

Risk Management in Underground Construction

Risk-Based Integrated Cost and Schedule Analysis

Washington D.C., 11/28/2017

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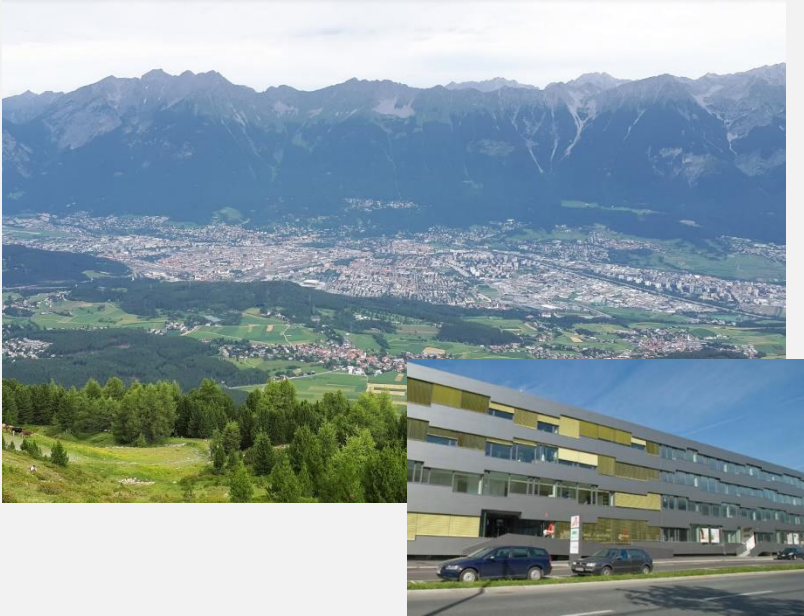
John Reilly

Olympiastr. 39 • 6020 Innsbruck • Austria
www.riskcon.at

1. Introduction

2. Considerung Uncertainties

3. Integrated Cost and Schedule Model



Olympiastr. 39, 6020 Innsbruck, Austria

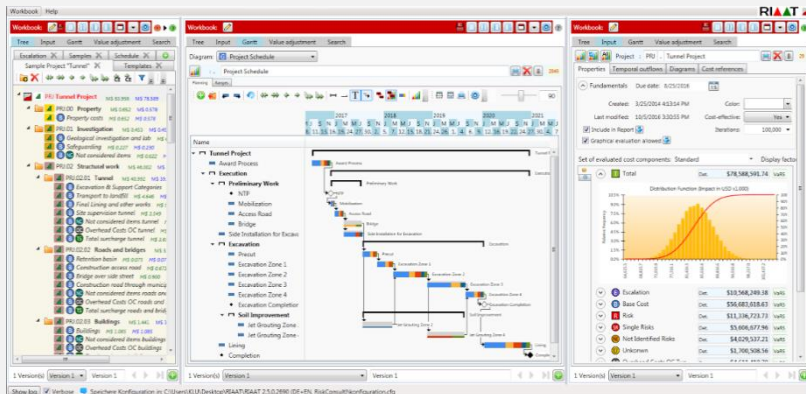
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Founded 2007

Staff: 12

Expert in Cost- and Risk Management:

- Risk Management for Infrastructure Projects
- Implementation of RM Processes
- Cost Estimation and Project Cost Control
- RAMS – Reliability, Availability, Maintainability, Safety
- Software development



Experience with major infrastructure projects in Europe, North and South America.

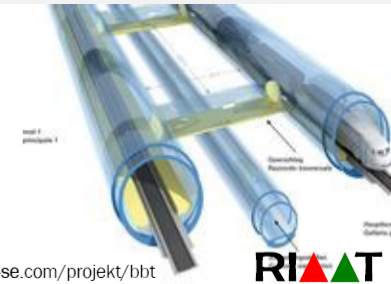


Selected Projects

Brenner Base Tunnel

The Brenner Base Tunnel is the main element of the new Brenner railway from Munich to Verona. At 64 km, it is the longest underground railway connection in the world, a pioneering work of engineering and it will markedly improve passenger travel and freight transport through the heart of Europe.

Services: Support and validation probabilistic risk assessment
Project costs: approx. \$ 12 Billion



Source: <http://www.bbt-se.com/projekt/bbt>



Subway New York: Canarsie Tunnel

New York City Transit

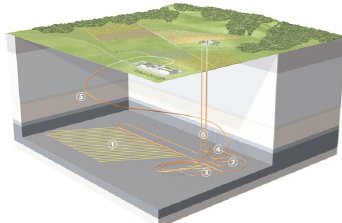
Flooding caused by Superstorm Sandy inundated the Canarsie Tunnel with seven million gallons of salt water. The rehabilitation includes upgrading of the Canarsie Tunnel facilities from 1st Avenue Station in Manhattan to Bedford Avenue Station in Brooklyn and three substations.

Service: Risk assessment, identifying and quantifying risks for project cost and schedule, quantify potential reduction in risk through mitigation.

Source: New York Times



NAGRA - Swiss National Cooperative for the Disposal of Radioactive Waste



Source: <http://www.nagra.ch/>

Safe long-term disposal of radioactive waste in deep geological repositories is a challenging task that NAGRA has committed to implementing in the interests of man and the environment.

Services: Probabilistic cost estimation and risk analysis,
software development, process development,
staff training



BMVI (German Ministry of Transportation and Digital Infrastructure)



Bundesministerium
für Verkehr und
digitale Infrastruktur

The German Ministry for Transport and Digital Infrastructure (BMVI) initiated the "Construction of Mega Projects" commission. Their task is to identify problems in the planning and construction phase of large projects and reveal reasons for cost increases and delays.

Services: Development of an integrated risk management approach in accordance with ISO 31000 and ISO 31010 for four pilot projects.

