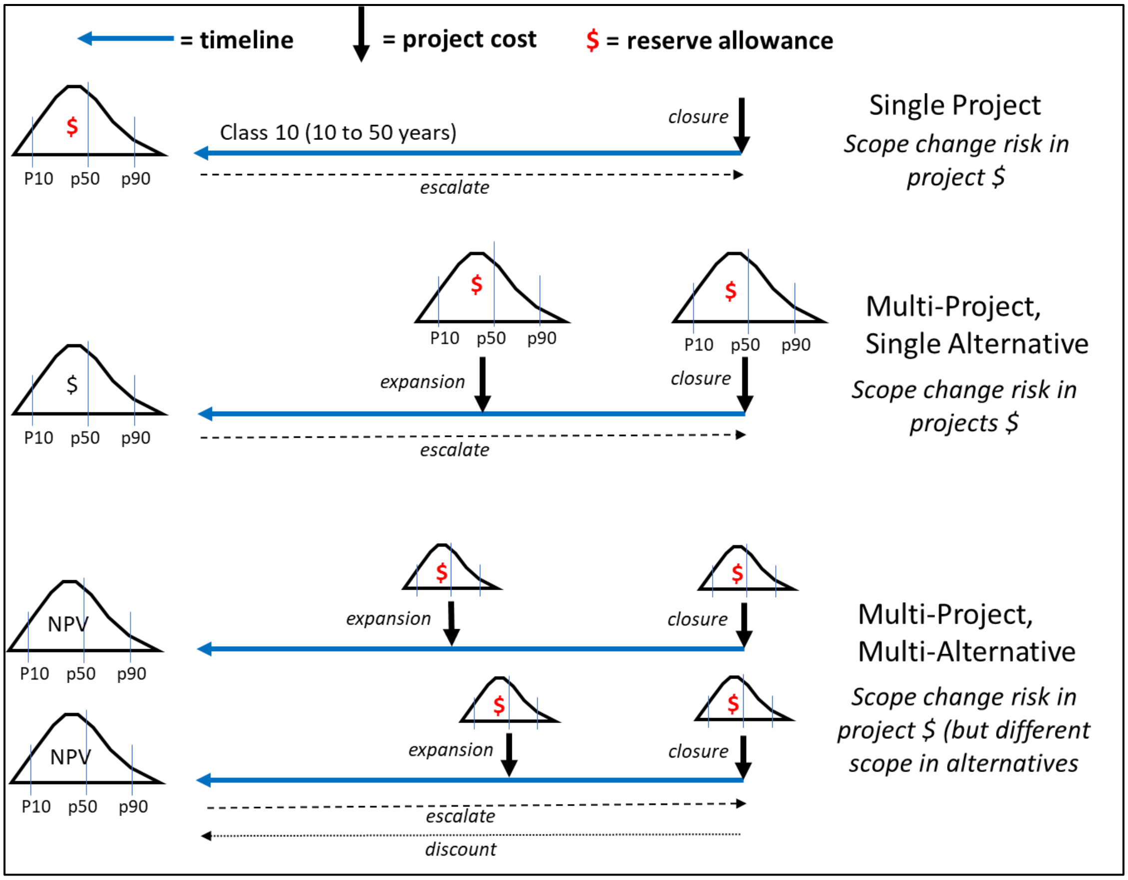

Figure 2–Typical Class 10 Estimate Studies and Economics Analysis Use

Empirical Studies of Unclassified/Class 10 Cost Growth: Low Expectations for Estimates

The discussion of Class 5 estimates for periodic surety use described studies that showed estimate-to-estimate cost growth was comparable to estimate-to-actual cost growth for traditional project Class 5 estimates. There have also been studies of cost growth for very long duration projects; for example, a 2020 study of 67 major US transport projects showed cost growth for projects of greater than 10 years duration exceeded that of projects of 4 to 10 years duration by about 20%[2] [24]. Another study of US transport projects showed that soft costs[3] as a percent of construction costs have increased by about 0.5% per year for the past 40 years. Such studies point to added risk in long-range estimates [25]. However, there were no references found that described empirical research of estimate-to-actual cost growth for estimates used in long-range (outside of phase-gate processes) studies and analyses. This was a surprise given the several decades of publications and guides on long-range closure/decommissioning projects (mining and nuclear in particular) that included development of standard cost models. [26]

One reason for the dearth of long-range cost growth studies may be that relatively few asset life cycles have actually been formally "closed", particularly where there are potential long-term

[2] The study did not normalize for escalation, however, the study authors believed that the funded amount (estimate) included escalation so no correction was necessary.
[3] Soft costs in that case included not only project management and engineering, but studies and permitting.

hazards. One report on mine closures showed that only 4 out of 57 mines being closed had actually relinquished control. The report stated “Not only has successful relinquishment been unattainable for most, but the financial cost of closure is often many times higher than was ever anticipated” [27]. Another report stated that of 147 shutdown nuclear reactors there was “only limited experience of fully completed decommissioning projects”. [28] The same is reportedly true for decommissioning offshore oil facilities [29].

Another reason is that project scope change and major risks in long-range studies are often assessed as economic scenarios, not as elements of continency/reserve allowance from the estimator viewpoint. Business and regulatory stakeholders have little expectation that study input estimates will be used directly for funding or other individual commitments and hence there is no perceived need to include cost for scope change and strategic risk in the LCC input estimates. However, this lack of clarity in expectations regarding cost growth can lead to communication confusion later. Key stakeholders often remember or see the recorded input cost numbers used in studies and this can lead to anchoring bias on their part; i.e., stakeholders may unreasonably resist later estimates that differ from the original number. Anchoring bias will make communication a key issue for any proposed QRA method RP. A key communication tool is the basis of estimate documentation; documenting where and how scope change and strategic risks are accounted for needs to be very clear for Unclassified/Class 10 estimates.

Review of Published QRA Methods Relevant to Unclassified/Class 10 Estimates

The literature on investment economics and LCCE/A and other long-range estimating practices was reviewed to identify probabilistic QRA methods proposed or in use that would be amenable to regular use for contingency/reserve allowance determination. In summary, the literature search did not find any new QRA methods not already covered by AACE RPs. Unfortunately, references often describe outdated methods that are not aligned with the principles in RP 40R-08, *Contingency Estimating-General Principles* [30]. However, some describe methods roughly aligned with existing AACE QRA RPs that, with some modification, could be recommended for Unclassified/Class 10 estimate use.

