Managing Uncertainty in Large Complex Projects[1]

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Key Points:

- **Critical Need for Measuring Uncertainty.** Large complex projects (LCPs) are inherently uncertain due to technical, organizational, environmental, and temporal complexities—understanding and measuring this uncertainty is vital to avoid cascading overruns and missed objectives .
- **Comprehensive Categorization of Uncertainty.** The paper breaks down uncertainty into manageable categories—ethical, option, and state-space uncertainty—and further details subsets like technical, regulatory/legal, market, operational, and strategic uncertainties relevant to large complex projects.
- **Development of Quantitative Metrics.** Specific quantitative metrics like the Schedule Uncertainty Index (SUI), Cost Uncertainty Index (CUI), Technical Uncertainty Score (TUS), Composite Uncertainty Metric (CUM), and Engineering Project Uncertainty Index (EPUi) are outlined.
- **Use of Advanced Analytical Tools.** The paper outlines practical tools such as Monte Carlo simulations, Bayesian inference, probabilistic finite element models, and earned value management to dynamically model and update uncertainty assessments
- **Integration of Market, Operational and Strategic Factors.** Beyond technical parameters, the paper stresses measuring state uncertainty through market indicators, operational metrics, and strategic metrics

Introduction

Large complex engineering and construction programs are inherently fraught with interdependent variables, shifting stakeholder requirements, and external shocks—from supply-chain disruptions to evolving regulatory landscapes. As project scale and technical intricacy grow, so too does the uncertainty surrounding cost, schedule, and performance. Without a structured approach to measuring and managing both complexity and uncertainty, even well-funded ventures risk cascading overruns and missed objectives.

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Complexity manifests in multiple dimensions:

- Technical (novel design features, untested materials)
- Organizational (distributed teams, multi-tier subcontracting)
- Environmental (site constraints, regulatory variation)
- Temporal (compressed schedules, evolving scope)

Uncertainty stems from data gaps, human judgment limits, and inherent randomness. In isolation, neither complexity nor uncertainty is fatal; together, they create a volatile cocktail that can undermine the most meticulously planned initiatives.

Understanding and tracking uncertainty in large complex projects (LCPs) isn't just about risk registers and probability curves—it's about dynamic insight. A structured approach, aligned with governance and integration best practices, is required. This approach must recognize that multiple types of uncertainty may exist simultaneously; that uncertainty, like complexity, is a fundamental characteristic of LCPs; and to be managed, it must be measured.

Types of Uncertainty

Uncertainty isn't one-size-fits-all. Uncertainty may be divided into a set of manageable categories. At a high level, these categories have been described as encompassing ethical, option and state space uncertainty.

Ethical uncertainty relates to the value we should associate with the consequences of our choices. In some instances this can be more simply considered to be regulatory or legal uncertainties such as those related to compliance or actions or inactions taken in a political context. In some scenarios ethical uncertainty is removed by a conscious choice to take corrupt or widely regarded unethical actions. Along the spectrum from choices with clearly defined and acceptable consequences to choices with legally, or worse morally, unacceptable choices, there is a wide range of ethical uncertainty. These will not be discussed further in this paper but reference is made to the National Academy of Construction Executive Insights focused on corruption.[2]

A second broad category of uncertainty can be described as **option uncertainty**. Option uncertainty arises when we don't know what the consequences of an action are. It is an empirical uncertainty with respect to what would happen if an action were taken. This form of uncertainty is often associated with technical uncertainty such as to the feasibility of an approach or solution; the ability to satisfactorily integrate all elements of a system to achieve the desired effects. Technical uncertainty can also relate to progress and success of any related research and development efforts such as new processes, materials or required scaling efforts and capabilities.

[2] See relevant National Academy of Construction Executive Insights listed at end of this paper

The final broad category of uncertainty is described as **state space uncertainty** and relates to when we don't know what the state of the world is or will likely be. Examples of state space uncertainty may include market uncertainty, such as that associated with demand shifts, changed customer behaviors, or evolving competition; and operational uncertainties related to resource availability (labor, materials, equipment, information) and supply chain variability, including potentials for significant disruptions. State space uncertainty may also arise from a range of strategic uncertainties related to long term vision (often reflected in changing Strategic Business Objectives (SBOs)) or dynamic stakeholder environments with changing alignments.

