Use of Applied Probability (Risk) in Decision-Making for the Mining Industry

CSVA 2011 Conference
Toronto, Ontario
Nov 14 -16, 2011

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Introduction

Applied probability (risk) analysis:

- uncertainty and its effects
- what is risk analysis (as opposed to R.M.)?
- how does it work?
- examples
  - mine site water balance
  - underground product storage facility
  - transportation facility
- closing remarks

Note: Some information included in presentation has been modified to protect confidentiality of clients and projects and is shown for illustrative purposes only.

Introduction

Uncertainty (“what ifs”)

- health & safety
- $, reputation, environmental
- projects, agencies, corporations & other organizations can fail

Risk Management

- anticipate surprises
- optimize ultimate performance
- select “best” alternative
- satisfy regulatory agencies

Introduction

Decisions related to complex systems are extremely challenging:

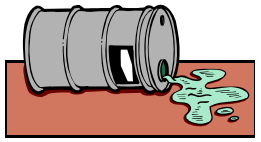
- many variables
- performance (decision) goals conflict
- opinions on importance of goals conflict
- consequences of failure can be mild or catastrophic
- eliminating all possibilities is impractical
- resources ($, t) are limited

Introduction

Complex systems demand robust decisions:

- design, construction and operation of underground nuclear waste repositories
- operation of mine tailings facilities
- management of major open-pit slopes
- construction of major transportation facilities (new highways, transit systems, etc.)

Risk Analysis – What is it?

- Description of project or system
  - logic & relationships
  - activities/components
- Definition of measures (metrics)
  - health & safety
  - money
  - time (schedule)
  - reputation
  - environment 
  - capacity

Risk Analysis – What is it?

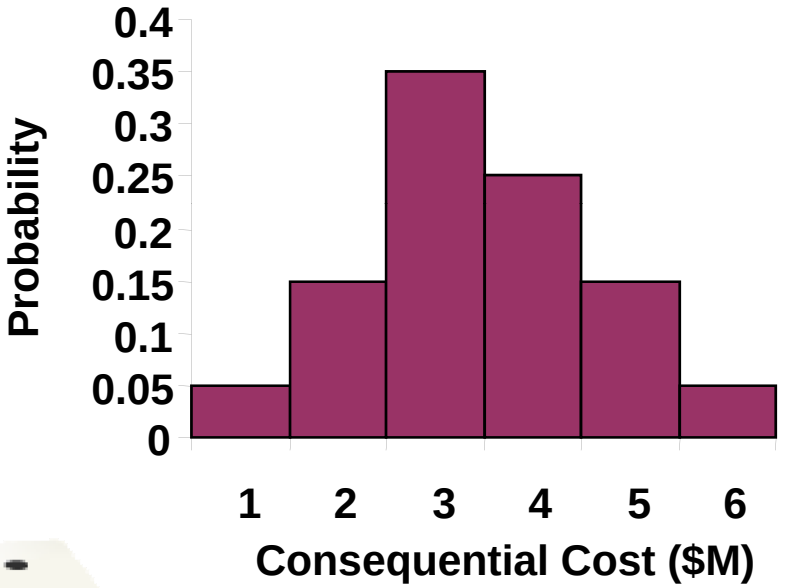
- Structured description of uncertainties
  - probability of occurrence
  - consequences according to metrics
- Mathematical simulation of project/system
  - “Monte Carlo” methods (rolling the dice thousands of times)
  - Each simulation samples risks/opportunities
- Ranking of results according to metrics
- Feeds subsequent management
  - Risk/Opportunity management
  - Value engineering

Risk Analysis – How does it work?

- Basic concepts
  - uncertainty
    - “Risk” - uncertain event, undesirable outcome (“threat”)
    - “Opportunity” - uncertain event, desirable outcome
    - Chances of event occurring x consequences if it does
  - probability (chances)
    - mathematical distribution
    - quantified ranges
    - qualitative ranges

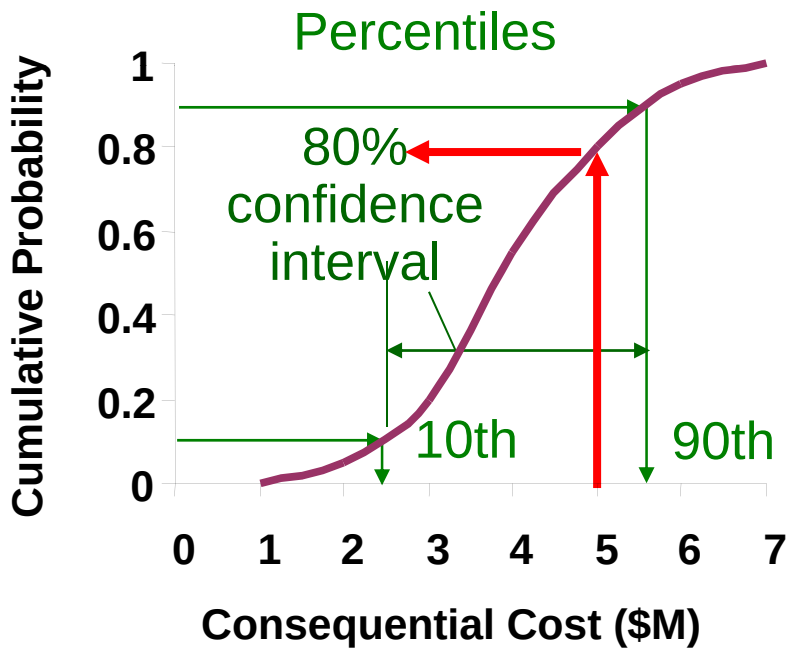
Risk Analysis – How does it work?

- Probability distributions
  - uniform
  - normal (“bell curve”)
  - triangular
  - other...



Risk Analysis – How does it work?

- Probability distribution
  - Percentiles (cumulative probability distribution)



Risk Analysis – How does it work?