Contingency/Reserve Allowance Methods Not Aligned with QRA Principles

In respect to contingency/reserve allowances for projects, many references described LCCE or other approaches that applied deterministic approaches (i.e., not probabilistic QRA methods) to putting a cost value on uncertainty/risk. For example, the Finnish and Swiss nuclear power plant decommissioning estimates applied predetermined 10 or 30 percent contingencies [28]. Another nuclear reference describes nationally-defined or data-based “factors” (e.g., 20 or 30% uplift) for out-of-scope cost [12]. As another example, a United Kingdom (UK) guideline recommended that 56% uplift be added to the base cost of new build rail investments at their earliest definition phase [31]. Further, as shown in Figure 3, an associated UK guideline for cost estimating, including risk analysis, suggests using deterministic (which may include uplifts) rather than probabilistic risk estimation methods at the earliest stages of scope definition[4] [32].

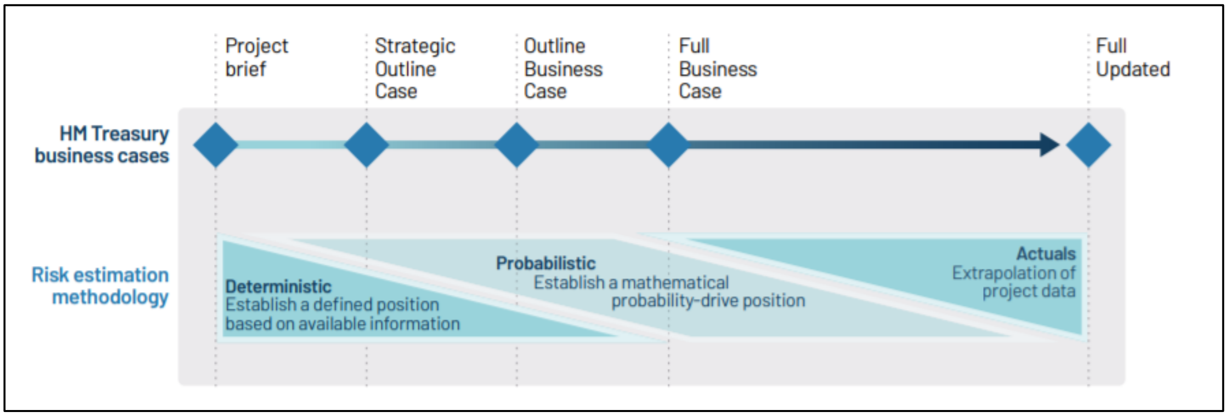

Figure 3–Risk Estimation Methodologies in UK Cost Estimating Guidance [32]

Given that the purpose of this paper is to advance QRA methods in a fit-for-use way that aligns with AACE QRA principles, the use of non-probabilistic methods (e.g., expert judgment, pre-determined ranges or contingencies, uplifts, etc.) is not further considered. Unfortunately, the predominate use of deterministic cost risk valuation for long-range estimating has likely not resulted from assessment of information needs, but from the fact that typical industry QRA practices are not fit-for-use (e.g., overly complex, purely subjective, etc.) and/or are widely perceived (with good reason) as unreliable and/or unrealistic. This unfortunate situation needs to be rectified.

The most common *probabilistic* approach found in literature search in respect to contingency/reserve allowances for projects was estimate ranging with Monte Carlo simulation (MCS) [12]. That method is described in AACE RP 118R-21, *Cost Risk Analysis and Contingency Determination Using Estimate Ranging for Inherent Risk with Monte Carlo Simulation* [33]. However, that RP limits its use to projects with minimal systemic risks. Systemic risks are uncertainties that are artifacts of the nature of the project system and that includes uncertainties arising from minimal scope definition [11]; i.e., that RP excludes ranging use on Unclassified/Class 10 or Class 5 estimates. That exclusion is based upon research that has shown that ranging is a "disaster" when used alone on projects with significant systemic risks (re: the prior paragraph about why deterministic methods are often used for long-range estimates.) [34].

The use of pre-determined contingency or pure ranging methods may also reflect the fact that many sources focus on the end result of an economics or NPV study (e.g., outcomes on the left of Figure 2). The most common references are about sensitivity analysis of LCC cost or NPV that study the impact of changes to various cost model inputs (e.g., discount rates, labor rates, etc.) *other than the risks addressed by project contingency* [23]. In short, <u>contingency/reserve allowances of the LCC project cost inputs are often treated as more or less irrelevant to the economics or portfolio level decision</u>. This may also reflect the fact that NPV analyses use

[4] The HM Treasury "Strategic Outline Case" in Figure 4 aligns with AACE Class 5 estimates.

compounded discounting of future costs (with understated escalation), often to the point of making investments later in the asset life cycle irrelevant. In any case, this common minimal regard for contingency/reserve allowances is disappointing for estimating practice purposes and may result in later communication problems related to anchoring bias.

Contingency/Reserve Allowance Methods Aligned with QRA Principles and AACE RPs

The aforementioned nuclear decommissioning reference listed several probabilistic QRA methods for consideration [12]. It suggests using the expected value approach (probability times impact) for both scope changes and for “strategic” risks [12]. This would be generally consistent with AACE RP 113R-20 *Integrated Cost and Schedule Risk Analysis and Contingency Determination Using Combined Parametric and Expected Value* [35] or RP RM-34 *Integrated Cost and Schedule Risk Analysis and Contingency Determination Using Estimate Ranging with Expected Value and Monte Carlo Simulation* [36]. However, for long-range estimates, the expected value method would be extended to considering potential scope changes and strategic risks rather than what the RPs call critical risks within the project scope [35].

The nuclear decommissioning source also suggests a method to “apply a factor tied to past experience” to a base contingency, but it goes on say this approach is not yet viable for that industry given the lack of historical data. However, as a general approach, this is consistent with AACE RP 42R-08, *Risk Analysis and Contingency Determination Using Parametric Estimating* which includes provision for calibrating a general parametric model to align with specific experience; in this case potential scope change and strategic risks [8].

While some sources apply the critical path schedule (CPM) with MCS QRA method in the context of sensitivity or scenario analysis on near term projects [37], none suggested that method’s use on long-range estimates given that CPM-models are generally not prepared for long-range planning.

The parametric and expected value methods will be explored further in this paper for potential use on Unclassified/Class 10 estimates. However, probabilistic methods used for LCCE/A studies also present possibilities as discussed in the next section.

Probabilistic Analysis Methods (but not for Contingency/Reserve Allowances)

Several common probabilistic LCCE/A methods were found in the literature. They are widely used in the context of overall investment economics and decision making considering the asset life cycle. These methods have long-range project estimates as inputs but these various input estimates (e.g., expansions, refurbishments, etc.) are not usually the focus of the methods. Most of the sources addressed the multi-input, multi-alternative case in Figure 2 with a focus on the ultimate NPV. Many public development and finance agencies provide guidelines that include these methods [38]. The most common methods include[5]:

[5] Note that an RP 40R-08 QRA principle is that methods should be fit-for-use, so complex or esoteric methods that were from the research or academic domains are not included.