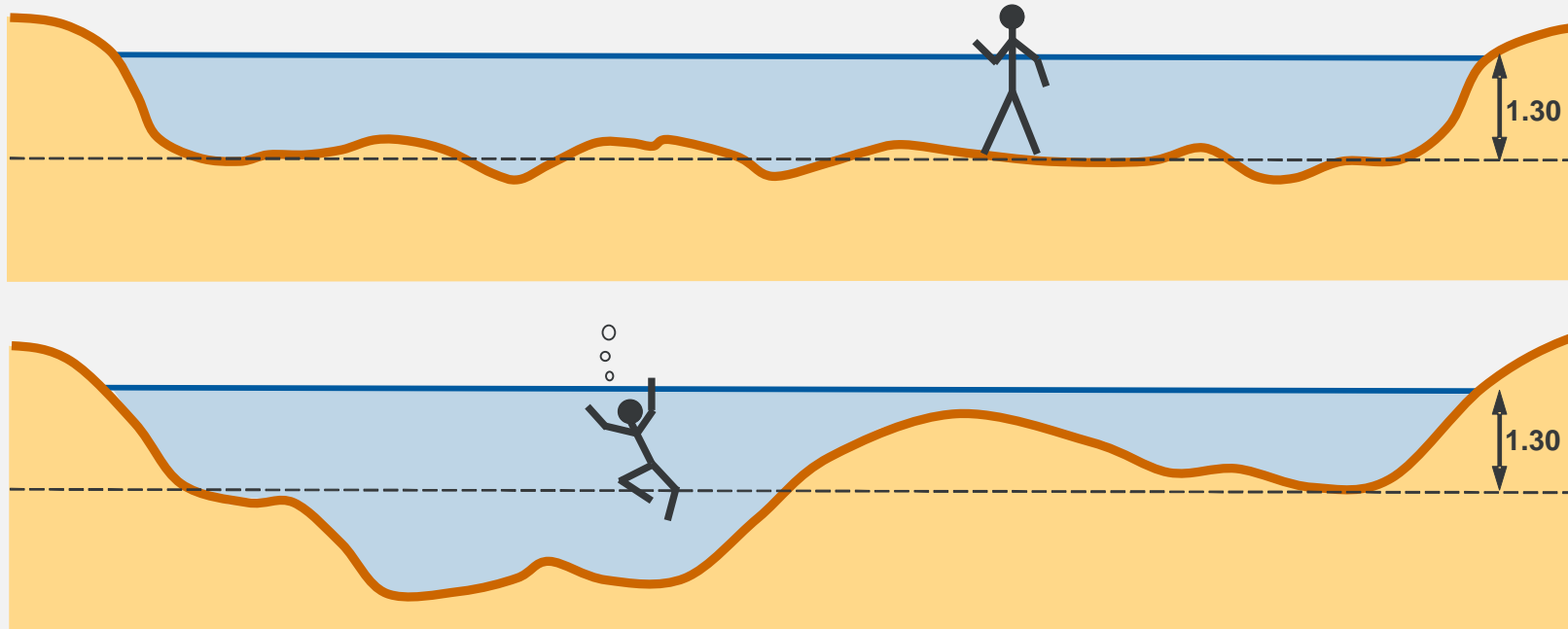


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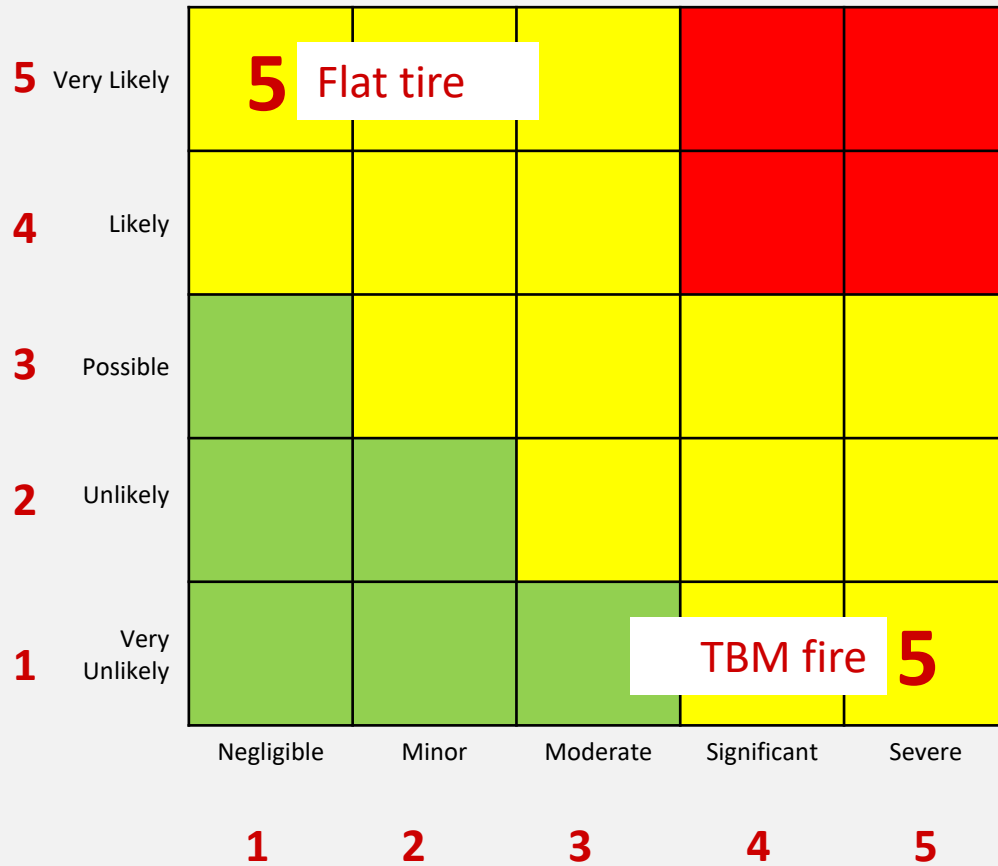
3. Integrated Cost and Schedule Model

„Would you wade through a river
1.30 meters deep on average?”



Information about uncertainty is necessary!

Fallacy of the Deterministic Approach



- Give equal weight to completely different scenarios.
- By multiplying the two elements of probability and impact, these values are no longer independent.
 - Losing the probability information
 - Losing the scenario impact information
- The actual impact will definitely deviate from the deterministic value (i.e., the mean) → see following example.

Example deterministic calculation:

Tire damage mine dumper:

$$80\% \times 10,000 \$ = 8,000 \$$$

TBM fire:

$$(1/500) \times 4,000,000 \$ = 8,000 \$$$

NPP accident:

$$(1/10,000,000) \times 80,000,000,000 \$ = 8,000 \$$$

RIAAT – Risk Administration and Analysis Tool



RIAAT is an advanced project management software, which integrates and links information from **cost management**, **risk management** and **schedule planning**.

Workbook

Tree Input Gantt Value adjustment Search

Samples X Schedule X

Sample Project "Tunnel" X Templates X Escalation X

PRJ Tunnel Project MS 83.933 MS 78.589

- PRJ.00 Property MS 0.652 MS 0.578
 - Property costs MS 0.652 MS 0.578
- PRJ.01 Investigation MS 0.453 MS 0.452
 - Geological investigation and lab MS 0.204 MS 0.200
 - Safeguarding MS 0.227 MS 0.230
 - Not considered items MS 0.022 MS 0.022
- PRJ.02 Structural work MS 45.999 MS 43.967
 - PRJ.02.01 Tunnel MS 40.987 MS 39.046
 - PRJ.02.02 Roads and bridges MS 3.571 MS 3.507
 - PRJ.02.03 Buildings MS 1.441 MS 1.415
- PRJ.03 Systems MS 8.178 MS 8.110
 - PRJ.03.01 Tunnel MS 7.874 MS 7.806
 - PRJ.03.02 Buildings MS 0.304 MS 0.304
- PRJ.06 Grounds and outside facilities MS 0.086 MS 0.086
 - Grounds and outside facilities MS 0.086 MS 0.086
- PRJ.07 Planning costs MS 3.829 MS 3.354
 - Fees for planners and services MS 3.829 MS 3.354
- PRJ.08 Other expenses MS 0.136 MS 0.136
 - Information and visitor management MS 0.136 MS 0.136
- PRJ.R Risks MS 12.686 MS 11.337
 - PRJ.R.VE Contract MS -0.248 MS 0.725
 - PRJ.R.BE Order change MS 0.000
 - PRJ.R.BG Ground risk MS 7.744 MS 6.429
 - PRJ.R. Change in Excavation&Support Categories MS 0.313 MS 0.000
 - PRJ.R.MA Market MS 0.795 MS 0.000
 - PRJ.R.FI Financing MS 0.000 MS -0.180
 - PRJ.R.PU Project context MS 0.586 MS 0.270
 - PRJ.R.IN Internal MS 0.033 MS 0.030
 - PRJ.R.VP Contracting parties MS 0.082 MS 0.362
 - PRJ.R.HG Force majeure MS 1.683 MS 1.608
 - PRJ.R.SF Project-specific special cases MS 0.000
 - PRJ.R. Design MS 0.000 MS 0.000
 - PRJ.R. Logistics MS 0.000 MS 0.000
 - Overall surcharge for non-identified risks MS 0.277 MS 0.200

1 Version(s) | Version 1 | Version 1

Workbook

Tree Input Gantt Value adjustment Search

Project : PRJ | Tunnel Project

Properties Temporal outflows Diagrams Cost references

Fundamentals Due date: 8/25/2016 1.5

Set of evaluated cost components: Main Items Display factor: 1000

Component	Det.	VarS	VarS0	VarR95
Total	\$78,588,591.74	\$72,026,656.00	\$83,933,360.00	\$95,852,360.00
Escalation	\$10,568,249.38	\$9,617,237.00	\$11,815,277.00	\$14,250,380.00
Risk	\$11,336,723.73	\$1,101,082.00	\$12,657,875.00	\$24,231,580.00
Base Cost	\$56,683,618.63	\$57,733,660.00	\$59,392,368.00	\$61,140,540.00

Distribution Function (Impact in USD x1,000)

Distribution Function (Impact in USD x1,000)

Distribution Function (Impact in USD x1,000)

1 Version(s) | Version 1 | Version 1

Further Information: <http://riaat.riskcon.at>

RIAAT – Risk Administration and Analysis Tool



RIAAT is an advanced project management software, which integrates and links information from **cost management, risk management and schedule planning.**

The image displays three screenshots of the RIAAT software interface, illustrating its capabilities in project management, risk analysis, and schedule planning.

Left Screenshot: Shows the 'Tree' view of a project structure. The project is 'Sample Project "Tunnel"'. The tree lists various tasks and risks, such as 'PRJ.R.BE Order change MS 0.000', 'PRJ.R.BG Ground risk MS 3.774 MS 2.791', and 'PRJ.R.PU Project context MS 0.586 MS 0.02'. Risks are categorized by type, such as 'Risk Extension of inner lining MS 0.798', 'Risk Mountain water inflow > 40l/s MS 0.578', and 'Risk Cave-ins > 20m³ MS 0.664 MS 0.520'.

