Engineering Risk Analysis - Application of Probabilistic Analysis Techniques for Asset Management and Design of Port Facilities

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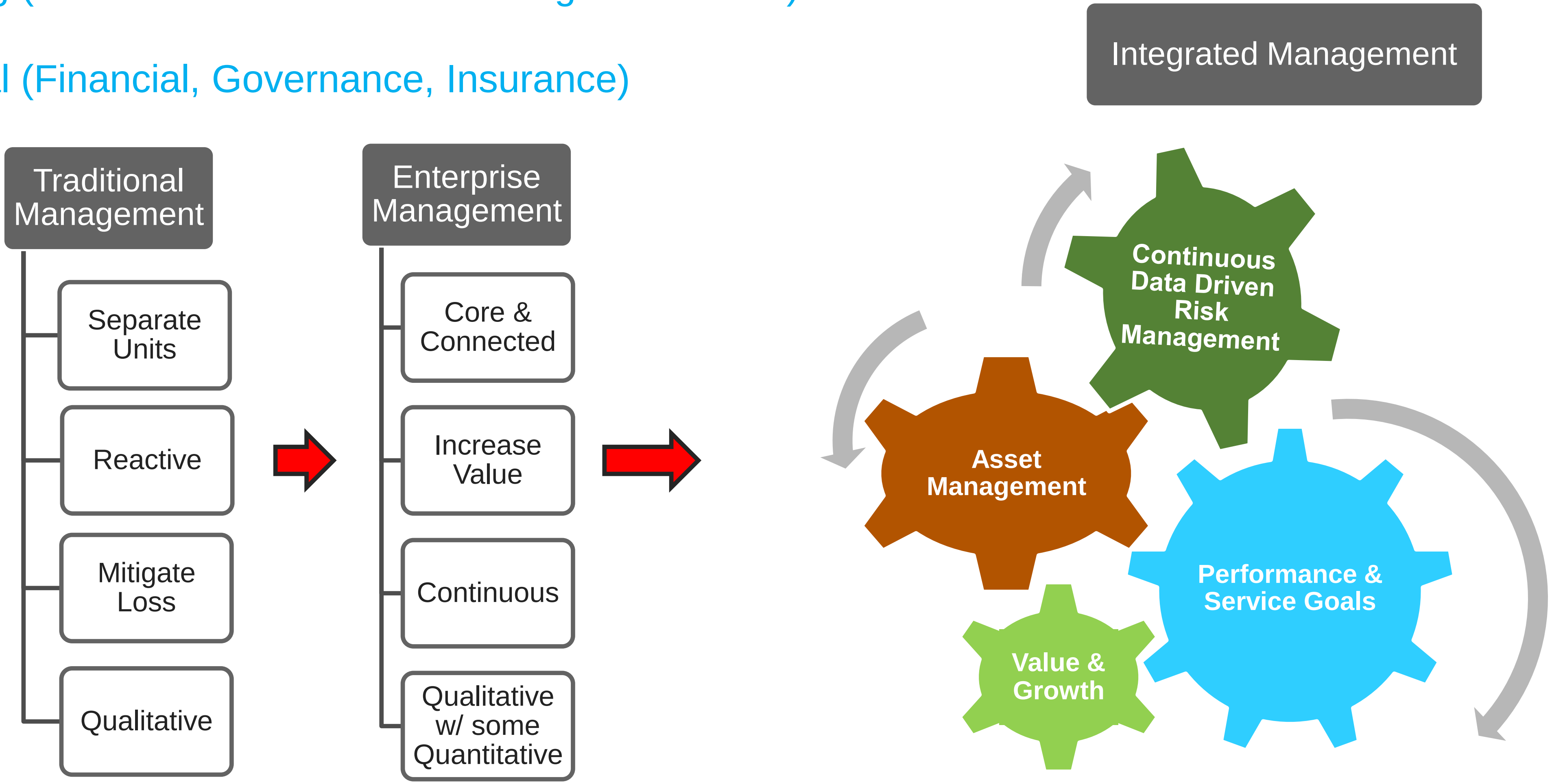
Agenda

- Risk Management Approach
- Risk Analysis – Key Concepts & References
- Risk Analysis – General Process
- Application Cases
  - Project Risk Modeling
  - Technical (Engineering) Risk Modeling
  - Commercial (Financial) Risk Modeling
- Q&A

Risk Management Approach

Project delivery or design navigated per possible risks in the process.

- Project Controls (Schedule, Cost, Discrete Life Cycle)
- Engineering (Performance in terms of Strength & Service)
- Commercial (Financial, Governance, Insurance)



Risk Analysis – Key Concepts

Law of Large Numbers (LLN) – Robust Sampling

- LLN is a **mathematical theorem** that states that the average of the results obtained from a large number of independent and identical random samples converges to the true value, if it exists.

Probability Distributions (PD)

- PD is the mathematical function that gives the probabilities of occurrence of different possible outcomes for an event.

Monte Carlo Simulation (MCN) / Laplace Hypercube Sampling (LHS)

- Both, MCN / LHS are perfect examples of LLN. Monte Carlo Simulation is broad class algorithm that perform repeated random samplings. LHS is essentially a more controlled MHS.