- sensitivity analysis with MCS;
- scenario analysis with MCS;
- decision tree analysis with MCS.

These general LCCE/A methods are summarized in the following sections, including select references and ideas as to how the method concepts could be leveraged for a QRA method to determine Unclassified/Class 10 project estimate contingency/reserve allowance. In general, this paper seeks to pull the attention back from being exclusively on the overall NPV output, to being more on getting scope and risk issues addressed in the estimate inputs.

Sensitivity Analysis with MCS

The definitions of the terms sensitivity and sensitivity analysis in RP 10S-90 [11] are:

- Sensitivity: the degree to which a change in an element of a model affects the outcome.
- Sensitivity Analysis: a test of the outcome of an analysis by altering one or more parameters from an initially assumed value(s).

Altering an input to a model to see the impact to the output is a simple concept. It is most often applied to a current, often detailed estimate. For cost, an example is to vary labor rates to see how they impact the project cost overall. For an NPV study, an example is to vary the discount rate. Figure 4 illustrates the concept that starts with a base cost estimate for a future project. Then the inputs to the estimate and/or to the NPV model (e.g., discount rate) are varied, and the respective NPV outputs are compared. This can be done probabilistically using MCS by entering the inputs as probability distributions rather than discretely, thus obtaining an NPV output distribution rather than a discrete outcome.

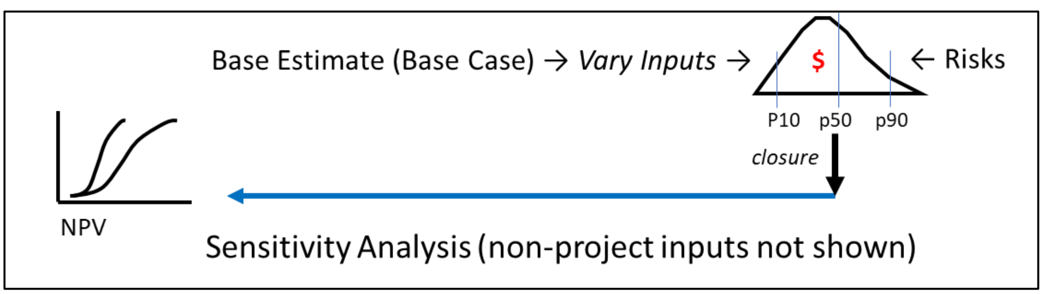

Figure 4–Conceptual Illustration of a Sensitivity Analysis

As discussed, papers on this method are usually focused on relative NPV outcomes. Relatively little attention is given to the cost uncertainty of projects in the model. For example, in a reference on using sensitivity analysis for the levelized cost of electricity (LCOE) for a long-range power plant investment, the plant input construction cost variation was represented by a relatively arbitrary, narrow +/-15% range [39].

However, it does not take much imagination to picture using this LCCA method for the LCOE output and applying RP RM-34 (combined estimate ranging and expected value [EV]) as a QRA model for the construction costs range including scope changes and strategic risks as EV inputs; i.e., putting some deserved focus on the cost input. Running the MCS would then support both contingency/reserve allowance for the project (i.e., a better number to anchor to should anyone be paying attention to it) and the LCOE output distribution. Similarly, RP 113R-20 (combined parametric and expected value) could be used which provides the added ability to do sensitivity analysis using the estimate parametric model input variables as well as EV for the scope changes and strategic risks.

Scenario Analysis with MCS

The definitions of the terms scenario and scenario analysis in RP 10S-90 [11] are:

- Scenario: a description of specific events and conditions and their probable outcomes. Usually limited to likely or probable scenarios versus all possible ones. Frequently, most likely, best case, and work case scenarios are used to define the most probable outcome and the range of outcomes.
- Scenario Analysis: methods to assess a range of events, conditions and outcomes employing specific scenarios. An alternative to simulation methods for assessing ranges.

Applying a model multiple times, with each run using inputs that together reflect artifacts of the selected scenario, to see the range of impacts on the output is a simple concept. This is more of a *big picture* or strategic approach than sensitivity which makes scenario analysis more suited to long-range planning; i.e., the scenarios can reflect a wide range of future states. Often, expert input is obtained to help define the scenarios.

A common use today is to consider different climate change scenarios which may affect many inputs to an NPV or economic cost model including variations in facility design and construction cost. Figure 5 illustrates the concept that starts with multiple cost estimates for the respective scenarios, defining appropriate inputs for the scenario, and comparing the respective outputs. This can be done probabilistically at two levels. One is to use MCS by entering the inputs to each scenario model as probability distributions rather than discretely, thus obtaining an output distribution for each scenario rather than discrete outcomes. At the second level, a simple decision tree can be set up wherein each scenario is assigned a probability for its occurrence (usually with stakeholder and expert input) and after running MCS, the output will be a single distribution.

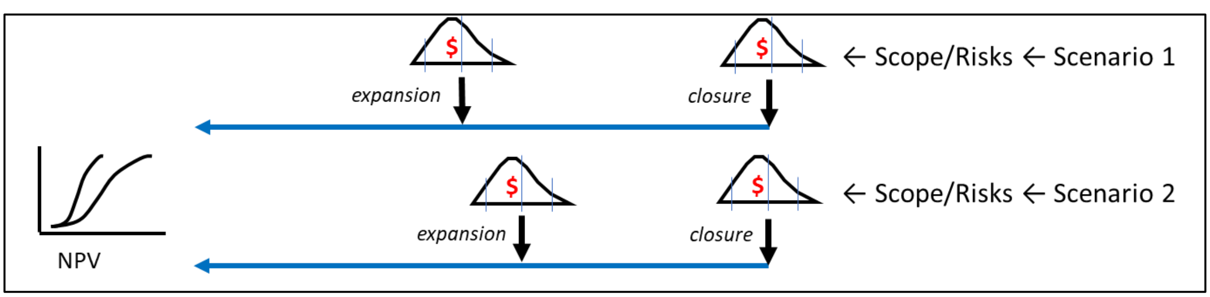

Figure 5–Conceptual Illustration of a Scenario Analysis

As discussed, papers on this method are focused on the NPV outcome and to devising scenarios and how the numerous inputs and their correlations would vary for these scenarios. Relatively less attention is given to the input project costs to the model.

Again, it does not take much imagination to picture using this method for the LCOE output and RP RM-34 (combined estimate ranging and EV) or RP 113R-20 (combined parametric and expected value) as the QRA model for the construction costs in long-range planning including scope changes and strategic risks as EV inputs.