For simplicity, we will consider the following five types of uncertainty as they relate to large complex project execution:

- Regulatory/Legal Uncertainty
- Technical Uncertainty
- Market Uncertainty
- Operational Uncertainty
- Strategic Uncertainty

The following table presents a topology for uncertainty, showing the relationship of uncertainty categories and types and associated uncertainty metrics.

Categorization of Uncertainty and Uncertainty Metrics			
Category	**Type**	**Dashboard Metric**	**Component Metric**[3]
Ethical	Regulatory/Legal	Compliance Deviation	Gaps between action/regulations
		Perception of Ethical Behavior	Stakeholder feedback
		Legal Risks	Litigation Frequency
Option	Technical	CUM – Composite Uncertainty Metric	SUI – Schedule Uncertainty Index
			CUI – Cost Uncertainty Index
			TUS – Technical Uncertainty Score

[3] Described later in this paper

Categorization of Uncertainty and Uncertainty Metrics			
		EPUi – Engineering Project Uncertainty Index	RVI – Requirements Volatility Index
			DMI – Design Maturity Index
			MPU – Material Property Uncertainty
			LRU – Load Response Uncertainty
			ΔCpk – Process Capability Index Variation
			YUR – Yield Uncertainty Ratio
			FIRS – Functional Integration Risk Score
			RGU
		Confidence	CI – Confidence Interval
			CL – Confidence Level
			PI – Prediction Interval
			BC – Bayesian Confidence
State Space	Market	Demand forecasts	VIX – Volatility Index
			GDP growth rates
		Customer feedback	Industry-specific sentiment surveys
			NPS - Net Promoter Score
		Competitor analysis	Market share

Categorization of Uncertainty and Uncertainty Metrics			
	Operational	Supply chain resilience	Lead time variability
		Equipment downtime	Mean time between failures (MTBF)
			Mean time to repair (MTTR)
		Labor	Turnover rates
	Strategic	SBO assessments	Outcome variance
		Stakeholder analysis	Stakeholder (internal) confidence
		Stakeholder analysis	Stakeholder (external) sentiment
		Adaptability	Response time to changes

Assessing Uncertainty

A range of methodologies exist for assessing uncertainty.

- Expert elicitation and Delphi technique (a structured method for gathering expert opinions and achieving consensus through multiple rounds of questionnaires)
- Scenario planning or Monte Carlo simulations
- Uncertainty matrices to rank likelihood vs. impact

Uncertainty Assessment vs. Risk Assessment

Monte Carlo simulations in risk assessment focus on identifying potential risks and their impact. It's assessment tackles specific risks by examining various scenarios and their probabilities. It quantifies the probability of different outcomes, helping with decision-making and risk mitigation strategies. It's like stress testing to see how different risks might impact your project.

In uncertainty assessment, Monte Carlo simulations explore the range of possible outcomes due to unknown variables, offering insight into the range and likelihood of various scenarios. . It's more about understanding the range of what's possible.

While risk assessment guides you on what could go wrong, uncertainty assessment opens up the bigger picture of possibilities, helping you navigate complex projects with a clearer view.

Quantifying Uncertainty

Once uncertainties have been identified using any of the techniques above we can apply tools to quantify and track the various uncertainties the LCP faces. Some tools are reflected in the following table.

Select Tools to Quantify Uncertainty

Tool	Purpose	Example
Monte Carlo Simulation	Models probabilistic outcomes; explores range of possible scenarios and uncertainties	Cost estimation and schedule buffers
Bayesian Networks	Incorporates new data dynamically to update probabilities	Updating project success probabilities
Earned Value Management (EVM)	Reveals schedule and cost variance trends over time	Percent schedule variance analysis
Risk-adjusted Forecasting	Combines expected value and volatility for portfolio projections	Project portfolio forecasting
Probabilistic Finite Element Models (PFEMs)	Quantifies structural load-response uncertainty by simulating variability in material properties and environmental conditions	Structural integrity analysis under variable loads ,
Requirements Volatility Index (RVI)	Measures scope changes and strategic uncertainty by tracking changed requirements ratio	Monitoring requirement changes throughout project lifecycle
Design Maturity Index (DMI)	Assesses technical uncertainty by tracking progress in design finalization	Percentage of finalized design elements versus total
Process Capability Index Variation (ΔCpk)	Tracks manufacturing process consistency under uncertain inputs	Variation in process capability indices between batches ,