Middle Screenshot: Shows the 'Project Schedule' Gantt chart. The chart displays the project timeline from 2017 to 2021. Key milestones include 'Mobilization', 'Access Road', 'Bridge', 'Side Installation for Excavation', 'Excavation', 'Precut', 'Excavation Zone 1', 'Excavation Zone 2', 'Excavation Zone 3', 'Excavation Zone 4', 'Soil Improvermer', 'Jet Grouting Z', 'Lining', and 'Completion'. The chart shows the duration of each task and the overall project completion date.

Right Screenshot: Shows the 'Risk Analysis' view. It displays a table of risks with their respective VaR (Value at Risk) and VaR95 (95th percentile) values. The table includes columns for 'Min./Max. VaR', 'VaR', 'Visible', 'Sorting', and 'VaR5 - VaR95'. The risks are sorted by their VaR values, and the table shows the distribution of risks across different VaR levels. For example, the top risk is 'Risk Natural' with a VaR of 3.01 d and a VaR95 of 67.73 d.

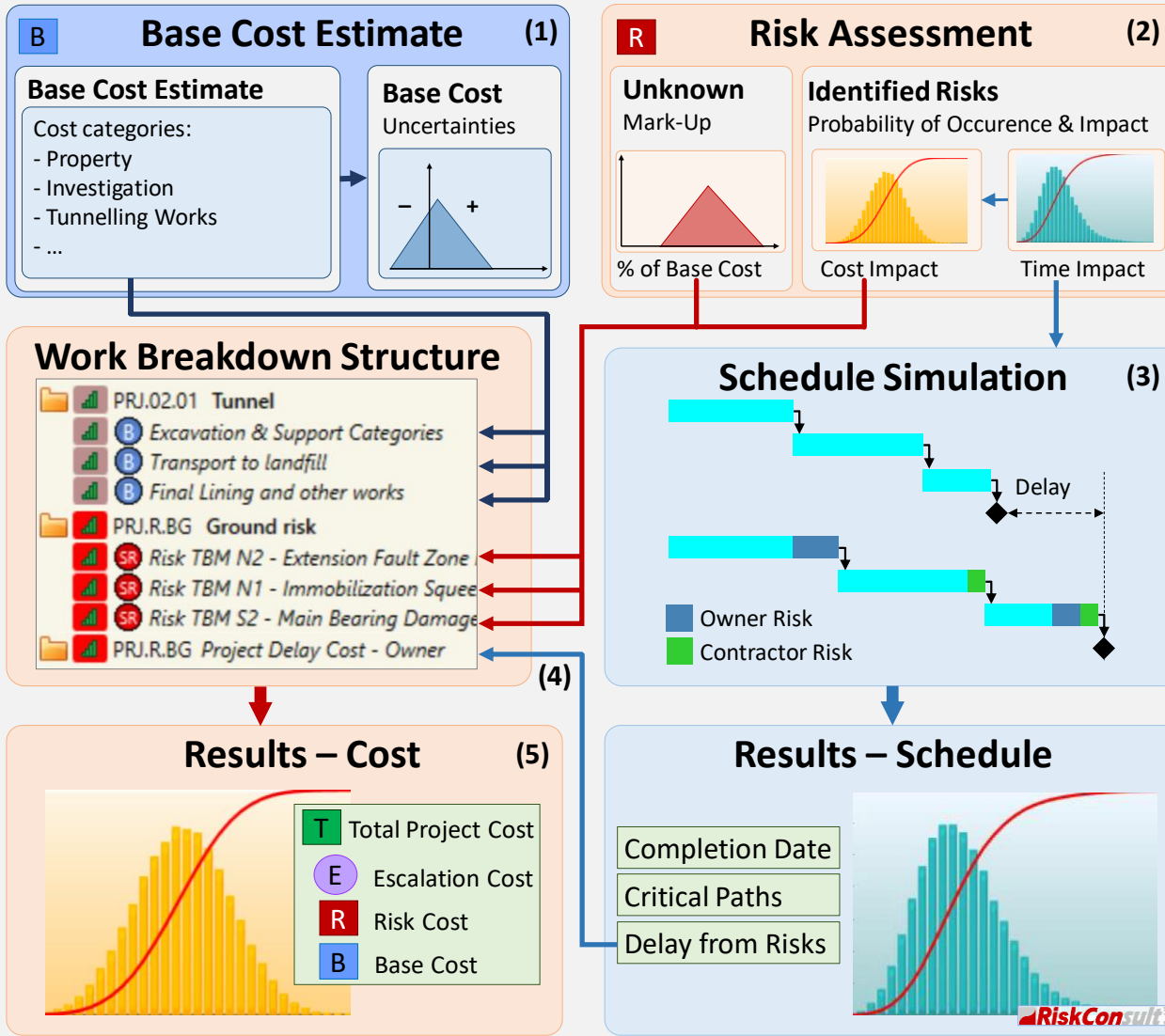
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Integrated Cost and Schedule Analysis



(1) Base cost estimate is reviewed, associated with uncertainties and integrated into the WBS.

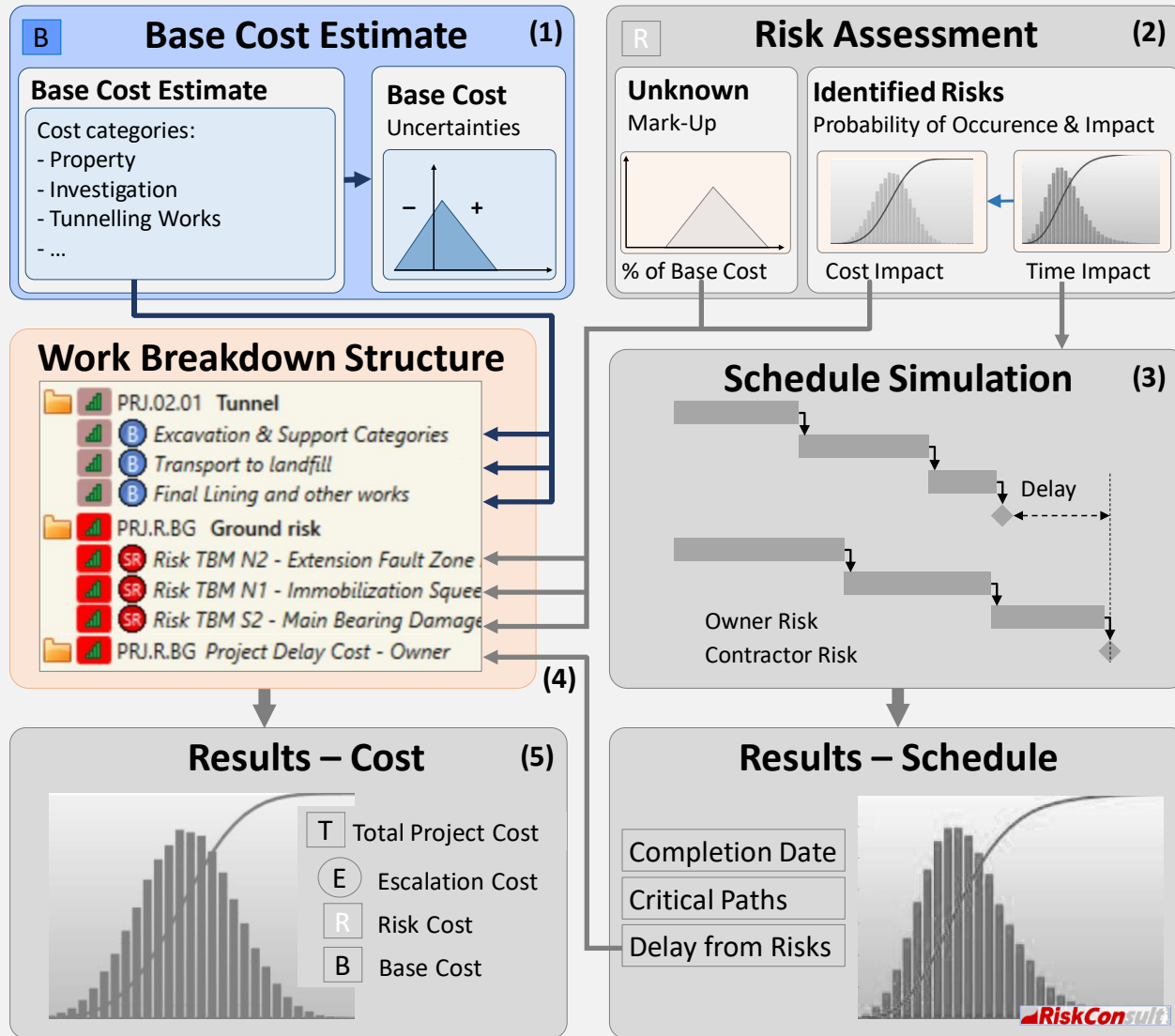
(2) Risks are assessed (cost & time impact) and integrated into the WBS.