One useful reference was found that used scenario analysis with MCS for QRA of a project ready for funding albeit as a check on the base case, not for funding the project contingency or reserve allowance per se [37]. It addresses the situation where a complex project faces a dynamic, uncertain external environment for which traditional risk registers and QRA methods tend to fall short. In essence, it is the same long-range planning situation faced with potential scope change and strategic risks, but compressed into a short-term project duration. The paper describes identifying scenarios for how things may change during project execution. It then applies the risk-driven CPM with MCS method (i.e., RP 57R-09 [9] given that the project planning is detailed at the sanction gate) for each scenario resulting in multiple outputs to compare to the base case that management is considering for funding. The paper suggests using the scenario analysis method as a risk communication tool rather than for funding. However, it is a small step to applying the probability of each scenario occurring and pulling these separate analyses into one probabilistic output. That approach will be discussed later as a possible Unclassified/Class 10 approach (albeit using a QRA method suitable for lesser defined projects without CPM schedules).

Decision Tree with MCS

The definition of the term decision tree in RP 10S-90 [11] is:

- Decision tree: A graphical representation of the decision process. Sequential decisions are drawn in the form of branches of a tree, stemming from an initial decision point and extending all the way to final outcomes. Each path through branches of the tree represents a separate series of decisions and probabilistic events.

This is one of the most common decision analysis methods. AACE offers RP 85R-14, *Use of Decision Trees in Decision Making* covering the basic method [40]. An AACE *Transactions* paper describes a decision tree for dispute resolution evaluating the expected value of different claim strategies, but no *Transactions* papers were found for use in QRA [41]. At its simplest, a decision tree may have only the initial decision node and two chance nodes for which there are various discrete outcomes with various probabilities of occurring. The valuation of the chance node is simply it's expected value (for cost, the expected monetary value of EMV); i.e., the sum of the products of the discrete probabilities x outcomes. For a cost-based decision, the decision maker would choose the chance node with the lowest EMV as shown in Figure 6. MCS can readily be applied by replacing fixed outcome values with distributions.

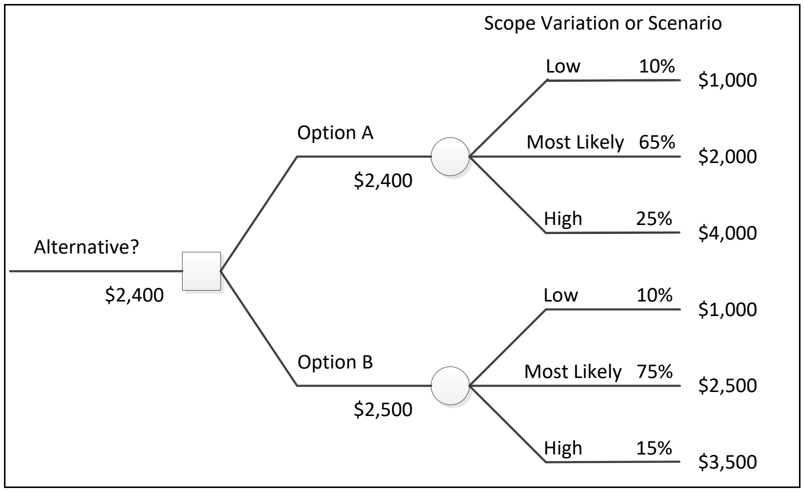

Figure 6–Simple Example of a Decision Tree

There is an opportunity to use this concept for Unclassified/Class 10 estimate contingency/reserve allowance determination. For example, a scenario analysis example for a complex, high external risk project was discussed previously [37]. If that project were Option A in Figure 6, and the scenarios were the Option A branches with relative likelihoods assigned to each, then the EV of Option A is a QRA outcome for the risks represented in the scenarios. If MCS were applied, the cost distribution of Option A could be used to determine a contingency/reserve allowance. The branches could also represent the cost impact of variations of design scope, impacts of strategic risks, and/or various scenarios.

A challenge with decision trees is to limit the discrete outcomes to consider. A practical approach is to quantify low/most likely/high scenario branches and their respective probabilities as was done in Figure 5. The use of this concept as an Unclassified/Class 10 QRA method will be discussed further in the next section.

Preface to Unclassified/Class 10 Estimate QRA Method Proposals

Based on the background and methods review above, several QRA and contingency/reserve allowance determination methods are proposed for long-range Unclassified/Class 10 estimates, but also phase-gate, short-range Class 5 project estimates subject to exceptional scope uncertainty (but within the bounds of the business scope) and/or strategic risks. However, there are several questions discussed below that need to be answered prior to considering the methods in this paper; i.e., will an existing QRA RP suffice, and what is the objective?

The Trouble with Class 5

In 2021, the author made several presentations on the topic of “the trouble with Class 5 ranges” [42] [43]. The presentations discussed a 2020 study of historical cost overruns for North American power projects [44]. That study looked at actual cost growth data for Class 5 estimates (and other classes) in a phase-gate system. It also included data from prior related studies. It found that the

Class 5 p90 value (i.e., 90% had less cost overrun) of the combined study dataset was +162% over the funded amount. However, the AACE estimate classification RP for hydropower projects (RP 69R-12, *Cost Estimate Classification Systems – as Applied in Engineering, Construction and Procurement for the Hydropower Industry*) suggests that the highest Class 5 p90 would typically be +100% [45]. Many would consider +50% to be a more typical p90 at Class 5 (e.g., as was seen in the nuclear decommissioning estimate report [12]). The immediate question for a project in a short-range phase-gate system was "*how can the high range be more than 3X what is considered the typical AACE estimate classification range*?" The answer is that estimating and QRA processes fail to recognize that at Class 5 there are almost always multiple scope options and strategic risks still on the table for more complex projects such as the hydropower facilities studied (i.e., it is not until the Class 4 gate that a single alternative is selected). This situation was also reported in the scenario example for complex upstream oil projects [27]. In short, phase-gate Class 5 estimates for complex projects will benefit from any Unclassified/Class 10 QRA methods to be identified here.

Will an existing QRA RP Suffice?

As a starting point of method evaluation, the only current RPs recommended for estimates with significant systemic risks such as poorly defined scope (i.e., for Class 5 or Unclassified/Class 10 estimates) are those incorporating parametric risk analysis, but not CPM which is not practical at early phases; those are RPs 42R-08 and 113R-20 [8] [35]. Figure 7 provides a flow chart of how to determine if these existing RPs will suffice. The first question is whether the project is subject to likely scope change as is expected with a greater than 10-year time horizon. If not, the next question is whether there is exceptional scope uncertainty (and/or strategic risks) within the general business scope. If no, then existing RPs will suffice, but if yes (even if Class 5), this RP's proposed methods should be considered.