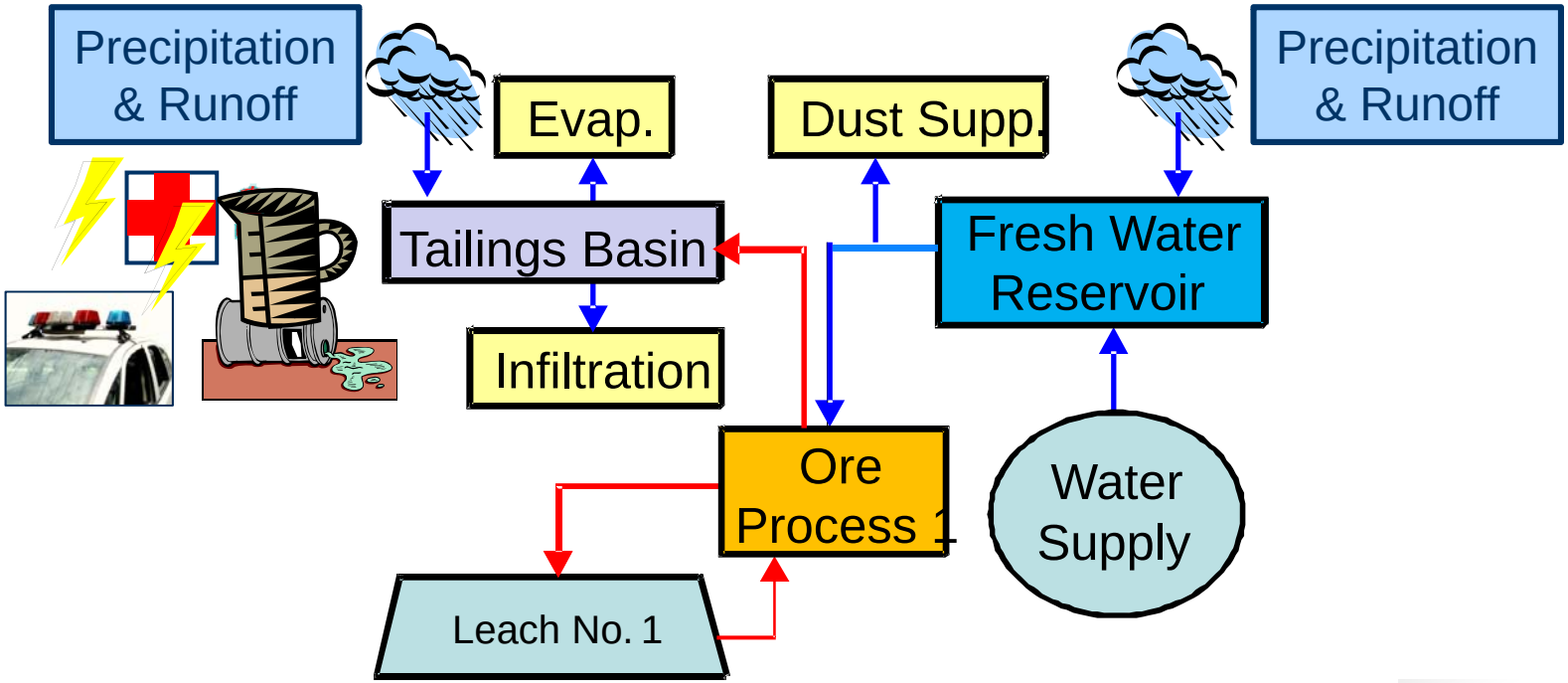
- Quantitative probability characterization
  - historical data
    - rainfall, hydrology
    - production rates
    - industry/facility failure rates
  - engineering analyses
    - reasonably known variability of input data
    - variability of geology & hydrogeology
    - variability of analysis output results based on variable input data (e.g., tailings dam stability analyses)

Risk Analysis – How does it work?

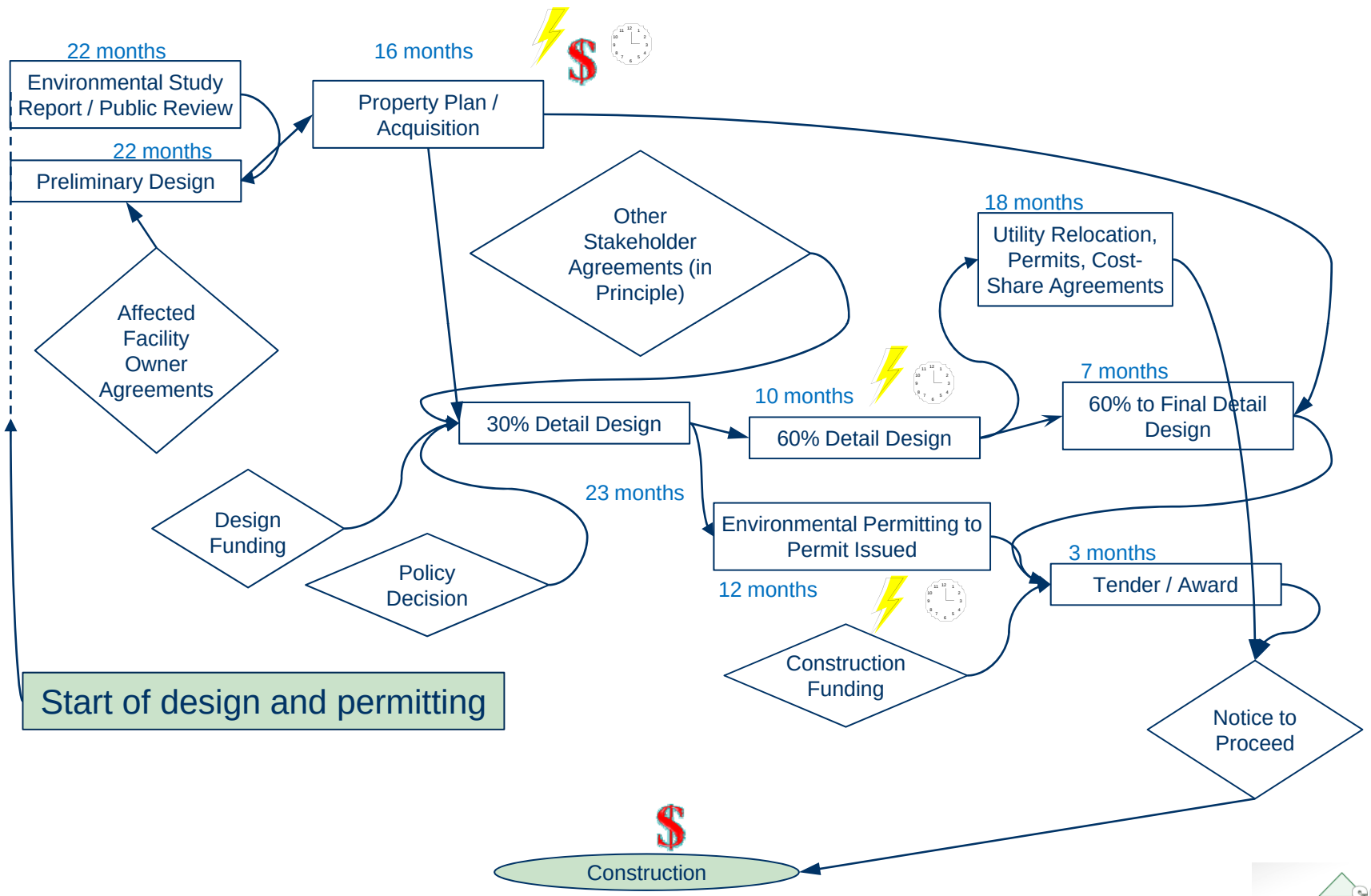
- Qualitative probability characterization
  - structured facilitation/elicitation in workshop
    - project/facility team
    - external experts
    - reasoned & seasoned judgment
    - experience on similar projects/facilities
- Semi-quantitative probability characterization
- Combined quantitative & qualitative metrics