(3) Risks are assigned to tasks in the project's schedule. Subsequently, completion date, critical paths and delays from risks are simulated.

(4) Cost impact from time delay is calculated with time-related cost and integrated into the WBS.

(5) Project Cost including uncertainty is available on all WBS levels and for all cost components.

Integrated Cost and Schedule Analysis



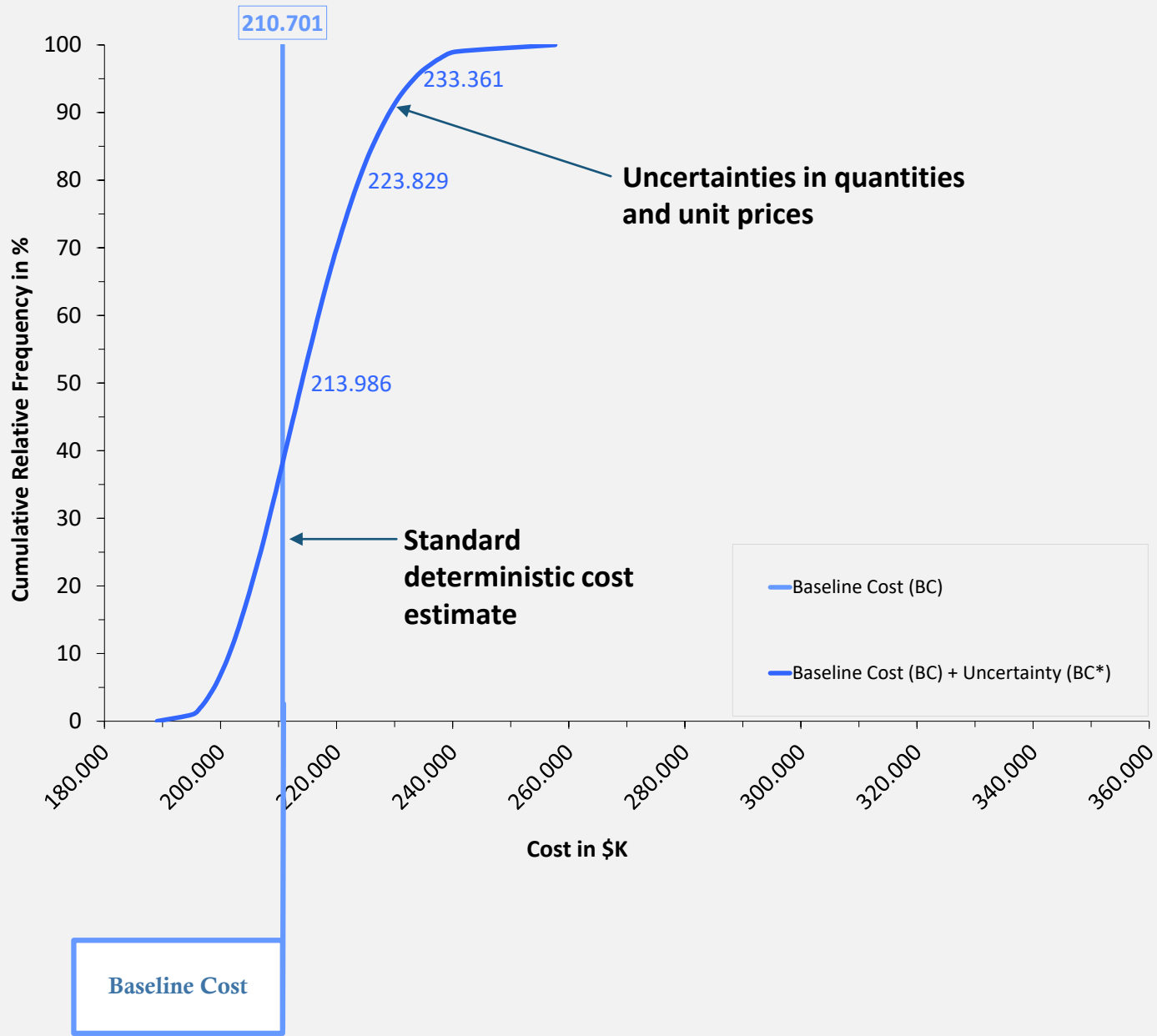
Example – Cost Estimate Concrete Works

Triangle

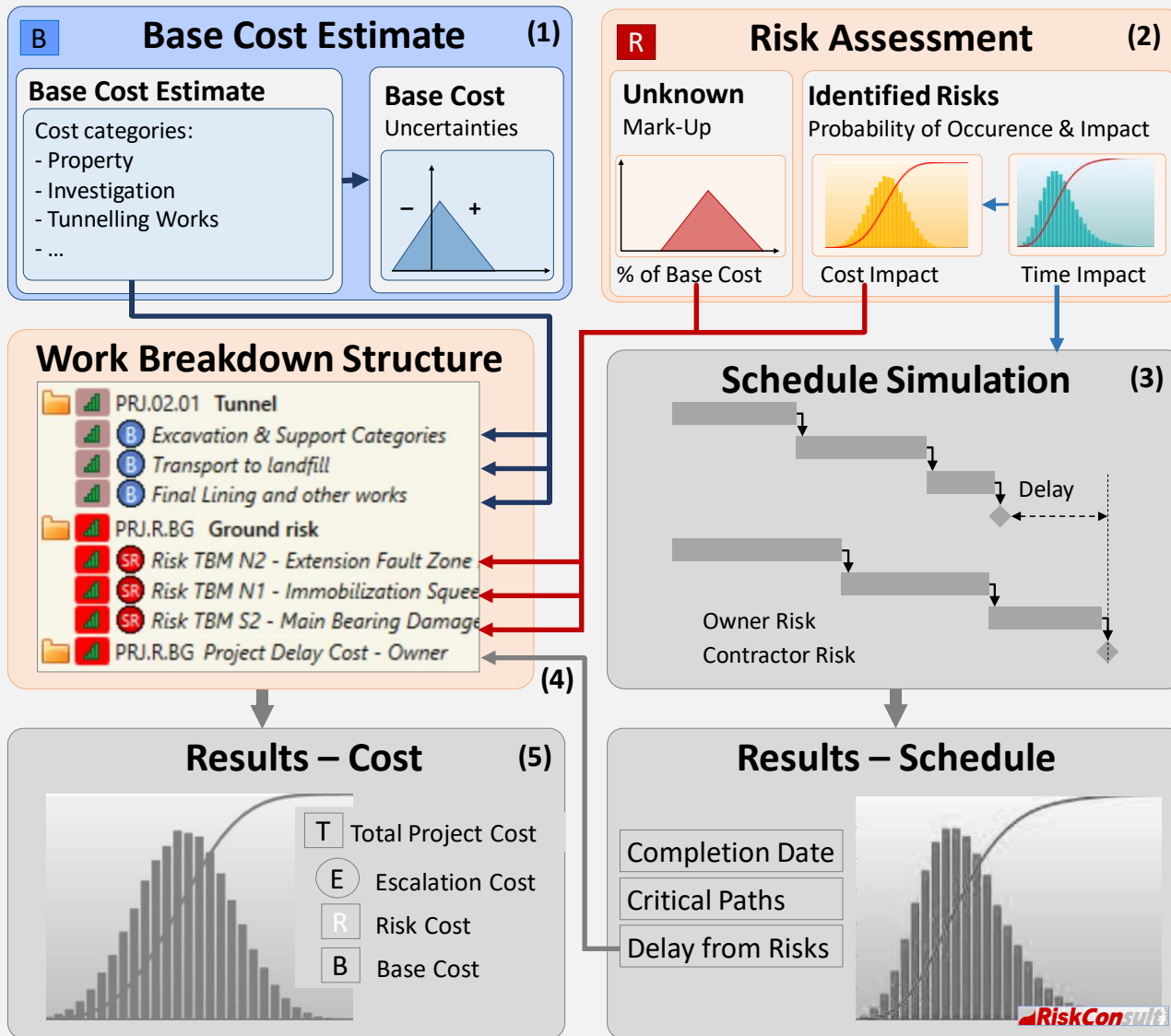
Triangle

Description	Quantity					Unit Price				Item Price USD
	Dist.	Min	ML	Max	Unit	Dist.	Min	ML	Max	
Concrete works										7,386,283.30
Concrete Tower Floor	Triangle	210.700	215.000	221.450	m ³	Triangle	101.85	105.00	115.50	22,575.00
Reinforcement Tower Floor	Triangle	51,049.200	53,736.000	59,109.600	kg	Triangle	1.04	1.15	1.32	61,796.40
Concrete Newsroom	Triangle	78.400	80.000	84.000	m ³	Triangle	94.50	105.00	115.50	8,400.00
Reinforcement Newsroom	Triangle	19,150.100	20,158.000	22,173.800	kg	Triangle	1.04	1.15	1.23	23,181.70
Concrete Basement	Triangle	77.126	78.700	82.635	m ³	Triangle	101.85	105.00	115.50	8,263.50
Reinforcement Basement	Triangle	18,696.950	19,681.000	21,649.100	kg	Triangle	1.12	1.15	1.26	22,633.15
Concrete Walls	Triangle	5,355.700	5,465.000	5,738.250	m ³	Triangle	346.70	361.15	390.04	1,973,684.75
Reinforcement Walls	Triangle	519,206.350	546,533.000	601,186.300	kg	Triangle	1.10	1.15	1.23	628,512.95
Concrete Slabs	Triangle	9,122.820	9,309.000	9,774.450	m ³	Triangle	220.80	230.00	248.40	2,141,070.00
Reinforcement Slabs	Triangle	1,072,502.500	1,128,950.000	1,241,845.000	kg	Triangle	1.10	1.15	1.23	1,298,292.50
Concrete Base Slab	Triangle	3,608.360	3,682.000	3,866.100	m ³	Triangle	220.80	230.00	248.40	846,860.00
Reinforcement Base Slab	Triangle	289,967.550	305,229.000	335,751.900	kg	Triangle	1.10	1.15	1.23	351,013.35

Uncertainty Baseline Cost



Integrated Cost and Schedule Analysis

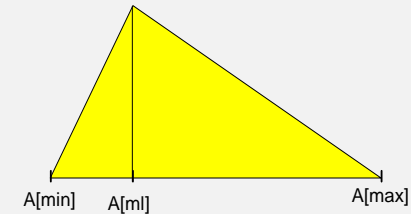


Probability of occurrence (%) or expected occurrence rate (multiple occurring risks)

Impact (cost and time)

3-Point Estimate

- Reality can be described much better with bandwidths than with single numbers
- Triangle function is easy to understand
- More complex modeling is possible at any point in the process



#	Identified Risk	Probability of Occurrence	Rate of Occurrence	cost impact (USD x 1000)			time impact (d)		
				best	most likely	worst	best	most likely	worst
1	TBM S2 - Main Bearing Damage	20%	-	1000	2000	3000	90	180	400
2	TBM N1 - Change in Exc.&Sup. Categ.	70%	-	500	3000	4500	20	120	180
3	TBM N1 - Immobilization Squeezing	25%	-	1500	3000	5000	60	120	200
4	Contractor Appeal	50%	-	-	-	-	30	90	180
5	No Release of Design	30%	-	225	900	1350	30	120	180
6	TBM N - Delay installation	25%	-	400	1200	2000	20	60	100
7	Extension Fault zone km 2.0	80%	-	0	840	1660	0	42	83
8	TBM S2 - Extension of inner lining	-	3	150	200	250	5	10	20