However, even if there is likely scope change but the decision analysis method addresses the change (and/or strategic risks) in the definition of the unique alternatives, and there is no single cost value reported (i.e., multi-project/multi-alternative case in Figure 2), then, existing RPs may suffice for each alternative. Otherwise, the Unclassified/Class 10 QRA methods to be identified in this RP should be considered.

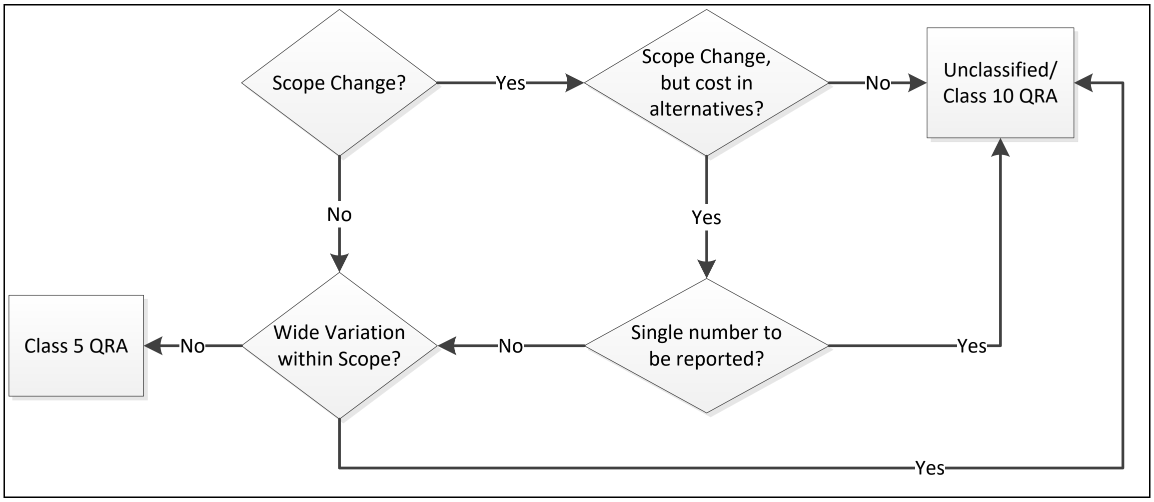

Figure 7–Chart for Determining the Need for Special QRA Methods

What is the QRA objective?

As discussed, stakeholders often have little expectation that strategic long-range LCCE/A or other study input estimates will ever be used directly for funding or other individual commitments. Hence, they may not perceive a need to include cost for scope change/variation and strategic risk in the LCC input estimates as a contingency/reserve allowance. After all, their thinking is nobody will remember or use the project input number later in its own right. In some cases, that will be true. However, in ongoing portfolio or systems management, these LCCE/A results will be revisited, projects will enter the phase-gate queue, and inevitably past project cost values will be recalled. Cost estimators are all too familiar with the push-back challenges created by stakeholder anchoring bias as well as losing credibility and trust when costs change from estimate to estimate (usually increases) and the difference cannot be clearly explained. The cost engineering objective should be to use the best, fit-for-use, practical QRA methods available to produce reliable results and avoid that situation.

In any case, the estimator/analyst should start any analysis by assuring there is clarity as to stakeholder expectations and objectives for the QRA and what is to be communicated about risk. Optimally, portfolio management and LCC study processes with appropriate estimate and QRA methods, quality requirements, documentation (i.e., basis of estimate), historical data capture, and other elements will be established.

Figure 8 illustrates typical Class-to-Class estimate evolution and QRA challenges, and the objective of Unclassified/Class 10 QRA methods to address the challenges. It shows that for complex projects with viable scope variations within the overall business scope and/or strategic risks, Class 5 estimate contingency is often significantly underestimated. Research indicates that actual cost growth may be 2 to 3 times the estimated contingency using traditional methods (often deterministic) [46]. The same is true for Unclassified/Class 10 estimates where time adds to the evolution challenge no matter how complex the project. The objective of the methods in this paper then is to realistically quantify the risks as they are; i.e., to address scope variation and strategic risks inherent to long-range planning and estimates.

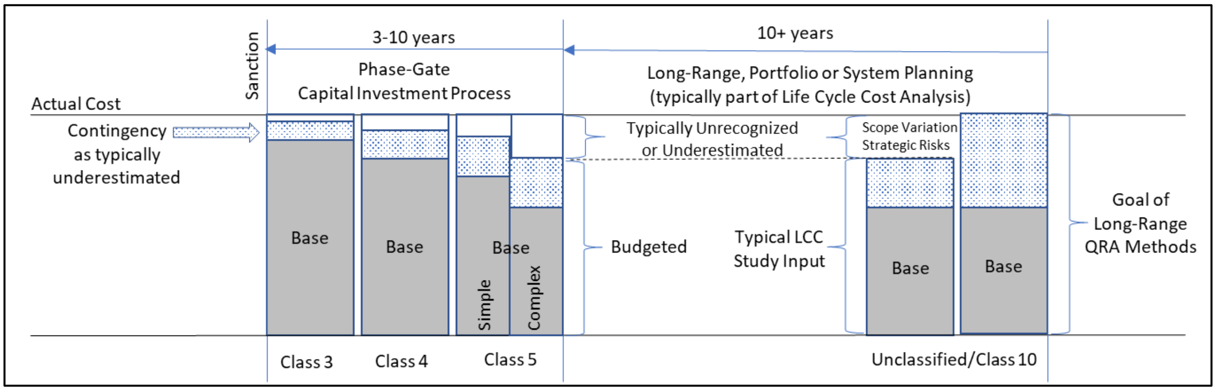

Figure 8–Typical Class-to-Class Estimate Evolution and QRA Challenges

Proposed QRA Methods for Unclassified/Class 10 Estimates

The following summarizes the viable QRA methods for project cost identified based on the preceding background and methods review. Again, these are for QRA and contingency/reserve allowance determination for long-range Unclassified/Class 10 estimates, but also for phase-gate, short-range Class 5 project estimates subject to exceptional scope uncertainty (but within the bounds of the business scope) and/or strategic risks. The following methods have been identified along with typical uses cases, roughly in the order of increasing risks on the project:

1. Modified RP 42R-08: Calibrated Parametric; primarily for more repetitive portfolio projects (e.g., water system growth) where life cycle data has been captured.
2. Modified RP 113R-20: Hybrid Parametric plus Expected Value with inclusion of scope variation and strategic risks along with critical risks; primarily for more unique projects, but with relatively stable foreseen futures.
3. Decision Tree with Scope and/or Scenario Variation Branches (no RP yet); primarily for projects with higher complexity and more dynamic external risk situations.