Risk Analysis – How does it work?

- Develop schematic representation of system
  - Basic components
  - Logic diagram of how components are related



Risk Analysis – How does it work?



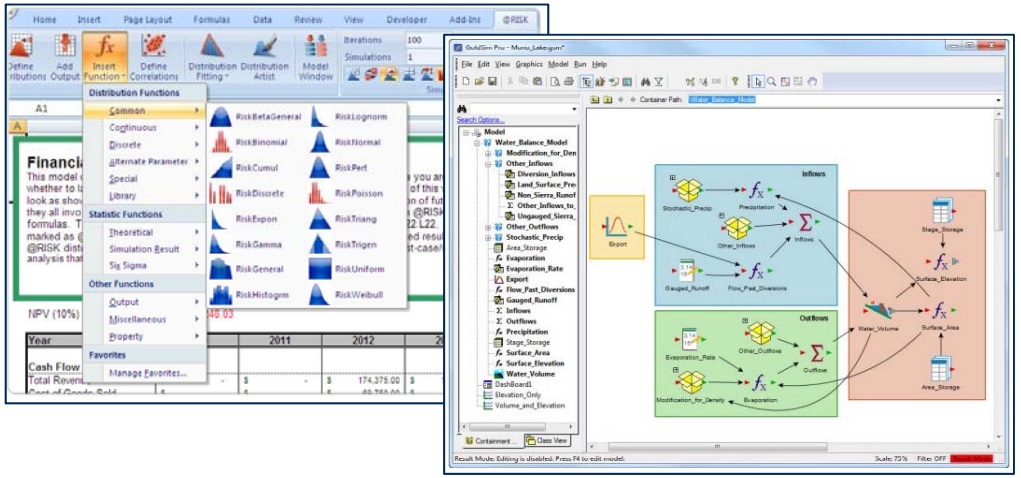
Risk Analysis – How does it work?

- Facilitated identification & characterization
  - workshop setting
  - risks and opportunities
  - independence (identify correlations or lack thereof)
  - characterize each risk by measurement metrics
  - typically captured in risk register (or annotated list)

Risk/ Opportunity Identification Number	Description	Affected Activity/ Component	Probability of Occurrence	Metric 1 ($, Millions)	Metric 2 (time, months)
C1	Foundation rock is more fractured than anticipated and additional grouting is required	Tailings dam construction	0.2	3.5	6
C2	Conveyor systems delivery delays production start date	Conveyor Installation		Minor	3
.....etc.					

Risk Analysis – How does it work?

- Simulation tools
  - Dedicated spreadsheets using logic equations & probability distribution functions
  - Spreadsheets with @RISK[1] probability distributions & “Monte Carlo” simulation functions
  - GoldSim[2] object-oriented modelling software



1. @RISK proprietary software developed by Palisade Corporation, www.palisade.com
2. GoldSim proprietary software developed by GoldSim Technology Group, www.goldsim.com

Risk Analysis – How does it work?

- Results
  - Risks ranked according to metric(s)
  - Risks can be quantified (depending on analysis)
  - Results tabulated & graphed
- Facilitate decisions
  - which risks are most important to manage
  - allocation of resources
- Measures of defensibility & rationale
- Documentation of project
- Communication tool

Risk Analysis – Applications

- Systems Analysis
- Failure Mode & Effects Analysis
- Cost & Schedule

Example of Systems Analysis

Site-Wide Water Balance of Mine

Systems Analysis - Water Balance Uncertainty

- Site-Wide Water Balance of Mine to Support Decision Making, e.g.,
  - Assess likelihood of excess or shortage of water for mine operations
  - Feasibility of mine expansion
- Evaluate alternative scenarios to address associated risks

Systems Analysis - Water Balance Uncertainty

Typical components

- Process mill
- Groundwater and surface water sources
- Tailings disposal facility
- Open pit or underground mine
- Water treatment plant
- Waste stockpiles
- Infiltration/evaporation basins
- Climate conditions (precipitation, evaporation)

Systems Analysis - Water Balance Uncertainty

Typical processes included

- Tailings consolidation
- Decant
- Seepage
- Evaporation
- Surface runoff
- Infiltration (rapid infiltration basin)
- Ore moisture
- Groundwater flow rate into open pit/ underground mine
- Treatment plant sludge production/reagent use
- Capital and operating cost for water management

Systems Analysis - Water Balance Uncertainty

Steps:

1. Develop logic model of mining site processes
2. Review with mine operators
3. Gather historical data & characterize
4. Gather technical analyses (considering uncertainties) results
5. Calibrate model