9	Logistic Problems Crosscut S (13-25)	30%	-	150	375	600	20	50	80
10	CC N - Mountain water inflow >40l/s	-	3	222	886	1782	1	3	14

Integrated Cost and Schedule Analysis

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Workbook Help

Workbook: [Tree Input Gantt Value adjustment]

Tree Input Gantt Value adjustment

Sample Project "Tunnel" X Templates X Escalation X Samples X Schedule X

Information and visitor management MS 67.360 MS 59.911

Risks MS 67.360 MS 59.911

Contract MS -3.896 MS 0.725

Missing/canceled work items MS 0.248 MS 0.476

Risk Contaminated excavation material deviating from cost estimation MS 0.000

Risk Sediment quality water protection facility MS 0.000 MS 0.325

Quantity variance MS -4.623 MS 0.000

Risk Quantity variance MS -4.623 MS 0.000

Tender/Contract Award MS 0.000 MS 0.000

Contractor Appeal MS 0.000 MS 0.000

System and process optimization MS 0.000 MS -0.037

Risk Reduced costs through use of milling machine MS 0.000 MS -0.030

Risk Optimizing standard Profile MS 0.000 MS -0.007

System and process changes MS 0.000

Adherence to regulatory/external requirements MS 0.182 MS 0.286

Risk Exceeding permissible noise limits MS 0.036 MS 0.207

Risk Additional access road to rescue area MS 0.000 MS 0.079

Order change MS 0.000

Ground risk MS 7.811 MS 6.048

Risk TBM N2 - Extension Fault Zone km 2.0 MS 0.000 MS 0.000

Risk TBM N1 - Extension Fault Zone km 2.0 MS 0.000 MS 0.000

Risk TBM N2 - Immobilization Squeezing Ground MS 0.000 MS 0.000

Risk TBM N1 - Immobilization Squeezing Ground MS 0.000 MS 0.000

Risk TBM S2 - Main Bearing Damage MS 0.000 MS 0.400

Risk TBM S1 - Main Bearing Damage MS 0.000 MS 0.400

Risk TBM S2 - Extension of inner lining MS 0.586 MS 0.600

Risk TBM S1 - Extension of inner lining MS 0.000 MS 0.981

Risk TBM N2 - Mountain water inflow > 40L/s MS 1.504 MS 0.820

Risk TBM N1 - Mountain water inflow > 40L/s MS 1.507 MS 0.820

Risk CC N - Mountain water inflow > 40L/s MS 0.886 MS 0.492

Risk Cave-ins of 5m³ to 20m³ MS 0.578 MS 0.505

Risk Cave-ins > 20m³ MS 0.664 MS 0.510

Risk Sinkholes MS 0.000 MS 0.427

Risk Fault zones MS 0.000 MS 0.011

Risk Contaminated ground MS 0.150 MS 0.083

Change in Excavation&Support Categories MS 0.313 MS 0.000

AS - Change in Excavation & Support Categories MS 0.000 MS 0.000

D&B S1 - Change in Excavation & Support Categories MS 0.000 MS 0.000

D&B S2 - Change in Excavation & Support Categories MS 0.000 MS 0.000

TBM S1 - Change in Excavation & Support Categories MS 0.000 MS 0.000

TBM S2 - Change in Excavation & Support Categories MS 0.000 MS 0.000

TBM N1 - Change in Excavation & Support Categories MS 0.000 MS 0.000

TBM N2 - Change in Excavation & Support Categories MS 0.000 MS 0.000

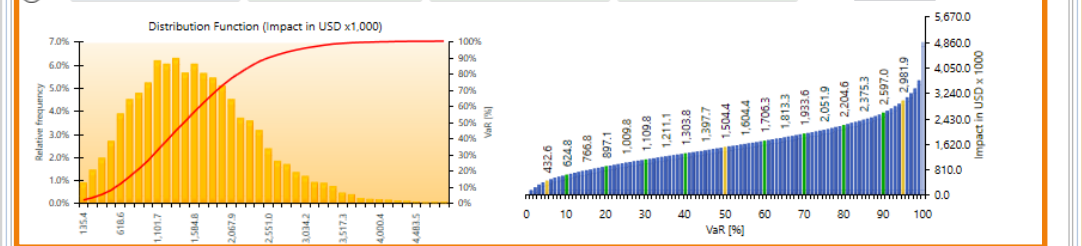
Workbook: [Tree Input Gantt Value adjustment]

Tree Input Gantt Value adjustment

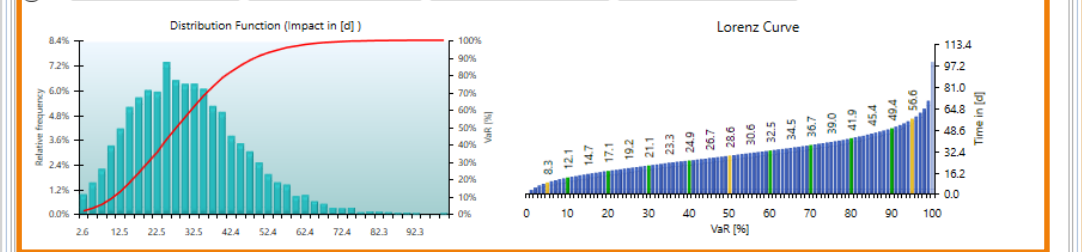
Cost element : Risk TBM N2 - Mountain water inflow > 40L/s 2450