The following sections provide some detail for each proposed method or variation. These should be considered as scoping statements for potential RPs to be developed after additional industry discussion and hopefully more published papers on the topics. Given that there is no existing RP for the decision tree QRA method, a more detailed treatment is provided in the Appendix.

1. Modified RP 42R-08: Calibrated Parametric

This approach is the same as RP 42R-08 which already addresses the need to calibrate a base parametric model to align with a company's experience[6] [8]. The factoring of a base model was also suggested in the OCED uncertainties report [12]. The existing RP provides guidelines for

[6] Obtain the latest revision of this RP (as one should do for all RPs) which includes the calibration guidelines.

performing calibration. It is recognized that few companies will have life cycle data with which to develop a parametric model from scratch using regression analysis. However, it is a common and expected practice to calibrate existing models where there is some nominal level of actual/estimate cost data available to do so.

For long-range planning, it is most likely that data will be available for utilities and others who have decades of water, power or other system planning experience with relatively repetitive project types and using technology that improves with time, but usually not dramatically so. The data needed, as discussed in RP 42R-08, is actual/estimate cost data that has been normalized to remove the effect of escalation. Figure 9 shows a calibration input screen from a commercial parametric risk model; the factors shown for project size attributes could readily be applied for short versus long-range estimates [47].

Calibration Factors

	Costs		Schedule	
	Mean	Std. Dev.	Mean	Std. Dev.
Small Projects	0.80	1.30	1.00	1.20
Large Projects	1.00	1.00	1.00	1.00

Figure 9–Calibration Factors for a Parametric Model (image from ValidRisk® software [47])

The calibrated parametric model will address the typical systemic risks for Class 5 estimates as well as the long-range scope variation and strategic risk impacts covered by the calibration factors. The model will produce an overall project cost distribution from which a contingency/reserve allowance value can be selected recognizing that this Class 10 value includes more scope definition and variation risk than for a Class 5 estimate.

2. Modified RP 113R-20: Hybrid Parametric plus Expected Value (EV)

For Unclassified/Class 10 estimates, this method is essentially the same as the RP with the exception that the definition of "critical risks" be interpreted to also include long-range scope variation and strategic risks and their cost impacts. The parametric model will address the typical systemic risks for Class 5 estimates, and the other enhanced critical risks are addressed in the EV model. The long-range risks would be identified using a workshop approach including appropriate business and technical staff involved in the associated portfolio or other long-range planning.

This approach would be appropriate for projects that had more unique long-range variation and risks than is typically involved in more repetitive system planning where the parametric method alone would suffice. However, the projects should have a relatively stable foreseen future, otherwise the number of discrete "critical" risks would become unwieldy and the quantification less reliable.

An advantage of the hybrid model is that it helps provide more understanding of the risks; i.e., systemic versus project-specific, but also risk-by-risk for the critical risks. It can also be used in sensitivity analysis by varying the parametric model inputs and/or the specific risk inputs in the EV model.

3. Decision Tree with Scope and/or Scenario Variation Branches

There is no AACE RP for a decision tree QRA method. However, the generic decision tree RP 85R-14 provides the basics of the general method [40]. A QRA RP would need to expand on that RP to more specifically address using a tree with scope and/or scenario variation branches. By leveraging scenario analysis (as per source [37]), the decision tree approach is more flexible in addressing complex projects with evolving technology and/or more dynamic, wider ranging, external risk situations. To provide a reference for a potential decision tree QRA RP, the method is further described in the paper Appendix including several examples.

If used for scenario modeling, the approach requires a scenario identification process. The paper by Meads et.al, describes a 3-step process [37]. In the first step, the study identifies external factors that could affect project execution. The second step is similar but focuses on internal uncertainties or trends. The third step defines 2-4 plausible situational scenarios (it suggests avoiding low probability scenarios). It also suggests grouping external factors and/or key uncertainties into a narrative or storyboard to better communicate and get consensus on the analysis. This is far from a perfect process, but a much more robust one than just analyzing a base case.

Conclusions

This paper reviews the concepts of estimate classification in general and Unclassified/Class 10 estimates in particular. Based on a literature review, it reviewed the concept of asset life cycle cost estimating and analysis. It also reviewed various decision analysis methods such as scenario analysis and decision trees to identify potentially useful QRA concepts. With this basis, proposed QRA and contingency/reserve allowance determination methods for long-range estimates were presented. Scoping statements were provided for potential Unclassified/Class 10 QRA RPs (or revisions to existing RPs to extend their application to long-range estimates). In particular, a new RP for decision tree based QRA method was outlined. It is hoped that this paper will encourage others to publish on the topic and share other potential QRA methods.

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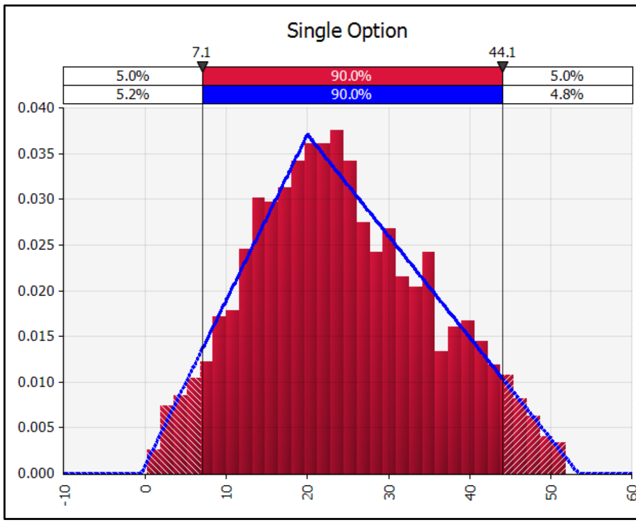
Appendix

Addressing Multiple Scope Options Using a Decision Tree

As discussed, a problem with most Class 5 QRA analyses as typically conducted is that project teams and estimators fail to recognize that in phase-gate systems there are still multiple, feasible options or “features” within a very broad, conceptual scope definition at Class 5. In most phase-gate systems, a single option that will be advanced through basic engineering or front-end engineering and design (FEED) is not chosen until the Class 4 gate. So, the p90 of a Class 5 estimate for a single option will not be the p90 considering the range of cost for all the active scope and feature options. The p90 considering all of the options will likely be higher in absolute cost terms than for a single middle-of-the-road option as is often chosen as the basis for the Class 5 budget number.