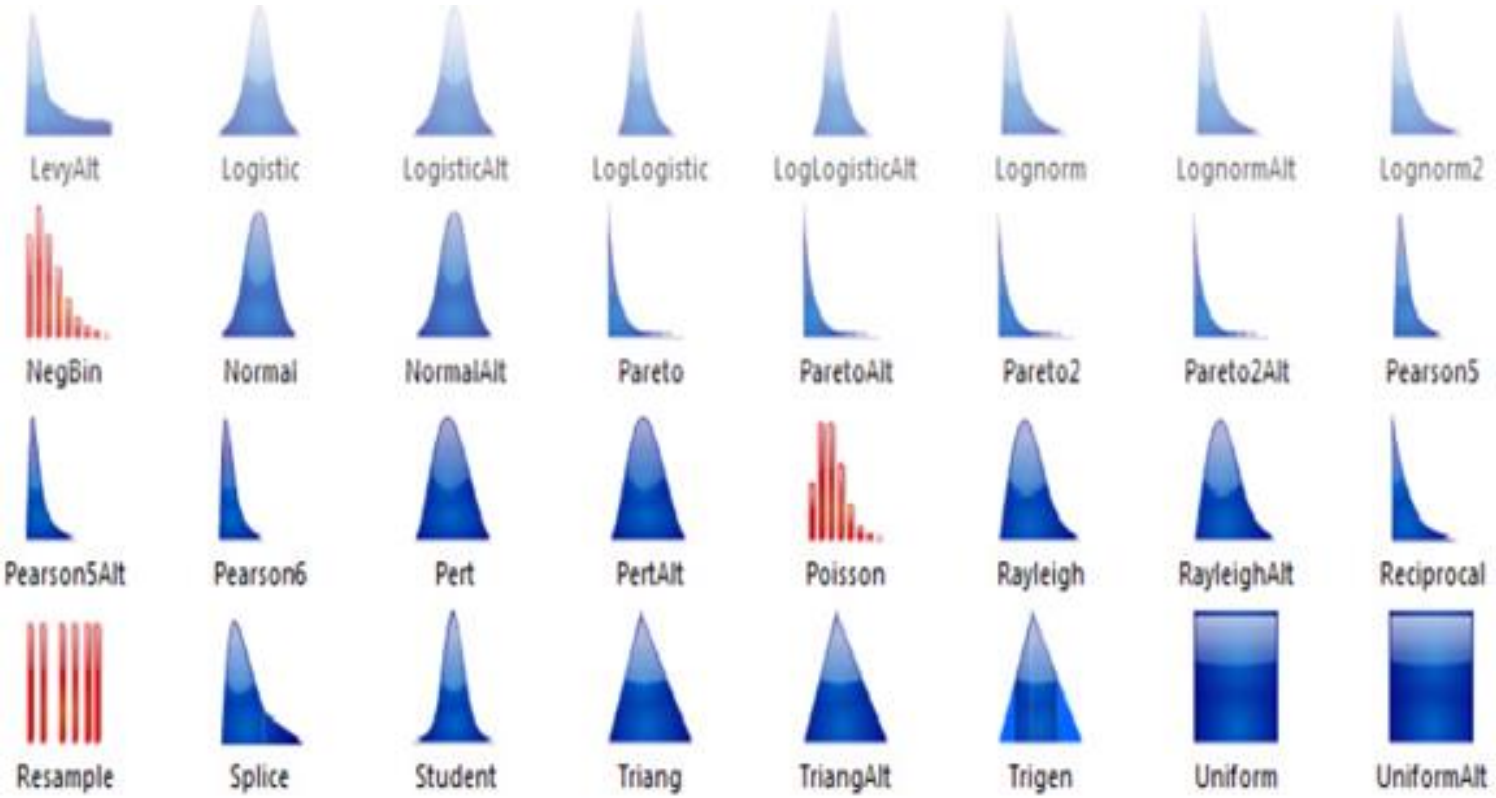
Deterioration or Demand Models (DM) – **Key Input**

- Both, deterioration or demand models are represented through Probability Distributions specific to the deterioration or demand at a given site.

Risk Analysis – Key Concepts

Probability Distributions (PD)

- PD are the building blocks of site-specific comprehensive risk analysis.
- **Most Accurate PD are created through historical, SHM / WIM, or synthesized data**.
- Use of Python, @Risk, R-Studio for distribution fitting or back testing of decades of Port or Marine data.



Possible Distribution Forms among Few Hundreds Available Classes

Risk Analysis – Key References

KEY REFERENCES

Unified Facilities Criteria (UFC) 3-740-05 Handbook: Construction Cost Estimating [Project Risk Analysis]

NCHRP Report 658 – Guidebook on Risk Analysis Tools and Management Practices to Control Transportation Project Costs [Risk Management Framework]

NCHRP Report 666 (Vol I & II) – Target-Setting Methods and Data Management to Support Performance-Based Resource Allocation by Transportation Agencies [Project Risk based Master Planning]

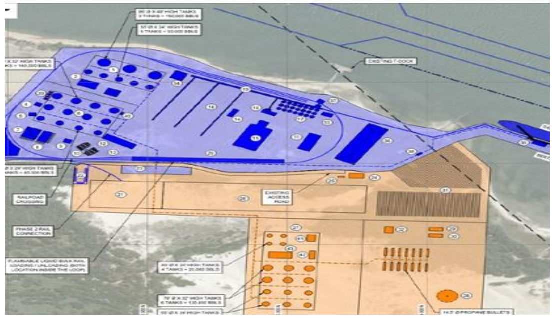
NCHRP Report 706 - Uses of Risk Management and Data Management to Support Target-Setting for Performance-Based Resource Allocation by Transportation Agencies [Risk Management Plans)

NCHRP Report 713 – Estimating Life Expectancies of Highway Assets [Life Expectancy Models]

NCHRP Report 489 – Design of Highway Bridges for Extreme Events [Structural Reliability Analysis]

PORT OF LONG BEACH - CA

NORTH COUNTY TRANSIT DISTRICT - CA



Port of Coos Bay - OR

PG&E Facilities - CA

Risk Analysis – Sample Reference Guidelines

KEY REFERENCES

Port of Long Beach, CA – Project Delivery Risk Management Manual [Project Risk Framework]

USDOT-FTA – Oversight Procedure (OP) 40 Risk and Contingency Review [Project Risk Framework]

Caltrans – Project Risk Management Handbook [Project Risk Framework]

NYSDOT – Risk Management Guide [Project Risk Framework]

FHWA-HRT-14-039 – Post-Tensioning Tendon Grout Chloride Thresholds [Deterioration Models]

FHWA-HIF-09-004 – Report on the Diagnosis, Prognosis, and Mitigation of Alkali-Silica Reaction (ASR) in Transportation Structures [Deterioration Models]

TIRC / NYSDOT – Bridge Element Deterioration Rates (Final Report) [Deterioration Models]

AASHTO – Load and Resistance Factor Design [Deterioration Models]

Caltrans – Bridge Deterioration Models and Rates – Preliminary Investigation [Deterioration Models]

Deterioration & Load Models generated through available SHM / WIM / Material testing, research and inspection data specific to site geography and bridge types.