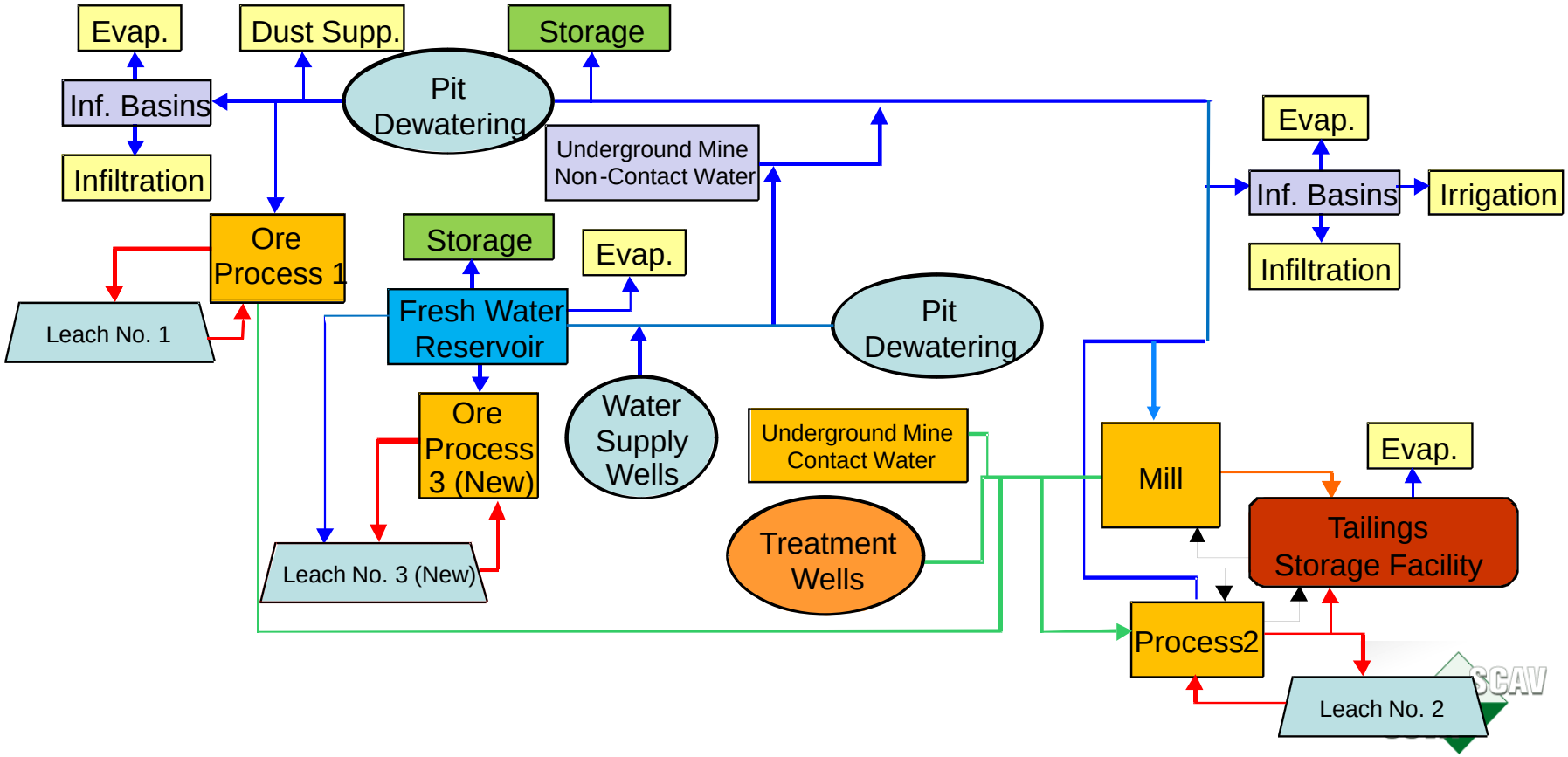
Systems Analysis - Water Balance Uncertainty

Steps:

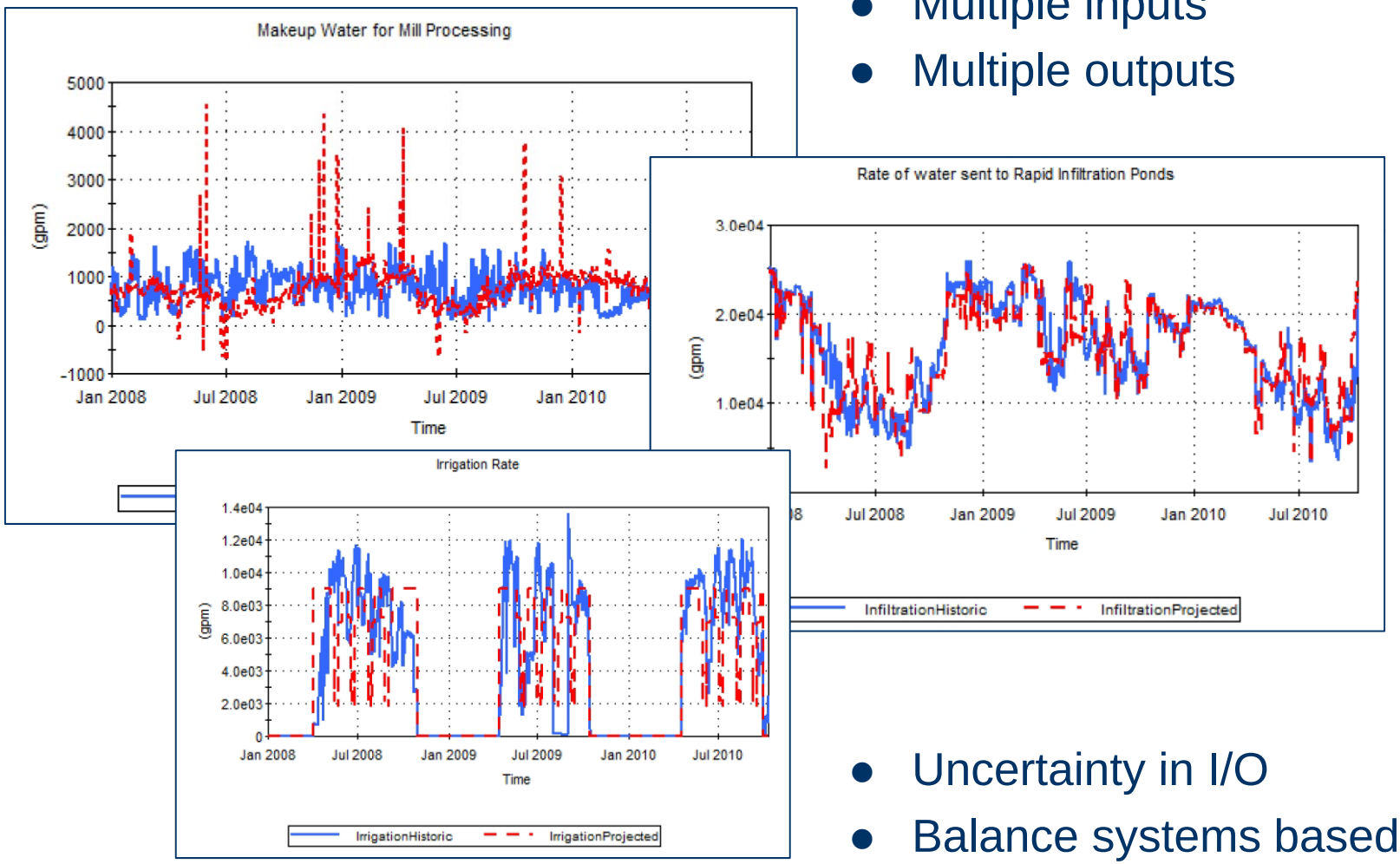
1. Complete “Monte-Carlo” simulations
2. Summarize variable output
    1. Probability distributions of component’s output for design & use planning
    2. Probability of failure (exceeding capacity)