As an example, consider a hydropower dam project. At Class 5, the scope may have been defined as a dam to support a given power generation capacity at a general river location. Within that broad scope statement, assume the business has identified three primary optional dam geometries as to how the structure might cross the river. The final geometry choice at Class 4 will depend on geotechnical study that will be done after the Class 5 gate decision. For a project that has any complexity, this situation of multiple options or features is the norm at Class 5. In addition to geotechnical studies as in this example, the phase following the Class 5 gate includes increasingly comprehensive studies and consultations regarding environmental, community and other sustainability considerations. However, for this example, only the three geometry options will be considered.

Assume the base estimates excluding contingency for the 3 options are $20, $20 and $40M. Based on the company's "ranging" QRA, assume that each had a p90/p10 range of +100/-50% (in an actual risk analysis, not using predetermined ranges, each would have a unique range). Now, assume the business decided to use as a base estimate for its long-term budget what they assumed was a mostly likely or middle-of-the-road value of $20M because 2 of the 3 options cost that much. What should the p50 and p90 be for a traditional QRA approach using one option as the favorite? If a Monte Carlo simulation (MCS) was used on this favored option, with a base estimate or most likely value of $20M and @Risk® trigen[10,90] distribution of -50/+100%, Figure A-1 is the result. The p50 is about $23M or a contingency of 15% on the $20M base estimate (recall that in a nuclear decommissioning reference, one agency only allowed 10% [12]). The p90 value is the +100% of the trigen distribution or about $40M. In summary, their budget using a single option ranging approach would be $23M at p50 with a p90 of $40M.



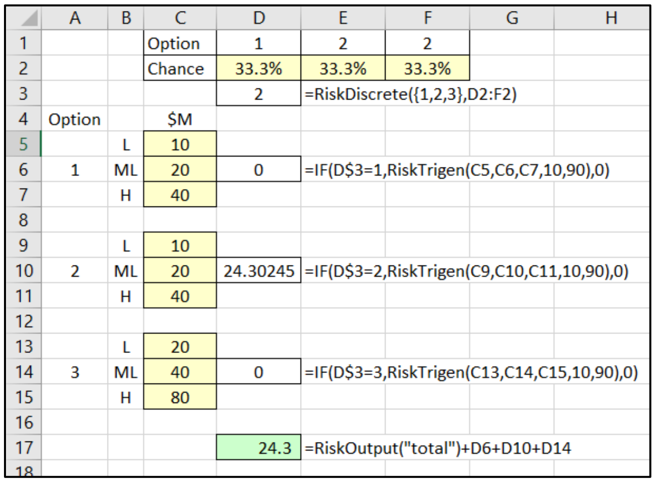
	ML	Trigen (10,20,40,10,90
5%	7.076	6.918
10%	10.297	10.000
15%	12.718	12.365
20%	14.465	14.359
25%	16.081	16.115
30%	17.818	17.703
35%	19.320	19.163
40%	20.721	20.533
45%	22.058	21.934
50%	23.368	23.400
55%	24.772	24.941
60%	26.228	26.570
65%	27.988	28.305
70%	30.004	30.169
75%	32.069	32.195
80%	34.557	34.437
85%	37.212	36.982
90%	40.343	40.000
95%	44.107	43.934

Figure A-1–Example MCS Outcome for a Single Option (using Palisade @Risk software)

The better way proposed here is to use a method to evaluate all the viable scope variations, not just the "base case". The following is simple example of using a decision tree approach with Monte Carlo simulation (MCS) for a Class 5 valuation with the 3 options.

The proposed method starts with the premise of multiple options and for each option there is a probability of being selected at the next gate after further study. In the example, the options are numbered 1, 2 and 3, and the probabilities of selection (i.e., the favorability ratings) are assumed equal; i.e., 1/3 or 33.3% for each. In MCS, the option choice can be set up as a "discrete" function such that in each MCS iteration, one of the three options will be selected in accordance with the respective selection probabilities.

Next, assume for each of the three options, a separate QRA ranging analysis has been done. For the example, this is represented by three trigen distributions with a p10/p90 range around the most likely value of -50%/+100%. Figure A-2 below shows the Class 5 multi-option analysis worksheet in Excel® using Palisade @Risk® functions. The trigen distributions include an "if" function that refers to the discrete sampling function that picks either option 1, 2 or 3 in each MCS iteration. The three options are summed with the summation being identified as the @Risk® output for plotting.



	A	B	C	D	E	F	G	H
1			Option	1	2	2		
2			Chance	33.3%	33.3%	33.3%		
3				2	=RiskDiscrete({1,2,3},D2:F2)			
4	Option		$M					
5		L	10					
6	1	ML	20	0	=IF(D$3=1,RiskTrigen(C5,C6,C7,10,90),0)			
7		H	40					
8								
9		L	10					
10	2	ML	20	24.30245	=IF(D$3=2,RiskTrigen(C9,C10,C11,10,90),0)			
11		H	40					
12								
13		L	20					
14	3	ML	40	0	=IF(D$3=3,RiskTrigen(C13,C14,C15,10,90),0)			
15		H	80					
16								
17				24.3	=RiskOutput("total")+D6+D10+D14			
18								

Figure A-2–Example 3-Option Decision Tree MCS Model (using Palisade @Risk for Excel)

The MCS output of the total cost distribution for the above model is shown in Figure A-3. Note the p50 of this distribution is about $27M or a contingency of 35% on the "base" of $20M. The p90 of this distribution is $53M. This is +165% more than the "base" of $20M (20 x 1.65 =$33M). By design of the example, this roughly compares to the previously referenced 2020 power project study that reported a p90 of +162% around the estimates with underestimated contingency [44].

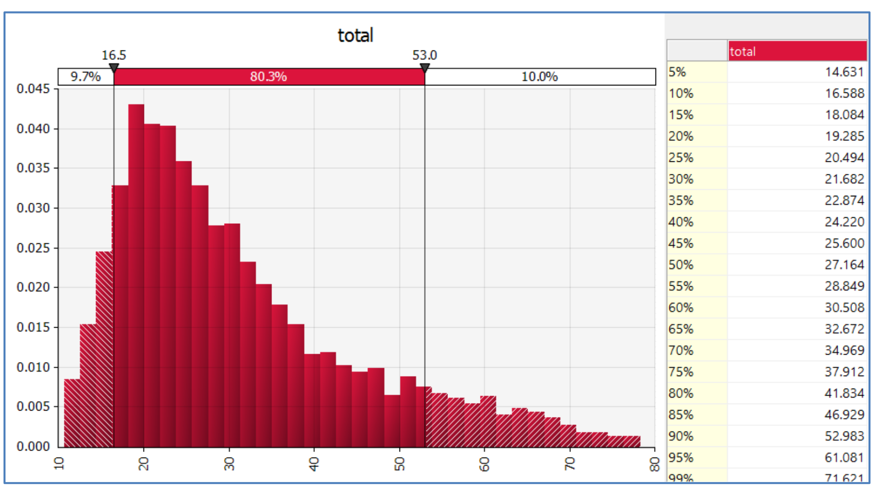


Figure A-3–Example 3-Option MCS Model Total Cost Output (Using Palisade @Risk)

If this simple model had been used as a basis for reporting a Class 5 budget, the p50 value would be $27M with a p90/p10 range of $53M/$17M or about +96/-37%; again, similar to the 2020 study with a corrected contingency.