Risk Analysis – General Process (Project Risk)

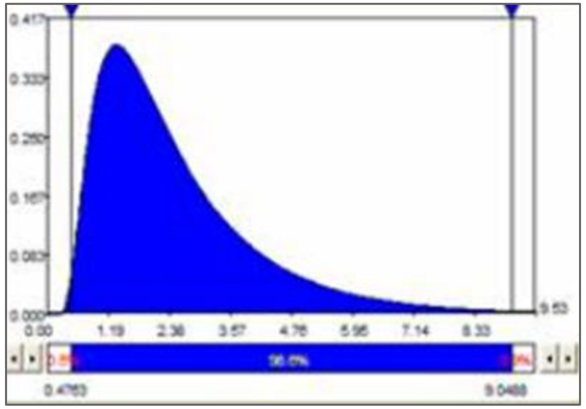
Monte Carlo Models

Individual Schedule Analysis (@risk / Primavera Risk)
- Summary Level
- Logic Adjusted

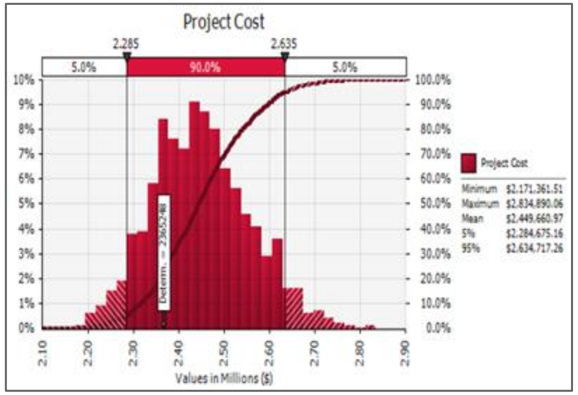
Individual Cost Analysis (@risk)
- Based on Budget Estimate
- (CSI Divisions, Labor, Materials, Equipment)
- Risk Events added as necessary
- Duration impact from schedule assessment

Combined Schedule/Cost (Primavera Risk)
- Based on Budget Estimate
- (CSI Divisions, Labor, Materials, Equipment)
- Risk Events added as necessary
- Duration impact from schedule assessment

Key Model Variables
- Duration
- Unit Cost
- Quantity
- Productivity
- Correlation Factors
- Losses (Risk Register Linked)



Key Model Outputs
- Identification / Impact of Key Activities (Sensitivity)
- Milestone/Activity Results with Confidence Levels (P90, P50, P10)
- Probability Distributions
- Critical Paths



Risk Analysis – Key Inputs (Project Risk)

Typical Risks causing largest Impacts

- Unknown Geotechnical or Underwater Conditions
- Shortage of Manual Labor & Conflict with Similar Vicinity Projects
- Coordination with Public Agencies & Port Tenants involved in Right of Way
- Contractor Oversight for imposing heavy temporary loadings
- Restrictions on Material/Service Manufacturer based on funding agency (ex. Foreign steel / Rebar / Port Machineries)
- Material Price Fluctuations (Steel, Concrete, Prestressed, Crushed Stone)
- Incorrect estimation of crane/equipment base conditions (ex. Changing Current speed in Waterbody for crane barge)
- Environmental Issues (Especially unknown issues causing schedule or remediation cost impacts)

(Key is to correctly account for hidden vulnerabilities in the cost of the project)

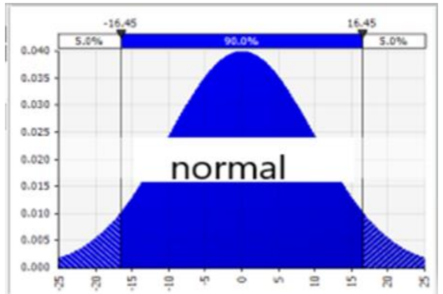
- Comprehensive Study of Geotechnical, Coastal, Structural, Wind, and Hydrological Conditions of the site.
- Consideration to Hurricane/Storm Level force demands on staging
- Expert Understanding of Structural Health Monitoring and Weigh-in-Motion to quantify risks
- Consideration to Service Life/Capacity/Deterioration for all elements on construction site

Risk Analysis – General Output (Project Risk)

1) Input Range/Risk Register for all Items in Schedule / Cost Analysis

(Using Qualitative, Subject Expert, and Reference Class Analysis)

(Ex. Task Duration => Low Range – 10 days; Medium Range – 20 days; High Range – 40 days)

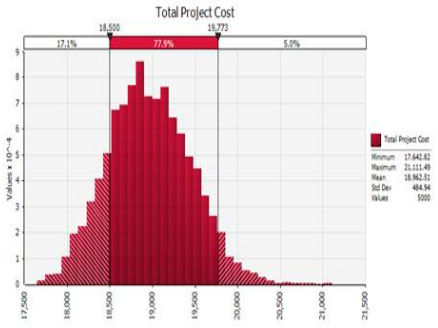


2) Probability of Results (P10, P50, P90, P99)

(Using Quantitative Probabilistic Analysis)

(Ex. Task Cost => P90 = $125,000 => 90% Probability that this activity cost won’t exceed $125,000)

(Ex. Project NPV => P95 = $5,025,000 => 95% Probability that this project NPV won’t exceed $5.025M)

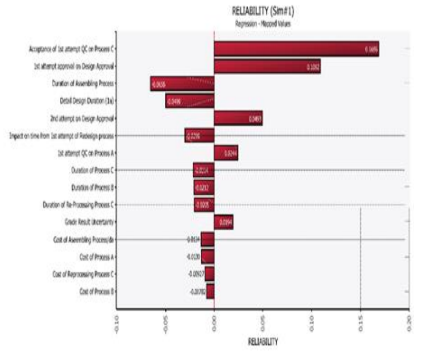


3) Sensitivity of Project to Activities / Scenario Analysis for Decision

(Using Tornado Charts / Simulation Tables)

(Ex. Activity 4 has the highest impact / 10 has the lowest impact on overall project cost/schedule)

(Ex. With Consideration of particular scheme (path in schedule), NPV rises by 5%.