Select Tools to Quantify Uncertainty		
Tool	**Purpose**	**Example**
Composite Uncertainty Metric (CUM)	Aggregates schedule, cost, and technical uncertainties for overall technical uncertainty measurement	Used as a baseline composite metric across technical domains
Stakeholder Sentiment Analysis	Monitors strategic uncertainty via internal and external stakeholder confidence and sentiment	Surveys and sentiment indices measuring stakeholder confidence
Heat Maps Over Time	Visualizes changing risk concentrations and uncertainty over project phases	Tracking risk hot-spots throughout project duration
Assumption Migration Tracking	Tracks changes in baseline assumptions to monitor evolving project uncertainty	Percentage of assumptions changed vs baseline plan
Stage Gate Reviews	Regular interval re-assessment of uncertainty with changing project scope or data	Milestone uncertainty reassessments
Rolling Wave Planning	Plans detail for near-term work, flexibility for future uncertain tasks	Dynamic project planning adapted to uncertainty levels

Over time, the trend analysis shows how confidence levels shift as new data emerges.

Assessing How Uncertainty Changes

In assessing uncertainty trends it is best to use regular intervals to measure change. Some assessment techniques include:

- Stage Gate Reviews - Re-assess uncertainty at major milestones
- Rolling Wave Planning - Detailed planning for near-term, flexible for long-term
- Heat Maps Over Time - Visualize changing risk concentration
- Change Logs and Issue Escalation Metrics - Track resolution rate vs. emergence rate
- Assumption Migration – Track percentage of recorded assumptions which have changed from the baseline plan

Types of Uncertainty

The following sections dive deeper into the three broad categories of uncertainty defined (ethical, option, state space) and the five broad types that we have ascribed to these categories.

A. Regulatory/Legal Uncertainty Measurement for Large-Scale Engineering & Construction Projects (Ethical Uncertainty)

There are several potential measures to address **ethical uncertainty** and specifically regulatory and legal uncertainties which are a measurable component of such uncertainty. Potential uncertainty measurements include compliance deviation, which tracks the gap between actions and regulations; stakeholder feedback for perceptions of ethical behavior; litigation frequency to gauge legal risks; and scenario analysis to assess potential ethical dilemmas.

Tracking these gives a comprehensive view of the ethical landscape and attendant levels of uncertainty.

B. Technical Uncertainty Measurement for Large-Scale Engineering & Construction Projects (Option Uncertainty)

Technical uncertainty measurements may be grouped by the type of metrics that describe each grouping. These three groupings consist of:

- Technical Uncertainty Metric
- Engineering Project Uncertainty Index
- Confidence Metrics

Let's consider each in turn.

B1. Technical Uncertainty Metric

To track and manage uncertainty effectively in large, complex engineering and construction programs, we'll define specific metrics for key domains (schedule, cost, technical), then aggregate them into a composite index. We will also describe a related Engineering Project Uncertainty Index (EPUi) metric that will be separately calculated and tracked as a measure of technical uncertainty.

Schedule Uncertainty Index (SUI)

Schedule uncertainty, a component of technical uncertainty, is reflected as greater dispersion of the schedule (greater uncertainty). A schedule uncertainty index (SUI) can be developed by estimating the project's schedule duration with a three-point or Monte Carlo approach. The SUI can then be calculated as:

SUI = (P90 – P10) / P50

- Where, P10, P50, P90 are the 10th, 50th, and 90th percentile finish dates from the Monte Carlo simulation.

- Higher SUI means greater schedule dispersion, greater uncertainty, and risk to milestones.

Cost Uncertainty Index (CUI)

A cost uncertainty index, a second component of technical uncertainty, can be calculated in a manner similar to the Schedule Uncertainty Index. The Cost Uncertainty Index (CUI) uses either a three-point cost estimates (low, most likely, high) or Monte Carlo outputs, such that:

$CUI = (Cost_{90} – Cost_{10}) / Cost_{50}$

- $Cost_x$ are percentiles of total-project cost distribution.