Properties Calculation Temporal outflow Diagrams References Risk Fact Sheet

Det. \$820,000.00 VaRS \$432,603.19 VaR50 \$1,504,445.75 VaR95 \$2,981,915.00 Factor 1000



Det. 15.00 d VaRS 8.31 d VaR50 28.64 d VaR95 56.58 d

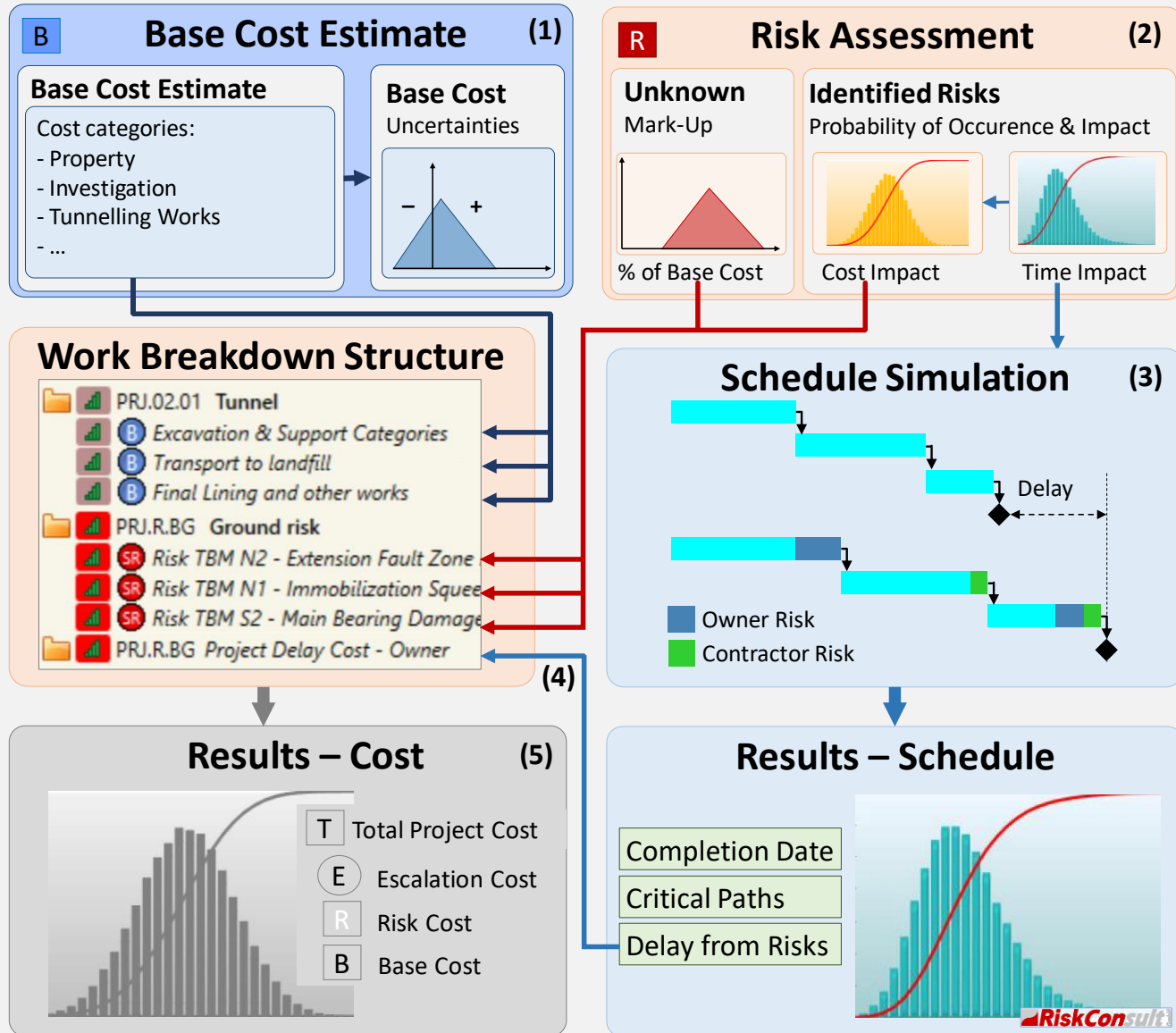


Probability of Occurrence 5 Zeroize negative fractiles

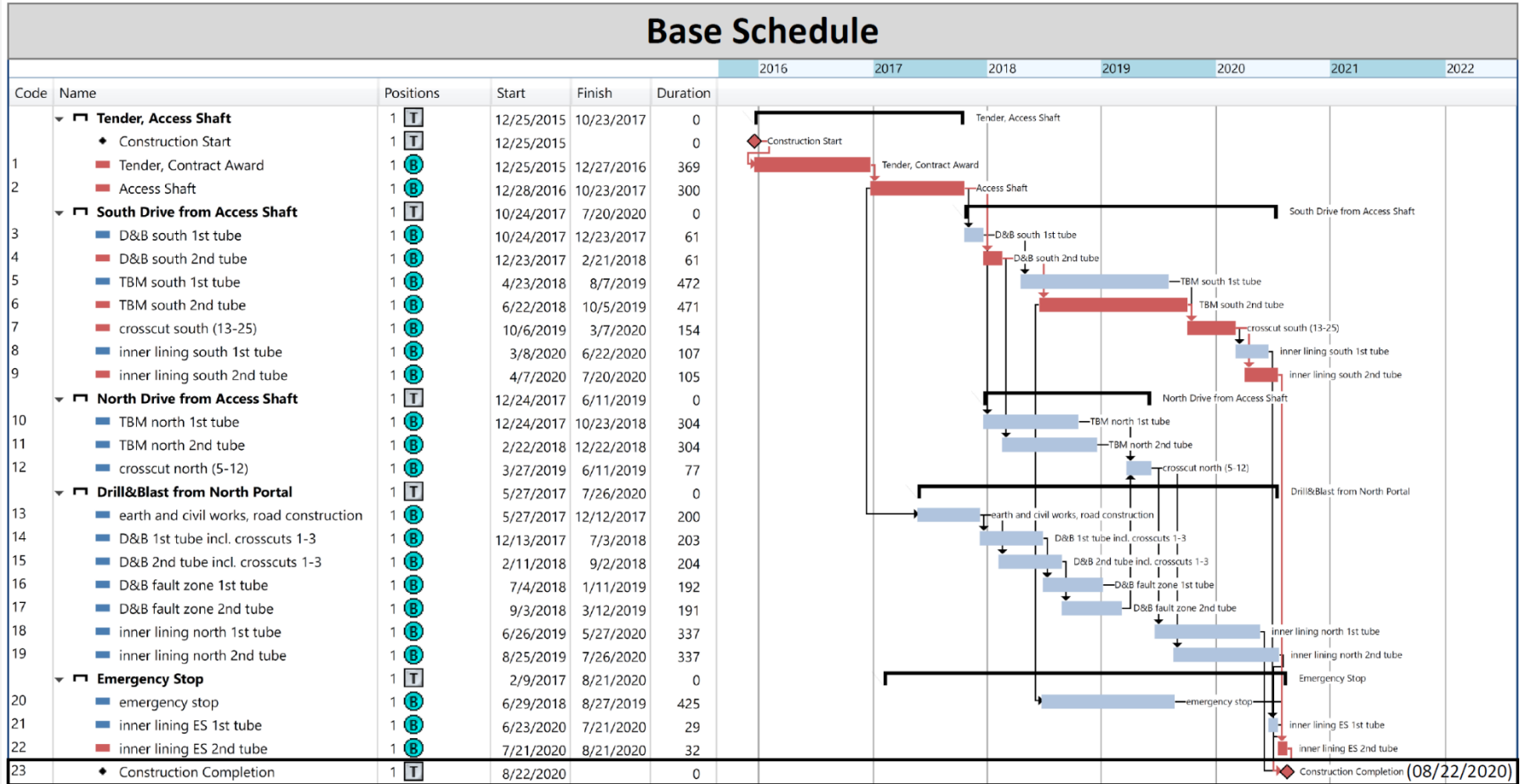
Subcomponent (4 positions)

Subcomponent	Quantities	VaR50	Det.	VaR95
Mountain water inflow	100.00 %	\$292,134.94	\$164,000.00	2451
001 Time-related costs	100.00 %	\$199,113.83	\$105,000.00	2452
002 Labor costs	100.00 %	\$73,996.52	\$39,000.00	2453
003 Material	100.00 %	\$18,693.13	\$20,000.00	2454
004 Delay in construction	100.00 %	5.54 d	3.00 d	2455

Integrated Cost and Schedule Analysis



Base Schedule



Schedule Density: the need to schedule at an appropriate level of detail based on the contemporary knowledge available to the project team.