Risk Analysis – General Process (Engineering Risk)

Probabilistic Distribution Fitting

DISTRIBUTION GENERATION

Element Capacity (Code / Mechanics)
- Theoretical material and element capacity (ex, moment, tension, compression, shear, etc. with established levels of uncertainty)

Element Deterioration (Code / SHM / Mat. Testing)
- Deterioration Model of material and element (ex, corrosion, ASR, freeze-thaw, settlement, etc. varying with time or reference variable)

Element Demand (Code / SHM / WIM)
- Load Variation with time or reference variable (ex, heavier loads, scour rate, wave loadings, fatigue cycles, etc. varying with time or reference variable))

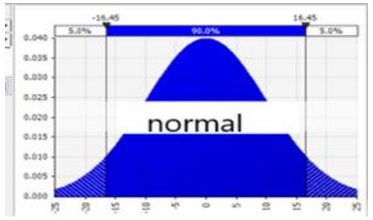
Probabilistic Simulations (For Ex. Monte Carlo)

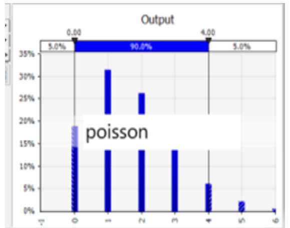
Key Model Variables

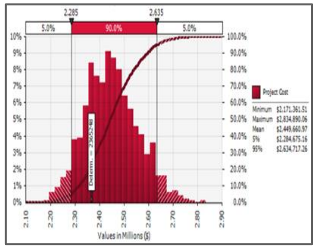
- Capacity
- Deterioration
- Load
- Load Path
- Failure Path

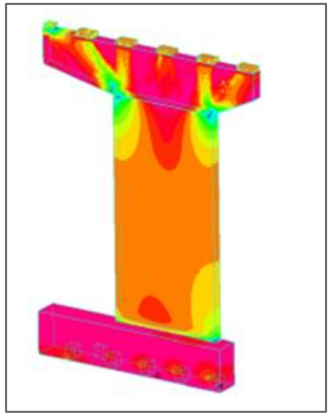
Key Model Outputs

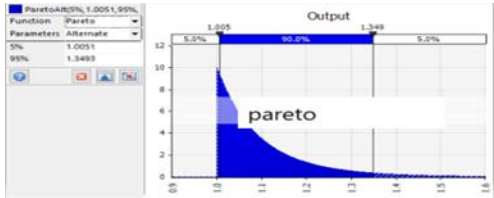
- Probability of capacity exceedance
- Probability of collapse
- Probability Distributions of capacity/distribution or collapse
- Criticality of elements in the system











Simulations to be performed in spreadsheets or directly in FEA Batch Analysis

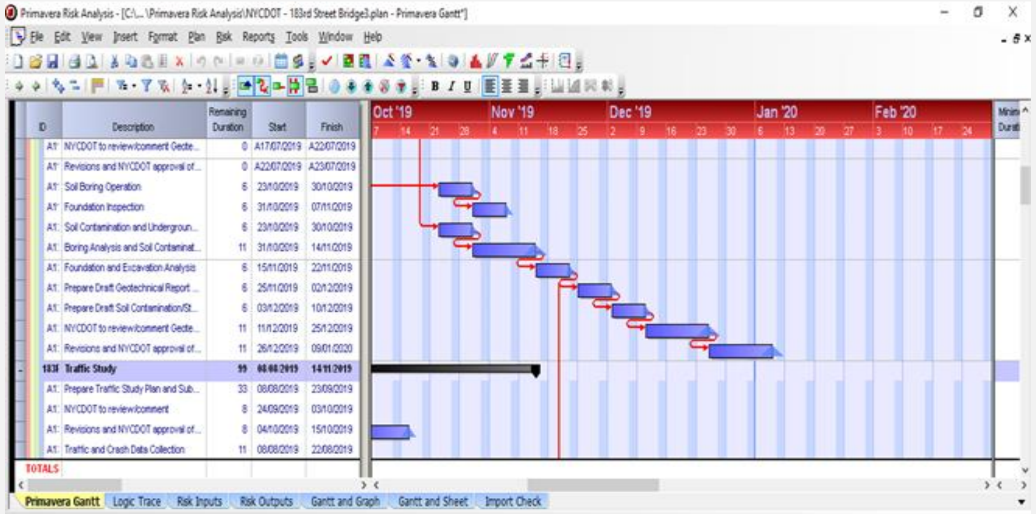
GENERAL PROCESS

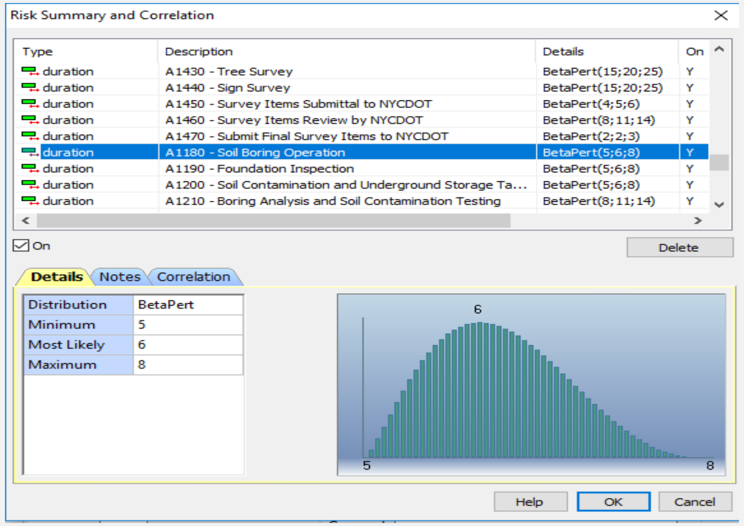
Application Case (Project Risk – Small Scale)

Project Risk Control for a Design Phase (Sea Wall Repair)

Input Variables *(Mostly Schedule Control yield satisfactory results)*

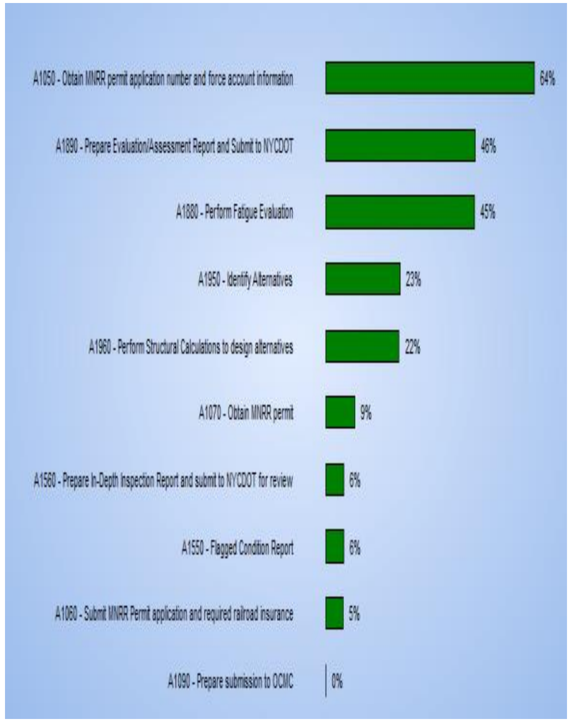
- Conventional Schedule in P6 and Probabilistic Ranges in Primavera Risk