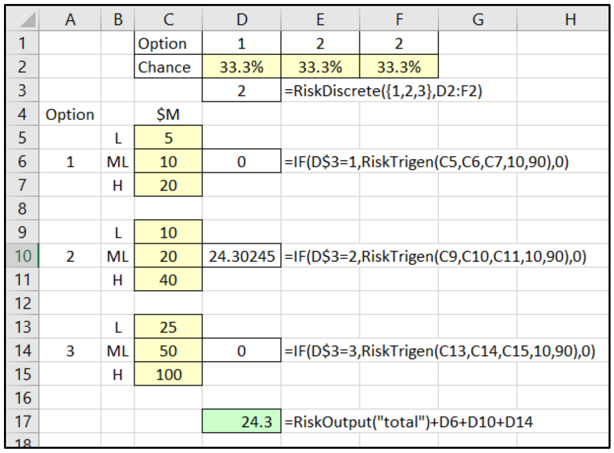
The trouble with Class 5 estimate accuracy then is not that the indicative AACE classification RP range-of-ranges are incorrect. It is that contingency and range are being underestimated for individual options and for the potential scope as a whole. The simplistic single-option view in the example had a p90 cost of $40M while the multi-option view p90 was $57M. The contingency on the "most likely" single option was 15% while the multi-option contingency (on the $20M base estimate) is 35%.

The decision tree approach can become cumbersome if there are too many options or branches; however, a more complex branched model than the example using the same concept is certainly practical. Also, the example used simplistic 3-point cost range inputs for each option; the inputs to this model could have used the distribution outputs from either the modified parametric or the modified hybrid parametric plus EV method described in the paper. In other words, this method adds a layer of analysis for more complex project situations, but with flexibility to keep it fit-for-use making it practical for a wide range of uses.

Addressing Multiple Scenarios Using a Decision Tree

The method described in the prior section can also be used to analyze the cost of various scenarios rather than discrete scope options. For example, a *low cost* scenario may reflect an opportunity to introduce new, lower capital cost technology, while the *high cost* scenario may reflect existing technology with increasing cost for environmental and other mitigations (i.e., strategic risks) to address ever more rigorous regulations.

Figure A-4 shows the same multi-option worksheet as for Class 5 in Figure A-2, but with low cost, base case and high-cost scenarios of $10, $20 and $50M respectively (excluding escalation). Figure A-5 shows the MCS outcome of the model. It exhibits a long tail with a p90 of $76M which is 3.8X the base case of $20M. In the example, the analyst would need to decide what *number*" to report given the highly skewed outcome. However, in all cases, the p90 is very important to life cycle cost analyses which usually apply a net present value (NPV) model. A key output of the NPV approach is usually the tornado diagram that ranks the importance of each NPV driver. Revenue is usually the most important driver. However, the higher the p90 on capital cost, the more management attention will be drawn to the capital cost tornado bar (as it should be). A realistic high p90 will also incentive the owner to invest in new technology to reduce the cost.



	A	B	C	D	E	F	G	H
1			Option	1	2	2		
2			Chance	33.3%	33.3%	33.3%		
3				2	=RiskDiscrete({1,2,3},D2:F2)			
4	Option		$M					
5		L	5					
6	1	ML	10	0	=IF(D$3=1,RiskTrigen(C5,C6,C7,10,90),0)			
7		H	20					
8								
9		L	10					
10	2	ML	20	24.30245	=IF(D$3=2,RiskTrigen(C9,C10,C11,10,90),0)			
11		H	40					
12								
13		L	25					
14	3	ML	50	0	=IF(D$3=3,RiskTrigen(C13,C14,C15,10,90),0)			
15		H	100					
16								
17				24.3	=RiskOutput("total")+D6+D10+D14			

Figure A-4–Example Multi-Scenario Decision Tree MCS Model (using Palisade @Risk for Excel)

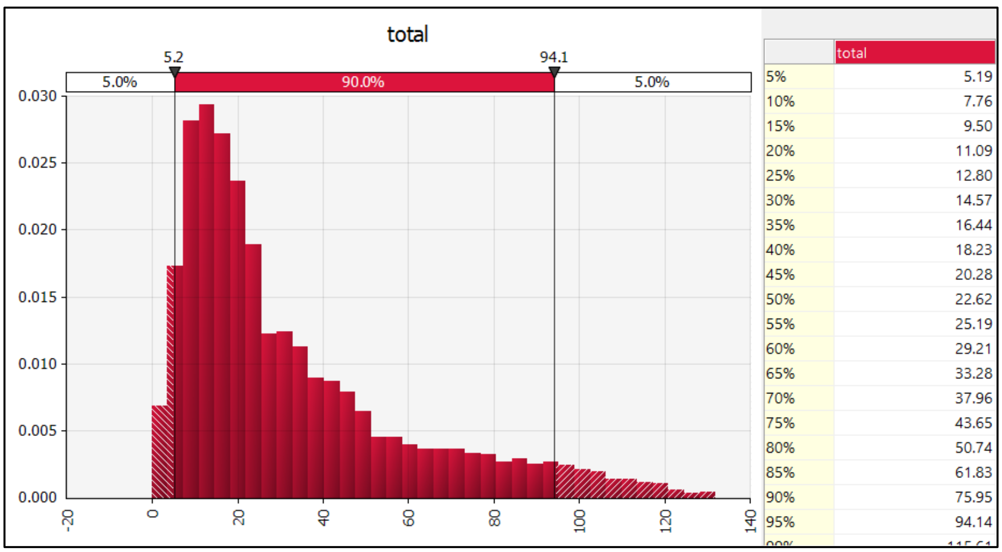


Figure A-5–Example 3-Scenario MCS Model Total Cost Output (Using Palisade @Risk)

The example used simplistic 3-point cost range inputs for each scenario; the inputs to this model could have used the distribution outputs from the other suggested QRA methods. In addition, the branching of scenarios could be much more complex, but still practical. This example could be applied in a new QRA RP for Unclassified/Class 10 estimates.