The CUI reflects the volatility in budget forecasts.

Technical Uncertainty Score (TUS)

The Technical Uncertainty Score (TUS), the third component of technical uncertainty, aggregates risk probabilities and impacts for critical systems. Careful definition of critical systems is an important first step in developing the TUS.

Critical Systems Examples in Large Complex Projects

Permits	*Utility Relocations*	*Site Stabilization*
Foundations	*Concrete*	*Structural Steel*
Mechanical Equipment	*Electrical Equipment*	*Piping*
Control Systems	*Specialty & Process Equipment*	*Information Systems*
Construction Modules		

TUS can then be calculated such that:

$TUS = \sum (p_i \times I_i) / \sum I_i$

- p_i = probability of failure for component i (from expert elicitation).
- I_i = impact score (e.g., 1–5 scale).
- Normalized between 0 (no uncertainty) and 1 (extreme).

Shortly, we will describe components of an Engineering Project Uncertainty Index (EPUi). Potential overlap with components included in TUS should be noted.

Composite Uncertainty Metric (CUM) for Technical Uncertainty

A composite uncertainty metric (CUM) for these components of technical uncertainty can be calculated by combining SUI, CUI, and TUS into a single index to track overall uncertainty. While a single metric is convenient, attention must be paid to each of the component parts.

In order to calculate CUM we begin by normalizing each metric [0, 1] such that:

- $\hat{SUI} = (SUI - SUI_{min}) / (SUI_{max} - SUI_{min})$
- $\hat{CUI} = (CUI - CUI_{min}) / (CUI_{max} - CUI_{min})$
- $\bar{TUS} = TUS$

Stakeholder-derived weights are then applied such that ($\alpha + \beta + \gamma = 1$). This results in:

- $CUM = \alpha \cdot \hat{SUI} + \beta \cdot \hat{CUI} + \gamma \cdot \bar{TUS}$

Again, it is important to not lose sight of the individual components.

Metric	Domain	Raw Range	Normalized Formula
SUI	Schedule	$[SUI_{min}, SUI_{max}]$	$(SUI - SUI_{min}) / (SUI_{max} - SUI_{min})$
CUI	Cost	$[CUI_{min}, CUI_{max}]$	$(CUI - CUI_{min}) / (CUI_{max} - CUI_{min})$
TUS	Technical	[0, 1]	TUS

Recommended weights often align with sponsor risk tolerance (e.g., $\alpha = 0.4$, $\beta = 0.4$, $\gamma = 0.2$).

Track this composite technical uncertainty metric overtime, updating assessments and recomputing SUI/CUI/TUS monthly or at each stage gate. A plot of the CUM trend will identify any rising uncertainty. Dashboard alerts can be set for example when CUM exceeds a threshold of say 0.7. Similar alerts may be set for each of the three component uncertainties. This tracking and alerts are Integrated into the project controls system for real-time visibility and data-driven decision making.

B2. Engineering Project Uncertainty Index (EPUi)

As a companion to the Composite Uncertainty Metric (CUM) an **Engineering Project Uncertainty Index (EPUi)** may be calculated. Elements of the EPUi include elements of Strategic Uncertainty and Operations Uncertainty, two parts of State Space Uncertainty, the third broad category of uncertainty described at the beginning of this paper. Also reflected in the EPUi are technical elements that may also appear in or be related to components of the Technical Uncertainty Score (TUS).

Similar to CUM, the EPUi consists of a number of components, that while being included in a composite EPUi, warrant individual tracking as well. These four component metric sets address:

- Design and requirements
- Structural and materials engineering
- Manufacturing and production
- System integration and reliability

Each of these is discussed below.

Design and Requirements

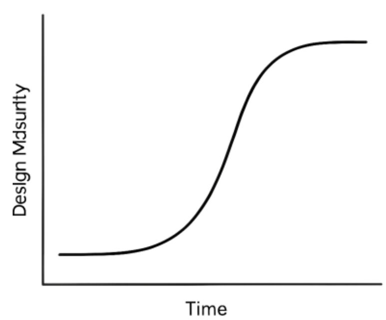
Uncertainty with respect to design and the requirements to be met can be measured utilizing two indices.