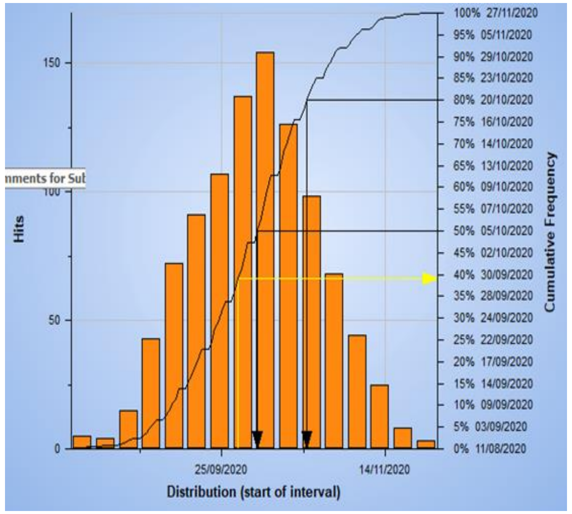




Output Variables

- Sensitivity Plots/Tables to concentrate efforts on key activities
- The most probable (realistic) schedule to meet milestones
- The effect of key activity delay on overall schedule and cost of project. (For example, the Railroad Permit delay of 3 weeks has potential to cause 3 months delay in project schedule, leading to \$50rate x 2multi. x 40hrs/week x 3 months x 4 weeks = \$48,000 productivity loss.





APPLICATION CASE

Application Case (Project Risk – Large Scale)

Major Port Program Analysis (All Stages – Port wide Wharf Rehabilitation)

Input Variables

- Conventional Schedule in P6 and loaded model in @Risk (+3000 activities)

RISK ASSESSMENT

CONSEQUENCE SCALE	Very Low 1	Low 2	Medium 3	High 4	Very High 5
Cost	< $20K	< $55K	< $200K	< $375K	< $500K
Schedule	< 5 days	< 10 days	< 21 days	< 30 days	< 45 days

Project Risks

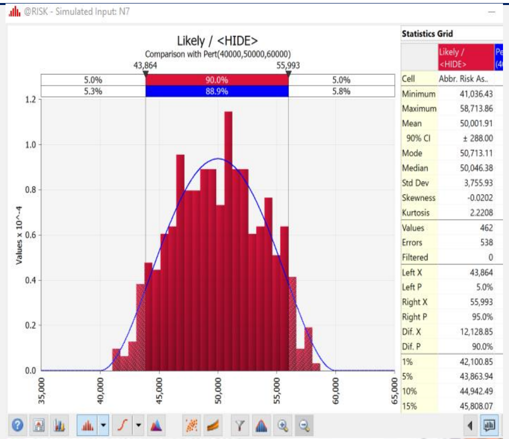
100% Design - Consequences & Likelihood

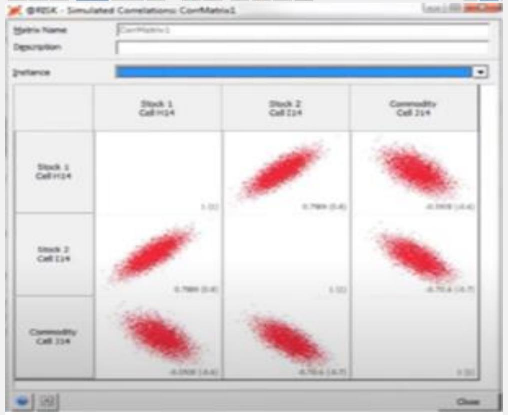
Risk Number	RISK Category	NEW! Risk Title/ Scope Element	Risk Description	Risk Type	HARD COST & SCHEDULE: Est. Risk Consequence - $			HARD COST & SCHEDULE: Est. Risk Consequence - Schedule (days)			*Likelihood	SOFT COSTS (Soft costs require estimated schedule delays and a burn rate to apply to Schedule Delays): Est. Risk Consequence - Schedule (days)			Burn Rate ($)
					Min	Most Likely	Max	Min	Most Likely	Max		Min	Most Likely	Max	
1	Design	Wharf structural capacity	Existing condition of the wharf (other than voids) may be worse than anticipated and require additional rehab measures	Active	$40,000	$50,000	$60,000	4	5	6	Likely	0	0	0	$300

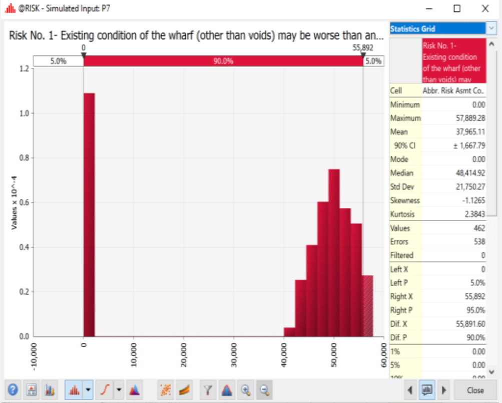
*Likelihood		Range	Lower Limit	Upper Limit
Rare (1)	5%	0% to 12.5%	0.0%	12.5%
Unlikely (2)	20%	12.5 to 35%	12.5%	35.0%
Moderate (3)	50%	35% to 65%	35.0%	65.0%
Likely (4)	80%	65% to 87.5%	65.0%	87.5%
Almost Certain (5)	95%	87.5% to 100%	87.5%	100.0%

Output Variables

- Consequence (Extra $) for Cost & Consequence (Extra Days) for Schedule
- Likelihood of Occurrence