➔ Condense large schedules to restore the overview!

Assign Risk to Schedule Activities

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 Workbook Help

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Tree Input Gantt Value adjustment

Sample Project "Tunnel" X Templates X Escalation X Samples X Schedule X

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 - Order change MS 0.000
 - Ground risk MS 7.811 MS 6.048
 - Risk TBM N2 - Extension Fault Zone km 2.0 MS 0.000 MS 0.000
 - Risk TBM N1 - Extension Fault Zone km 2.0 MS 0.000 MS 0.000
 - Risk TBM N2 - Immobilization Squeezing Ground MS 0.000 MS 0.000
 - Risk TBM N1 - Immobilization Squeezing Ground MS 0.000 MS 0.000
 - Risk TBM S2 - Main Bearing Damage MS 0.000 MS 0.400
 - Risk TBM S1 - Main Bearing Damage MS 0.000 MS 0.400
 - Risk TBM S2 - Extension of inner lining MS 0.586 MS 0.600
 - Risk TBM S1 - Extension of inner lining MS 0.000 MS 0.981
 - Risk TBM N2 - Mountain water inflow > 40l/s MS 1.504 MS 0.820
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 - Risk Sinkholes MS 0.000 MS 0.427
 - Risk Fault zones MS 0.000 MS 0.011
 - Risk Contaminated ground MS 0.150 MS 0.083
 - Change in Excavation & Support Categories MS 0.313 MS 0.000
 - AS - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - D&B S1 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - D&B S2 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - TBM S1 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - TBM S2 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - TBM N1 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - TBM N2 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - D&B N1 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - D&B N2 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - D&B F1 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - D&B F2 - Change in Excavation & Support Categories MS 0.000 MS 0.000
 - ES - Change in Excavation & Support Categories MS 0.000 MS 0.000

Tree Input Gantt Value adjustment

Diagram: Schedule+links, uncertainties

Planning Ranges

Schedule+links, uncertainties, risks

Code	Name	Start	Duration
10	North Drive from Access Shaft	4/24/2018	584
10	TBM north 1st tube	4/24/2018	448
11	TBM north 2nd tube	6/23/2018	357
12	crosscut north (5-12)	8/29/2019	92
13	Drill&Blast from North Portal	7/11/2017	1,282
13	earth and civil works, road construction	7/11/2017	200
14	D&B 1st tube incl. cross	1/27/2019	230
15	D&B 2nd tube incl. cross	3/28/2018	222
16	D&B fault zone 1st tube	9/14/2018	284
17	D&B fault zone 2nd tube	11/5/2018	283
18	inner lining north 1st tub	12/13/2019	337
19	inner lining north 2nd tub	2/11/2020	337
20	Emergency Stop	10/28/2018	887
20	emergency stop	10/28/2018	429
21	inner lining ES 1st tube	1/2/2021	29
22	inner lining ES 2nd tube	3/1/2021	32

General Duration Links Milestone

Total duration Det: 448.00 d | VaRS: 328.93 d | VaR50: 457.17 d | VaR95: 621.38 d

Distribution Function (Impact in [d])

Lorenz Curve

Baseline Time	Uncertainty	Owner
304.00 d	0.00 d	Owner
30.00 d	15.00 d	Owner
15.00 d	84.00 d	Owner
15.00 d	15.00 d	Contractor

Baseline Time 304.00

Uncertainty 0.00 d 100.00 % -20.00 0.00 40.00

Owner 30.00 d 0.00 d 0.00 d 152.70 d from Risk TBM N1 - Immobilization Squeezing Ground 2436 Risk Owner

Owner 15.00 d 8.02 d 28.59 d 56.27 d from Risk TBM N1 - Mountain water inflow > 40l/s 2444 Risk Owner

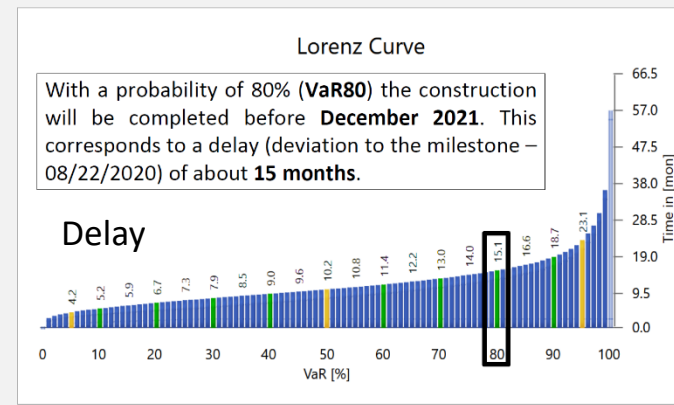
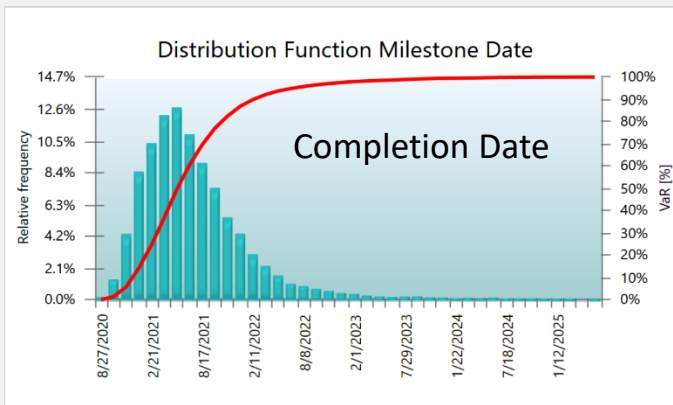
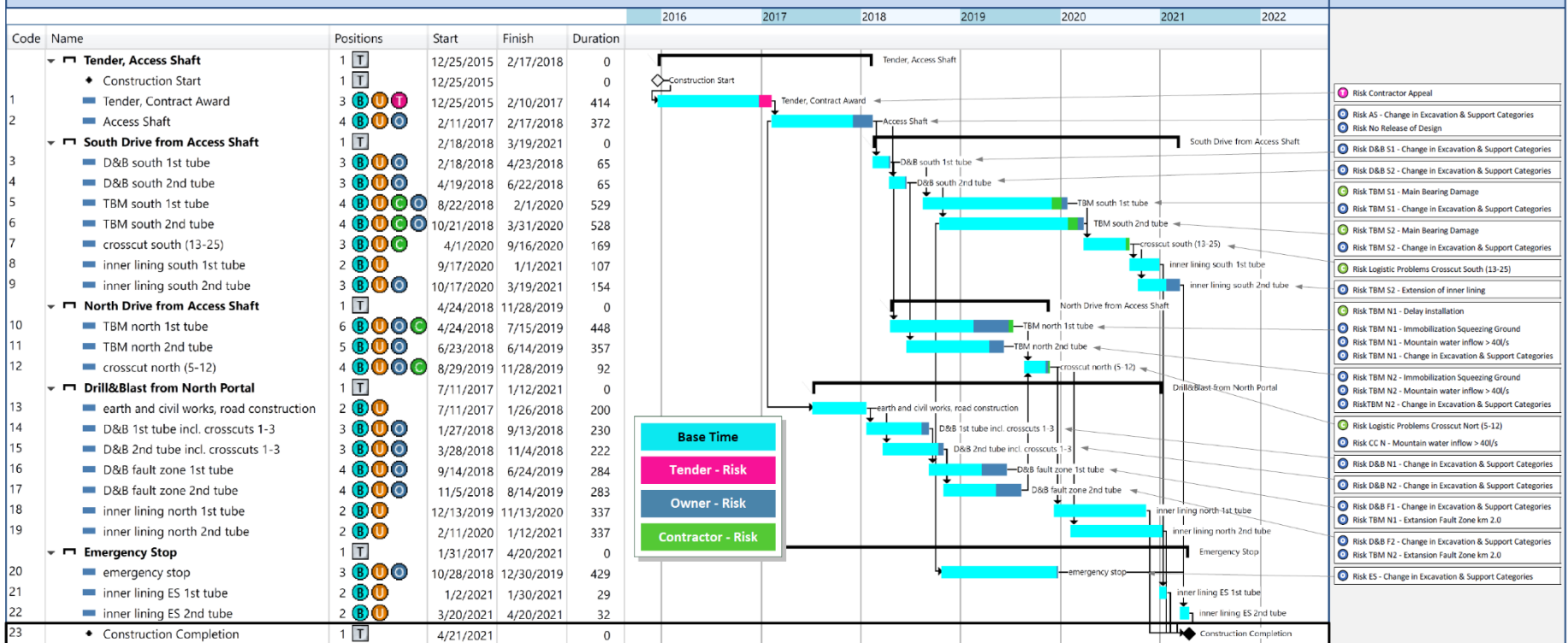
Owner 84.00 d 0.00 d 87.61 d 153.82 d from TBM N1 - Change in Excavation & Support Categories 2359 Risk Owner