Systems Analysis - Water Balance Uncertainty

Complex system of multiple facilities with variable use/discharge rates



Systems Analysis - Water Balance Uncertainty



- Multiple inputs
- Multiple outputs

- Uncertainty in I/O
- Balance systems based on active areas of mine site

Systems Analysis - Water Balance Uncertainty

- System Restrictions:
  - water pumping from supply wells
  - use of excess fresh water for irrigation
- Results needed for decision-making:
  - Flow rates for multiple operational scenarios
  - Estimate effects of new processing and leach facility on water use/output for storage and irrigation
  - Probability that storage capacity would be exceeded (e.g., breach of tailings impoundment)

Example of Failure Mode & Effects Analysis (FEMA)

Underground Storage Facility

FMEA – Underground Storage Facility Study

Main project elements

- Product (or byproduct) source
- Pipeline (source to site boundary)
- Wells (injection, production, abandoned, and legacy)
- Surface facilities (separators, well heads, storage tanks, etc.)
- 3rd party infrastructure (roads, adjacent facilities)
- Injection formation (inside and outside boundary)

FMEA – Underground Storage Facility Study

Main project elements (cont'd)

- Cap rock above the injection formation
- Faults and fracture networks
- Subsurface hydrocarbon zones
- Potable water aquifers
- Biosphere (root zone to tree tops)
- Atmosphere (above the tree tops)
- Surface water
- Human receptors

FMEA – Underground Storage Facility Study

Steps:

1. Convened experts and experienced facilitator
2. Agreed on analysis scope
3. Defined key metrics
4. Likelihood and consequence categories
    a. likelihood categories represent failure probability
    b. consequence categories describe effects severity if failure occurs

FMEA – Underground Storage Facility Study

5. Risk Prioritization Number (PRN) = likelihood rating ***x*** consequence rating
6. Identify possible control measures
7. Update likelihood & consequence ratings
8. Recalculate residual risk RPN
9. Document the results

FMEA – Underground Storage Facility Study

- Consequences scale – consultation with team and internal policies

	Potential Consequences			
Potential Severity		Health & Safety	Financial	Corporate Responsibility
	4 Catastrophic	Fatality(ies) Permanent Disability(ies) Multiple Lost-Time Injuries	Loss > $100M	Global loss of public trust/ social licence to operate throughout organization
	3 Severe	Lost time injury Lost time illness	Loss $50M - $100M	Loss of public trust/social licence to operate in multiple regions
	2 Moderate	Medical aid Restricted Work	Loss $5M - $50M	Loss of public trust/social licence to operate in single region
	1 Negligible	First aid	Loss < $5M	Local loss of public trust/social licence to operate

FMEA – Underground Storage Facility Study

- Likelihood scale – expert judgment-based evaluation of potential occurrence of event

Probability of Occurrence	Potential Frequency	
5 Frequent	>75%	Expected to occur several times per year
4 Probable	50-75%	Likely to occur once every several years
3 Occasional	25-50%	Likely to occur every 5 to 10 years
2 Remote	5-25%	Not likely to occur
1 Improbable	<5%	Very unlikely to occur but not impossible

FMEA – Underground Storage Facility Study

- Risk priority matrix example

RPN = Severity x Probability		Severity			
		1 Negligible	2 Moderate	3 Severe	4 Catastrophic
Probability of Occurrence	5 Frequent	(5) Medium	(10) High	(15) Unacceptable	(20) Unacceptable
	4 Probable	(4) Low	(8) Medium	(12) High	(16) Unacceptable
	3 Occasional	(3) Low	(6) Medium	(9) Medium	(12) High
	2 Remote	(2) Low	(4) Low	(6) Medium	(8) Medium
	1 Improbable	(1) Low	(2) Low	(3) Low	(4) Low

FMEA – Underground Storage Facility Study

Risks without additional controls:

- Increased heavy equipment on roads adds to driving hazards for employees and residents. H&S risk unacceptable, high risk scores for financial and social responsibility categories.
- Preferential/geologically-directional movement of product within rock resulting in risk of plume movement into nearby sites. Unacceptable H&S risks, high potential financial consequences.

RPN = Severity x Probability		Severity			
		1 Negligible	2 Moderate	3 Severe	4 Catastrophi
Probability of Occurrence	5 Frequent	(R10) release of process water from pipelines	(R3) Road damage		
	4 Probable			(R6) Product impurities	
	3 Occasional			(R20) Minor product release	
	2 Remote				
	1 Improbable				

Corporate Responsibility Results

FMEA – Underground Storage Facility Study

- Risk summary table – initial and post-control RPN rankings

Failure Mode	Control	Initial RPN	Post-Control RPN
Hazardous roadway	Regular maintenance, Restricted hours	$ - High H&S – Unacceptable CR - High	$ - Low H&S – Medium CR – Low
Product Migration	Notification/Education of adjacent landowners, Underground monitoring systems around boundary	$ - High H&S – Unacceptable CR - Medium	$ - Medium H&S – Medium CR - Medium
……etc.			