- **Requirements Volatility Index (RVI)** = number of changed requirements/total number of requirements. This indice relates to Strategic Uncertainty and indicates scope drift or weak or unstable project foundations.
- **Design Maturity Index (DMI)** = number of final designed elements/ total number of elements to be designed. Low DMI, early in the design process, signals high technical uncertainty.

Design Maturity Index

A typical baseline DMI curve starts flat, gradually ramps up as the design progresses, then levels off as most elements are finalized. It's like an S-curve, showing early slow progress, rapid development, and a final plateau as the project nears completion.

DMI Curve



For a major civil engineering project like a tunnel or bridge, the DMI curve would typically start slow, reflecting initial planning and concept designs. It'd ramp up as detailed design elements are developed and approved, peaking as construction drawings are finalized. The curve would then plateau as the project nears completion and all design elements are finalized.

Structural and Materials Engineering

Uncertainty with respect to materials and structural properties are measured through two uncertainty measures.

- **Material Property Uncertainty (MPU),** uses the standard deviation or coefficient of variation (CV) for critical properties like tensile strength. Here,

  MPU = $CV = \sigma / \mu$

  where σ = standard deviation, μ = mean. MPU is stated as a percentage and is useful for simulations and tolerance analysis.

- **Load-Response Uncertainty (LRU)** is quantified using probabilistic finite element models to assess how varied load conditions affect a structure.

Load-Response Uncertainty (LRU)

Probabilistic Finite Element Models, or PFEMs, are used to quantify Load Response Uncertainty by incorporating variability and randomness in material properties, geometry, and loading conditions. This involves running numerous simulations to generate a statistical distribution of responses. Load Response Uncertainty is then quantified by evaluating metrics like mean, variance, or confidence intervals.

Imagine you're analyzing a bridge. So, you'd create a finite element model of the structure and include variables like material strength, load magnitude, and environmental factors. You'd run simulations. These simulations capture the randomness of each variable. By doing this thousands of times, you get a range of possible outcomes. Then, you analyze these results statistically by looking at how much the load response varies. This helps in understanding and managing the uncertainty in the bridge's performance. It's a powerful way to predict how structures might behave under various conditions.

Manufacturing and Production

Two measures of uncertainty related to manufacturing and process capability are utilized in assessing the Engineering Project Uncertainty Index (EPUi). These include:

- **Process Capability Index Variation (∆Cpk)** This tracks how consistent a process remains under uncertain inputs. It is calculated as the change in the Process Capability Index over time or between different batches:

  $\Delta Cpk = Cpk_2 - Cpk_1$

  Where,

Cpk_2 is equal to (USL - μ)/3 σ for the upper specification limit, and

Cpk_1 is equal to (μ - LSL)/3 σ for the lower specification limit

Where,

- **Cpk**: Process Capability Index.
- **μ**: Process mean (average).
- **σ**: Standard deviation (measure of process variability).
- **LSL**: Lower Specification Limit.
- **USL**: Upper Specification Limit.

If Cpk ≥ 1, the process is capable of producing outputs within specification limits.

If Cpk < 1, the process is not capable and may produce defects outside the limits.

The ΔCpk over time highlights production instability. Cpk accounts for both the process variability (spread) and the centering of the process mean relative to the specification limits. This metric is widely used in quality control and Six Sigma methodologies to ensure processes meet customer requirements effectively.

- **Yield Uncertainty Ratio (YUR)** helps estimate scrap risk and throughput variability and is an important consideration with respect to supply chain effectiveness. It is calculated as:

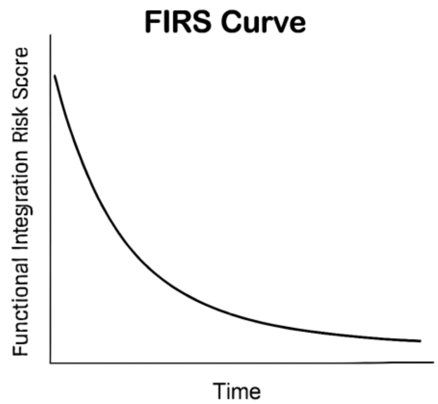
  YUR = σ/ μ

  σ: Standard deviation of the process yield

  μ: Process mean (average yield)

System Integration and Reliability

- **Functional Integration Risk Score (FIRS)** is a way to measure the average risk across multiple subsystems. It is the sum of how likely each subsystem is to fail multiplied by how bad it would be if it did, all divided by the number of subsystems. It can be extended to include weighting factors, time-dependent risk, or interdependencies between subsystems.