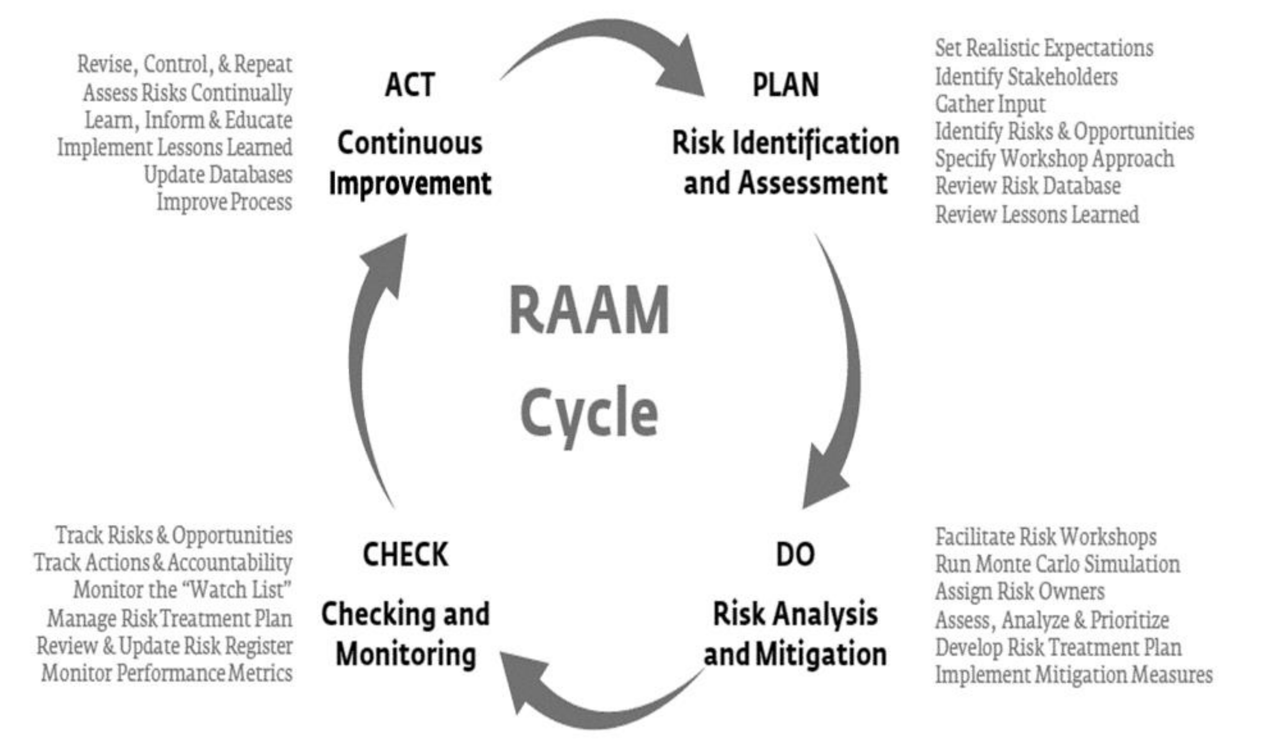


Application Case (Project Risk – Large Scale)

APPLICATION CASE

Major Port Program Analysis (All Stages – Port wide Wharf Rehabilitation)

Apply this to each identified activity of every single project in a 3 year program



Program Delivery Process

(30%, 50%, 100%, Final, Bid & Award, Construction)

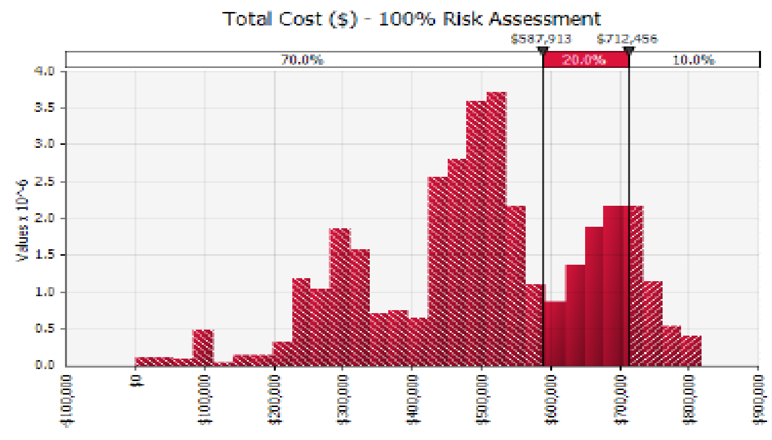
- Development of Task Budget & Schedule
- Kick Off Meeting
- Document Review for Risk Identifications
- **Development of Draft Risk Register**
- Review & Inputs by POLB Team
- Development of Pre-Workshop Risk Register
- Pre-Workshop Meeting with POLB Team
- **Risk Workshop**
- Obtain Designer/CM Inputs (Tracking)
- Develop Final Risk Register
- **Develop & Execute Risk Model Simulation**
- Review & Inputs by POLB Team
- Generate & Submit Risk Report

Application Case (Project Risk – Large Scale)

Program Analysis (All Stages – Port wide Wharf Rehabilitation)