Example of Cost & Schedule Risk Analysis

Design & Construction

Design & Construction

- Major Urban Highway
  (as illustrative example because of confidentiality)
- External uncertainties
  - External influences
  - Municipalities
  - Railways
  - Environmental permitting
  - Species at Risk
- Other uncertainties
  - Cost escalation/inflation
  - Properties
  - Etc…

Design & Construction

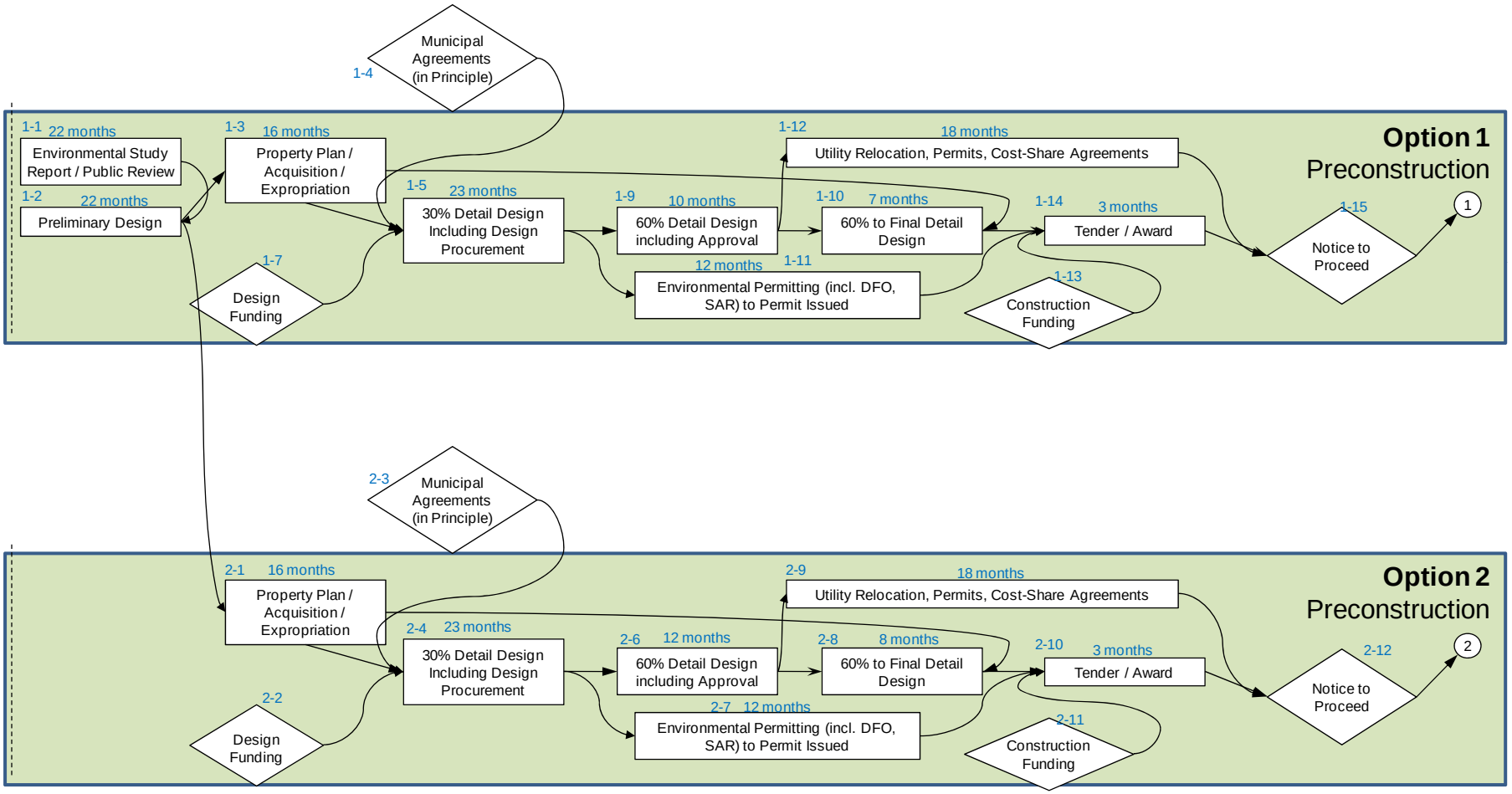
Steps:

1. Developed base (unbiased) cost & schedule estimates
2. Draft flow-chart/logic diagram
3. Convened project team, outside experts and experienced facilitator
4. Validated base cost, schedule & flow chart