It is similar to the Technical Uncertainty Score (TUS) but specific to interoperability and performance mismatches.

- **Reliability Growth Uncertainty (RGU)** Using reliability growth models (e.g., Duane, AMSAA), track the confidence bounds as testing proceeds. Reliability growth is applicable to all levels of design decomposition from complete systems down to components. The maximum achievable reliability is locked in by design, so reliability growth above the design reliability is only possible through design changes.

Composite Engineering Project Uncertainty Index (EPUi)

The composite **Engineering Project Uncertainty Index (EPUi)** blends volatility in design, execution, and performance such that:

$$EPUi = w_1 \times RVI + w_2 \times MPU + w_3 \times \Delta Cpk + w_4 \times FIRS$$

- Weights are assigned based on project context (e.g., $w_1 = 0.3$ for design-intensive projects).
- Normalize components between 0 and 1 before aggregation.

B3. Confidence Metrics

Uncertainty and confidence metrics often work hand in hand. In engineering and construction projects, uncertainty metrics quantify the unknowns, while confidence metrics assess the reliability of those estimations. Higher confidence in data or models typically means lower perceived uncertainty.

Candidate Confidence Metrics

Four confidence metrics are worth considering for use in large complex engineering and construction projects. These include:

- Confidence Interval (CI)

- Confidence Level (CL)
- Prediction Interval (PI)
- Bayesian Confidence (BC)

Let's look at each of these in turn.

Confidence Interval (CI): Represents the range in which a parameter lies with a certain probability level. In projects, CI can be applied to cost estimates, durations, or performance metrics.

Confidence Level (CL): Indicates the probability that a parameter will fall within a certain range. A higher confidence level suggests a more reliable estimate.

Prediction Interval (PI): Similar to CI, but accounts for the variability in future observations. It is useful for predicting project outcomes like completion dates or budget adherence.

Bayesian Confidence (BC): Applies Bayesian inference to update confidence based on new data. It can be applied to risk assessments, adjusting the likelihood of events as the project progresses.

Confidence metrics can provide a probabilistic view of project outcomes, guiding decision-making and risk management.

Assessing Confidence in Engineering and Construction Projects

Assessing confidence in engineering and construction projects can be approached in a structured step-wise manner:

Step 1: Define Key Phases

Step 2: Establish Confidence Metrics

- **Expert Judgment:** Using expert opinions to estimate confidence levels based on experience.
- **Historical Data:** Analyzing past project data to determine typical confidence levels at each stage.
- **Monte Carlo Simulation:** Running simulations to model potential outcomes and assess the probability of different scenarios.

Step 3: Calculate Metrics

- **Confidence Intervals:** Collecting and analyzing statistical data for estimates to determine the range of values.
- **Bayesian Inference:** Updating initial estimates with new evidence to adjust confidence levels.

Step 4: Composite Confidence Metric

Combine the metrics using a weighted approach, considering each phase's impact and importance.

Step 5: Monitor Over Time

Regularly update confidence levels as the project evolves, adjusting based on new information and progress.

This structured approach ensures a comprehensive assessment of confidence, adapting to the unique challenges of large and complex projects.

C. State Uncertainty

State uncertainty, the third broad category of uncertainty we identified at the outset of this paper, broadly consists of:

- Market uncertainty
- Operational uncertainty
- Strategic uncertainty

For tracking **market uncertainty**, we look at demand forecasts, customer feedback, and competitor analysis. Specific market related uncertainty metrics include:

- volatility indices like the VIX
- economic indicators like GDP growth rates, and
- industry-specific sentiment surveys
- client specific Net Promoter Score (NPS)
- changes in market share

Operational uncertainty metrics include supply chain resilience, equipment downtime, and labor turnover rates. Specific operational uncertainty metrics include:

- lead time variability in your supply chain to gauge resilience
- equipment downtime tracked by mean time between failures and mean time to repair
- labor turnover rates measured by the employee turnover ratio.