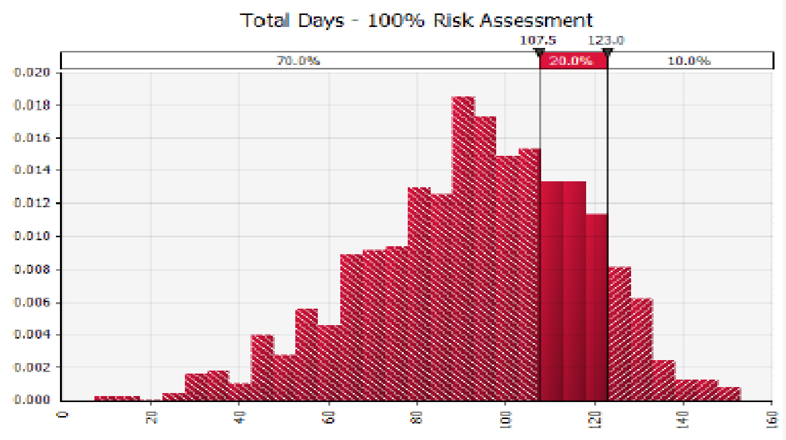
Output Variables

Design Cost Consequences

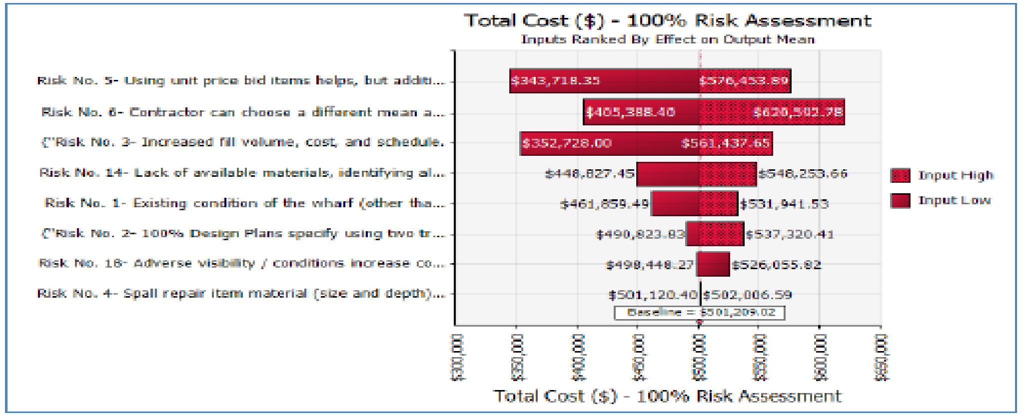


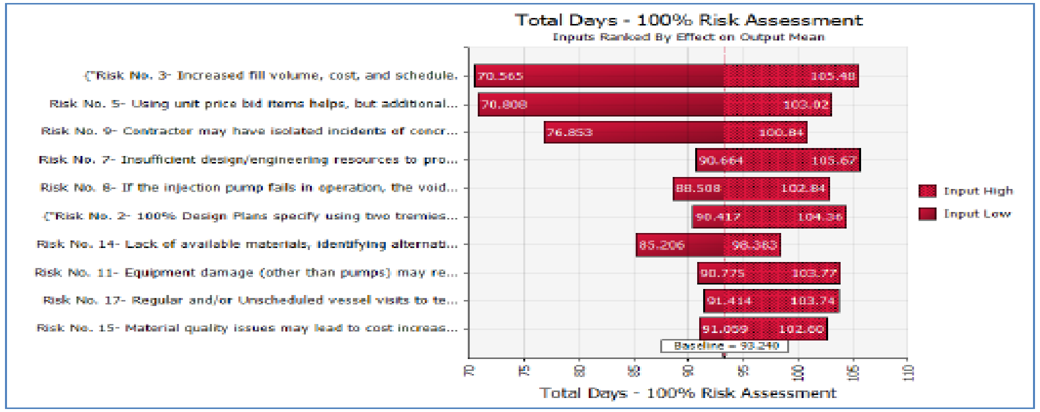
	Total Cost ($) - 100% Risk Assessment
15%	$308,291.16
20%	$340,673.81
25%	$415,570.79
30%	$440,353.90
35%	$462,399.01
40%	$478,197.11
45%	$492,459.69
50%	$506,185.61
55%	$518,211.28
60%	$530,773.95
65%	$547,869.67
70%	$587,913.10
75%	$639,670.70
80%	$664,649.21
85%	$690,835.79
90%	$712,456.30
95%	$738,960.74
99%	$791,078.86

Design Schedule Consequences



	Total Days - 100% Risk Assessment
10%	60.15
15%	66.49
20%	72.64
25%	77.85
30%	81.83
35%	85.83
40%	89.11
45%	91.68
50%	94.68
55%	97.62
60%	100.52
65%	103.86
70%	107.45
75%	111.00
80%	114.60
85%	118.59
90%	123.03
95%	129.08
99%	142.92





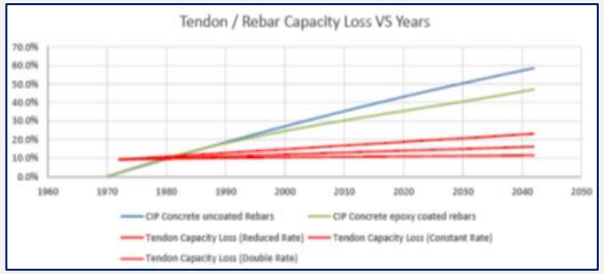
- **Project Cost ($30M) & Contingency ($800k) in 3 Year Program Budgeting**
- **Critical Activities to Control**

Application Case (Engineering Risk – Case 1)

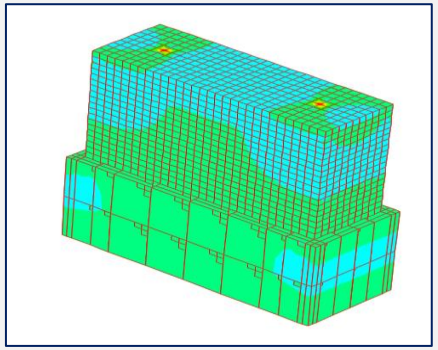
Probabilistic Service Life Assessment of Port Pier

Input Variables

- Dead Load variations for past 25 years and next 25 years
- Live Load variations for next 20 years, depending on region development



- Rate of Corrosion in Steel Rebar
- Rate of ASR activity in concrete

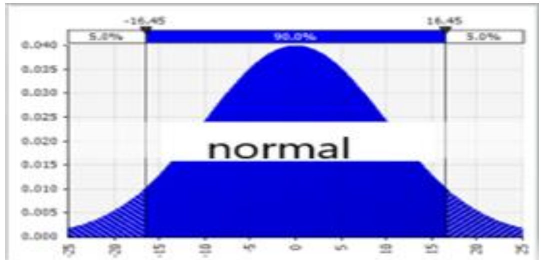


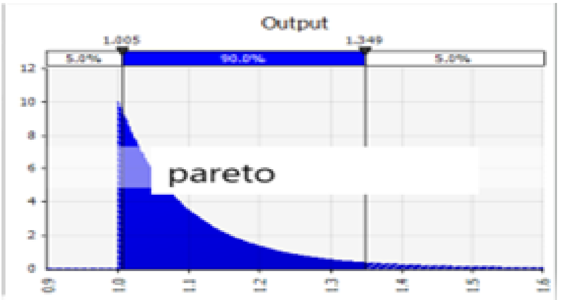
- Extreme event forces (seismic)
- Extreme event forces (hurricane winds/wave)

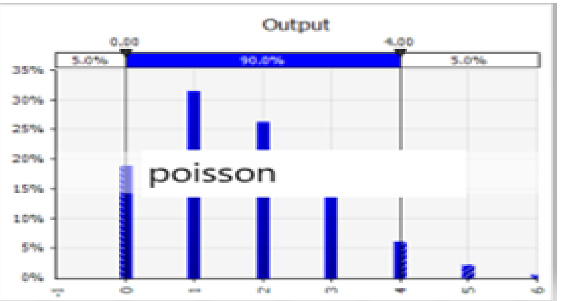
Output Variables

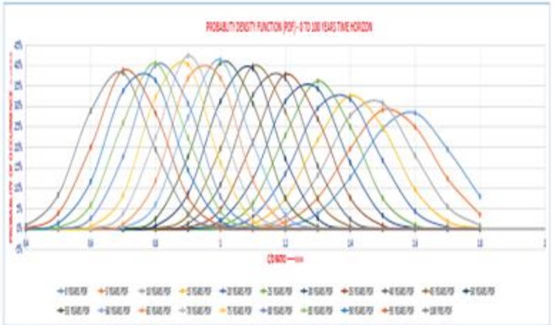
- Probability of Deteriorated Pier Collapse in 5 years, 10 years, 15 years, 20 years