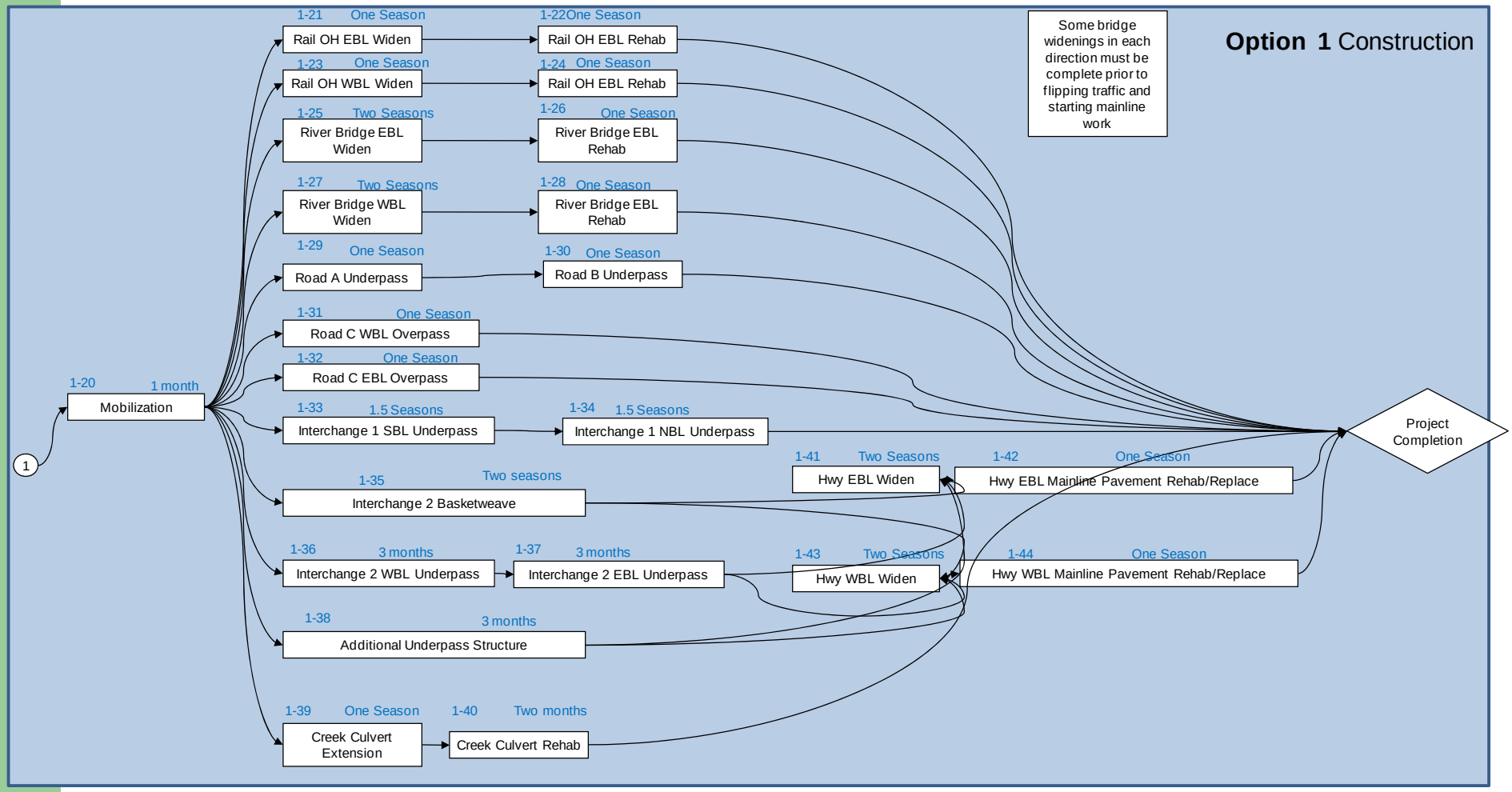
Design & Construction

1. Identified & quantified risks ($, *t*)
2. Completed “Monte-Carlo” simulations
3. Report results (draft & final)

Design & Construction



Design & Construction



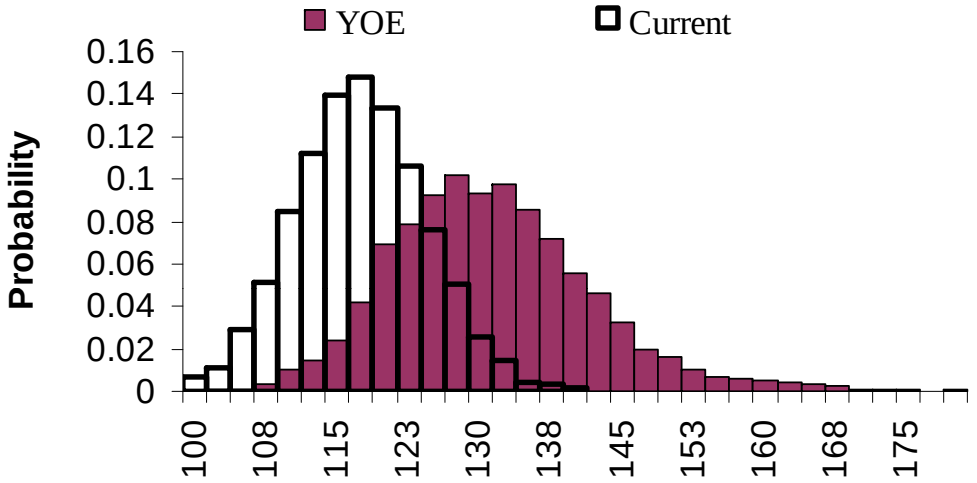
Design & Construction

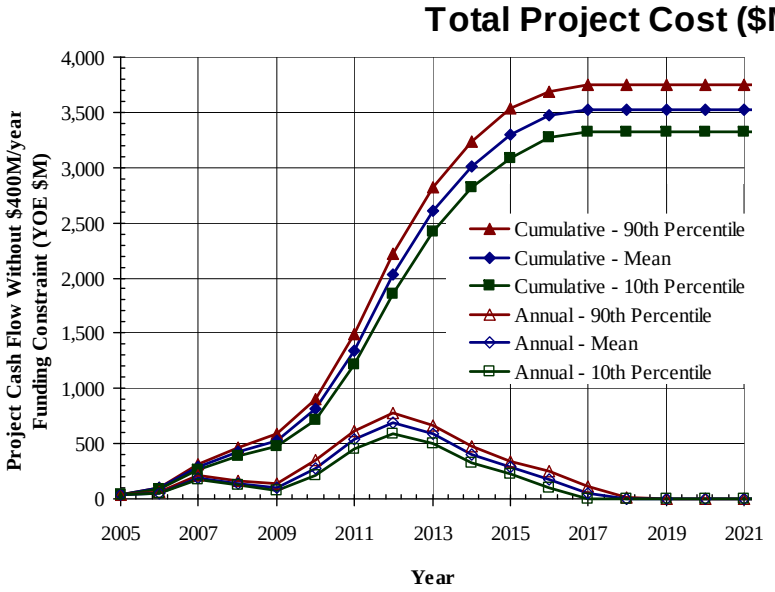
Item	Risk or Opportunity	Affected Project Activities	Probability of Occurrence	Cost Change (current $M)	Duration Change (months)
RR 2	**Clearance at Rail Structures** At rail structures clearance is very tight and survey information is preliminary. Clearance may require raising profile of road by building-up profile of existing bridges, raising new bridge elevations, or replace existing bridges. Railways could ask for additional clearance because of new work in area. A: delay to design and bridge replacement P=0.2 B: additional design changes related to falsework P=0.8 C: no change	West Project RR21 East Project 1-21, 1-23 Independently for cost, detail design for delay	A: 0.2 B: 0.8 C: 0.2	A: see new structure costing + demolition B: +0.5 C: 0	A: +6 B: +2 C: 0
RR 3	**Construction Inefficiency** Loss of productivity due to changes in allowable work schedule when working on railroad crossing bridges	West RR21 East Probability apportioned among:	0.5	Extended Overheads Only	+ 1 season to rail bridge crossing