Finally, **strategic uncertainty** can be monitored through strategic goal assessments, stakeholder analysis, and adaptability measures. Specific strategic uncertainty metrics include:

- Variance between projected and actual outcomes (outcomes are contrasted with outputs). High variance signals strategic uncertainty.
- Stakeholder (internal) confidence levels as it relates to perceptions of strategic direction.
- Stakeholder (external) confidence in project’s strategy as measured by stakeholder sentiment.
- Response time to market changes and time to implement changes measure organizational agility

Conclusion

A structured approach to measuring uncertainty is essential in large complex projects. It is a complement to measuring and tracking project complexity. In this paper we've outlined a comprehensive view of the various types of uncertainty that a project may face. While tracking all of these uncertainty measures and metrics may be daunting, so is failure on these projects.

A measured approach can prove beneficial with metrics added as may be required to address the scale and specific types of uncertainty the project may face. As a starting point including CUM, the Cumulative Uncertainty Metric for technical uncertainty and its schedule, cost and technical uncertainty score components, will provide an initial benefit.

In a more developed form, a more comprehensive set of uncertainty metrics would provide value to component parts of a project and even the overall project. The following figure shows a top level uncertainty dashboard with drill down possible for each element.

Uncertainty Dashboard (Top Level)				
Ethical	**Option**	**State Space**		
Regulatory/Legal	**Technical**	**Market**	**Operational**	**Strategic**
Compliance	**CUM**	**Demand**	**Supply Chain**	**SBO**
Stakeholder Perception	**EPUi**	**Customer**	**Equipment**	**Stakeholder**
Litigation	**Confidence**	**Competitor**	**Labor**	**Adaptability**

Disclaimer on Use of AI: *In preparing the manuscript, AI-based editorial tools (e.g., Grammarly) were used for grammar refinement, and language models (e.g., ChatGPT or similar) were selectively consulted to explore alternate phrasing and improve clarity. All core ideas, structure, and substantive content are original, derived from the author's professional experience and past presentations. Included formulas are from broadly used industry sources and are not referenced with in-line text citations. Where relevant, previous materials have been appropriately referenced or adapted.*

National Academy of Construction Executive Insights for Further Reading

Assumption, Risk Driver, and Constraint Tracking https://www.naocon.org/wp-content/uploads/Assumption-Risk-Driver-and-Constraint-Tracking.pdf

Complex Projects; https://www.naocon.org/wp-content/uploads/Complex-Projects.pdf

Considering the Uncertainty for Large Projects; https://www.naocon.org/wp-content/uploads/Link-Considering-Uncertainty-for-Large-Projects-02.08.19.pdf

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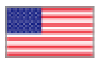

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Bob's board level experience includes Parsons Brinckerhoff (Chairman); Cardno (ASX listed; non-executive director); Mott MacDonald (Independent Member of the Shareholders Committee); and Dar al Riyadh Group (current)

Bob consults with owners of large, complex capital asset programs in the development of programmatic delivery strategies encompassing planning, engineering, procurement, construction, financing, and enterprise asset management. He has assisted engineering and construction organizations to improve their strategy and execution and has served as an executive coach to a new CEO. He is author of eleven books, over 1000 papers and National Academy of Construction Executive Insights, and an inventor on 4 issued patents.

Bob's industry involvement includes the National Academy of Construction and Fellow of the Construction Management Association of America (CMAA). He serves on the New York University Tandon School of Engineering Department of Civil and Urban Engineering Advisory Board and New York University Abu Dhabi Engineering Academic Advisory Council and previously served as a trustee of Polytechnic University. He has served on the Millennium Challenge Corporation Advisory Board and ASCE Industry Leaders Council. He received the ASCE Outstanding Projects and Leaders (OPAL) award in Management (2024). He was appointed as an honorary global advisor for the PM World Journal and Library.

Bob served until 2006 as one of three U.S. presidential appointees to the Asia Pacific Economic Cooperation (APEC) Business Advisory Council (ABAC). He chaired the World Economic Forum's Engineering & Construction Governors and co-chaired the infrastructure task force in New York after 9/11. He can be contacted at rpstrategic@comcast.net.