(Ex. Risk Premium of not repairing or fixing pier (or given element) in next 6 months, 5 years, 10 years, etc. - Helps decision maker to create or not create a particular project)









Application Case (Engineering Risk – Case 2)

Long Term Crane Productivity Estimate on Shipping Pier

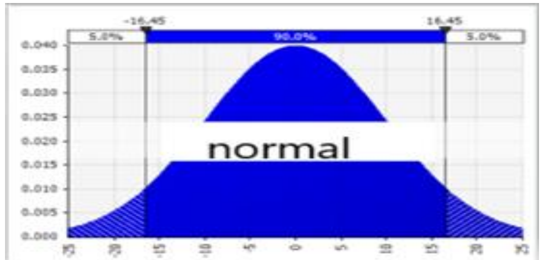
Input Variables

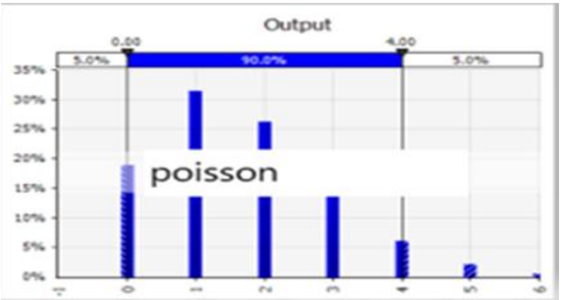
- Loading Condition (Per Crane Utilized & Range of Load) – OK or Overload
- Crane/Hoisting Condition – (Per Age/Maintenance) – New or Rundown
- Placement Condition – (Per Site Condition) – Stationary or Moving (Barge)
- Rigging Condition – (Per Uncertainty of Load / Past Records) – (Check Inadequacy)
- Crane Operation – (Per Operator Experience / Past Records) – (Safe or Un-Safe)

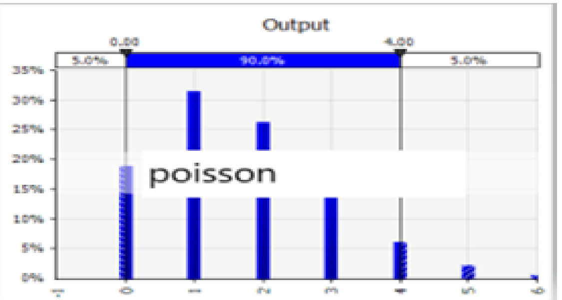
Output Variables

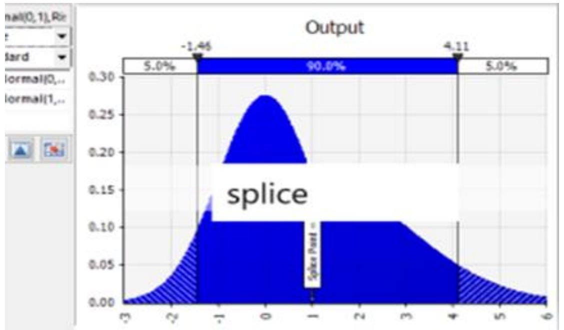
- Probability of No Incident / Distribution of Crane Risk Item / Range of Productivity

(Ex. 25% chance of Crane Incident and 75% chance of loss productivity during phase 1 ;
5% chance of Crane Incident and 30% chance of loss productivity during phase 10)









Application Cases (Example Engineering Risk Analysis)

Probabilistic Service Life Analysis – Performance Estimate for future timeframes

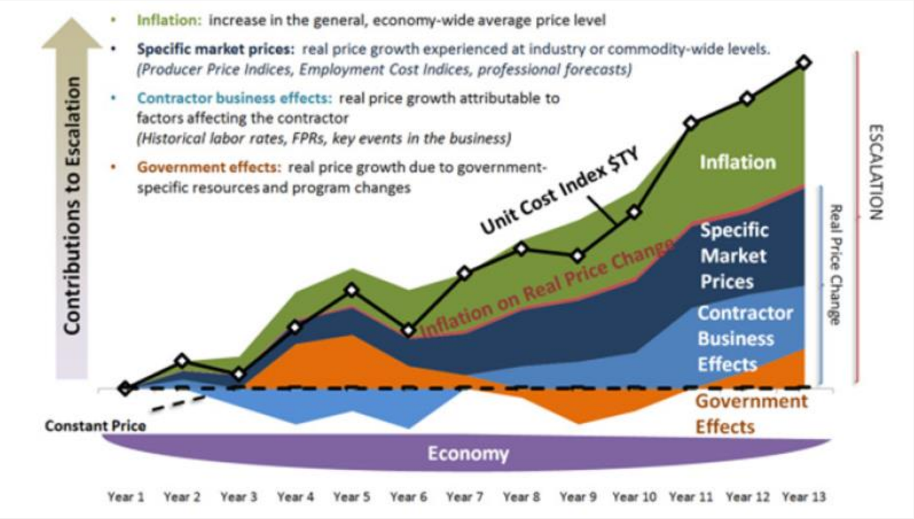
- **Underwater Port Structures - Piles / Wharf – Site Specific Performance Estimate**
- **Site Specific Post Tensioned or conventional concrete Service Life (50 years to 75 years) based on deterioration models**
- **Site Specific Steel Structure Gusset Plate or Redundancy Analysis**
- **Bridge or Crane Cables – Site Specific Deterioration Estimate (NCHRP 534)**

Lower Manhattan Coastal Resiliency Project - NY

Golden Gate Bridge Cable - CA

Application Cases (Commercial Risk Analysis)

Probabilistic Analysis of Escalation Rates – For Future Budgeting



Material Demand / Supply Cost Analysis

Labor & Equipment Cost Analysis

Interest Rate Modeling specific to Port or Public Agency

Probabilistic Opportunity Lost or Hazard Assessment for asset management plan

Questions?