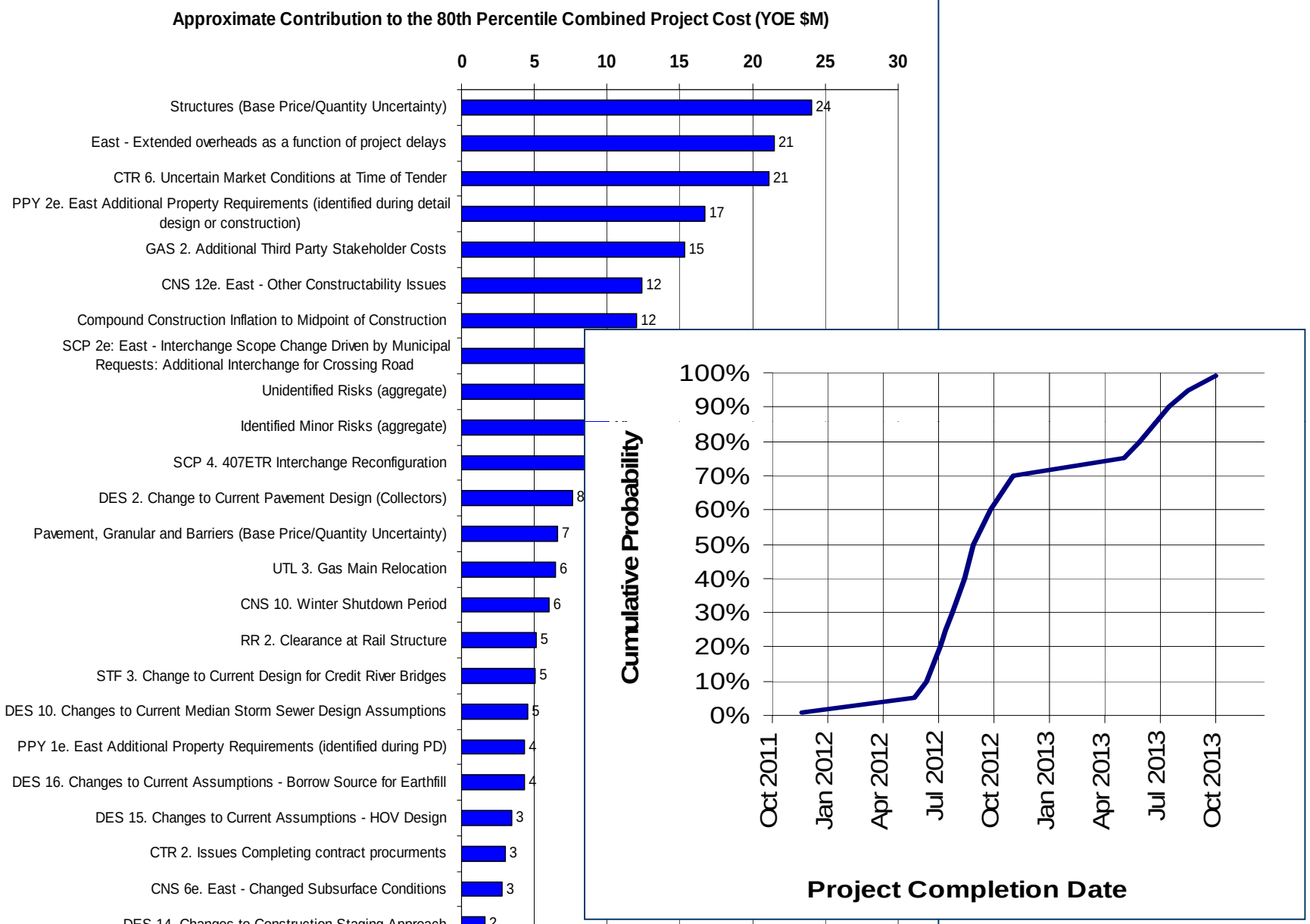
Item	Risk or Opportunity	Probability of Occurrence	Cost Change (current $M)	Duration Change (months)
ENV 2 (formerly E3)	**Matters of Provincial Importance including new Ontario Endangered Species Act, heritage features, and/or aboriginal or treaty rights influences environmental approval** Project regulation identifies the above as factors that could influence MOE minister decision. A: base (approved with no or minor conditions) B: approved with major conditions requiring only mitigation C: further studies required (delay and mitigation)	A: 60% B: 30% C: 10%	A: 0 B: less than 1% C: less than 1%	A: 0 B: 0 C: +12 To Minister approval

Design & Construction

- Ranges – chances of meeting financial/schedule targets
- Cash flow analysis






Approximate Contribution to the 80th Percentile Combined Project Cost (YOE $M)
0
5
10
15
20
25
30
Structures (Base Price/Quantity Uncertainty) 24
East - Extended overheads as a function of project delays 21
CTR 6. Uncertain Market Conditions at Time of Tender 21
PPY 2e. East Additional Property Requirements (identified during detail design or construction) 17
GAS 2. Additional Third Party Stakeholder Costs 15
CNS 12e. East - Other Constructability Issues 12
Compound Construction Inflation to Midpoint of Construction 12
SCP 2e: East - Interchange Scope Change Driven by Municipal Requests: Additional Interchange for Crossing Road
Unidentified Risks (aggregate)
Identified Minor Risks (aggregate)
SCP 4. 407ETR Interchange Reconfiguration
DES 2. Change to Current Pavement Design (Collectors) 8
Pavement, Granular and Barriers (Base Price/Quantity Uncertainty) 7
UTL 3. Gas Main Relocation 6
CNS 10. Winter Shutdown Period 6
RR 2. Clearance at Rail Structure 5
STF 3. Change to Current Design for Credit River Bridges 5
DES 10. Changes to Current Median Storm Sewer Design Assumptions 5
PPY 1e. East Additional Property Requirements (identified during PD) 4
DES 16. Changes to Current Assumptions - Borrow Source for Earthfill 4
DES 15. Changes to Current Assumptions - HOV Design 3
CTR 2. Issues Completing contract procurments 3
CNS 6e. East - Changed Subsurface Conditions 3
DES 14. Changes to Construction Staging Approach 2
Electrical (Base Price/Quantity Uncertainty) 2
Cumulative Probability
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Oct 2011
Jan 2012
Apr 2012
Jul 2012
Oct 2012
Jan 2013
Apr 2013
Jul 2013
Oct 2013
Project Completion Date

Risk Analyses for Mining Industry – Systems, FMEA, Cost/Schedule

- Water balance models
- Tailings dam failure remediation
- Underground product storage facilities
- Mine block failure
- Mine flooding
- Overall tailings management
- Nuclear waste repositories
- Mine ventilation
- Underground science laboratories
- Flood protection

Closing Remarks

- Applied probability (risk) analyses support rational decision making for complex problems
- Workshops conducted by experienced facilitators key component for success
- Methods scalable and flexible
- Applicable to many problems & industries
- Decision metrics can address competing characteristics and opinions
- Results facilitate VE, corporate communication, & public communication

Closing Remarks

QUESTIONS?

Closing Remarks

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- Other information
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- http://www.mto.gov.on.ca/english/transtek/ve/
- http://www.wsdot.wa.gov/Projects/ProjectMgmt/RiskAssessment/