Contractor 15.00 d 0.00 d 0.00 d 74.71 d from Risk TBM N1 - Delay installation 2424 Risk Contractor

Base Schedule with Assigned Risks

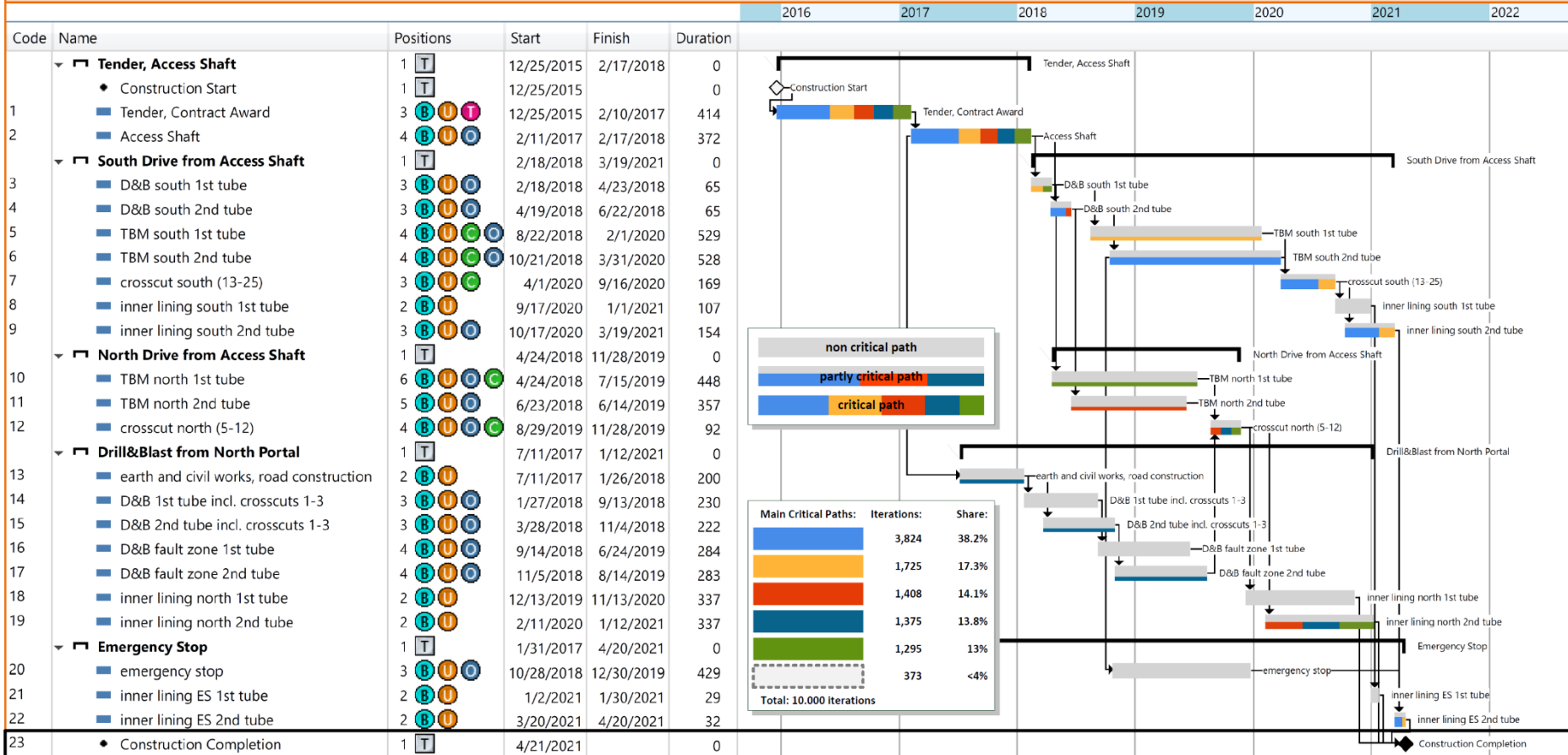
Base Schedule with Assigned Risks

Assigned Risks



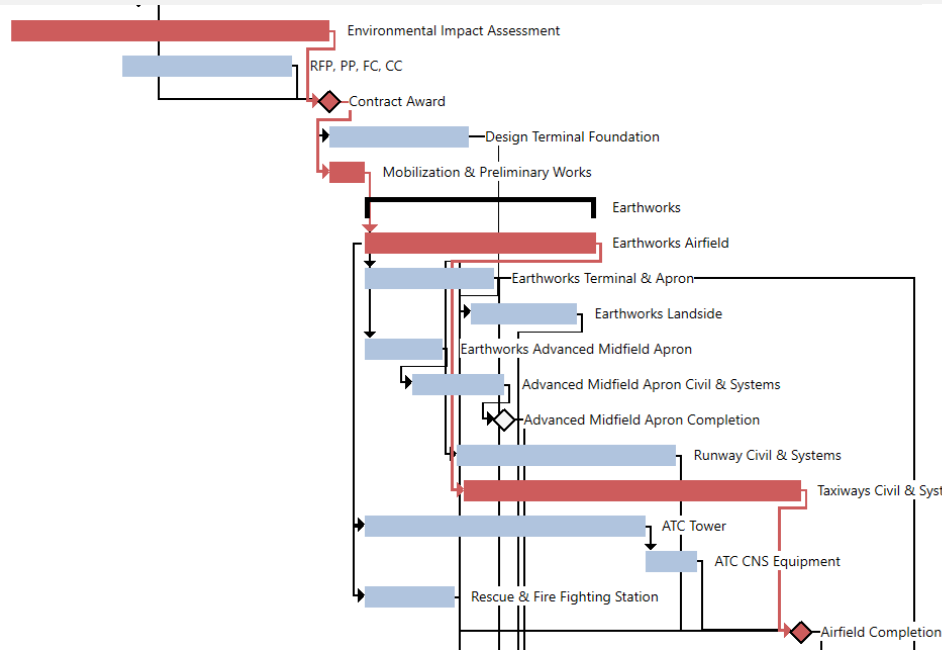
Critical Paths View

Critical Paths

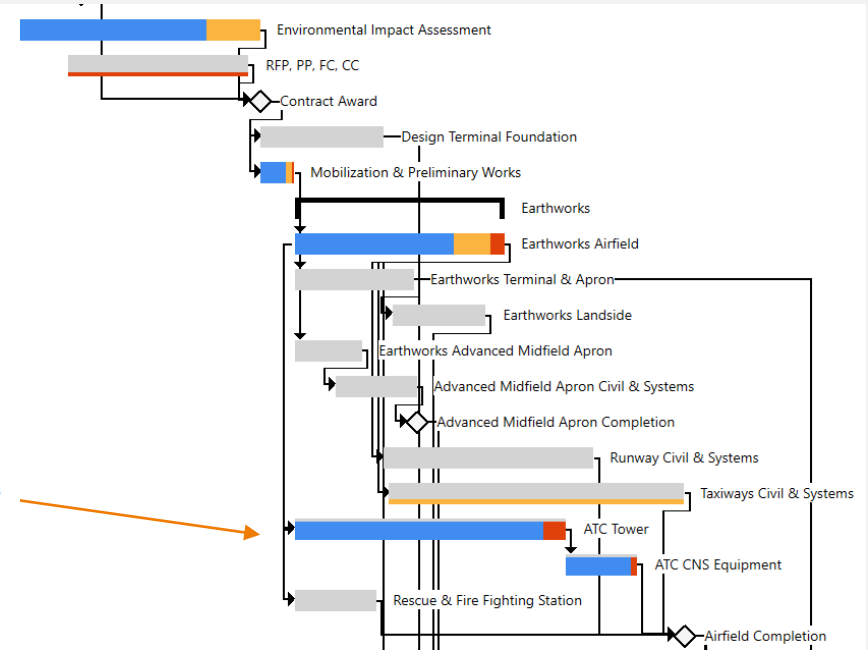


Example: Change of the Critical Path

Base Schedule

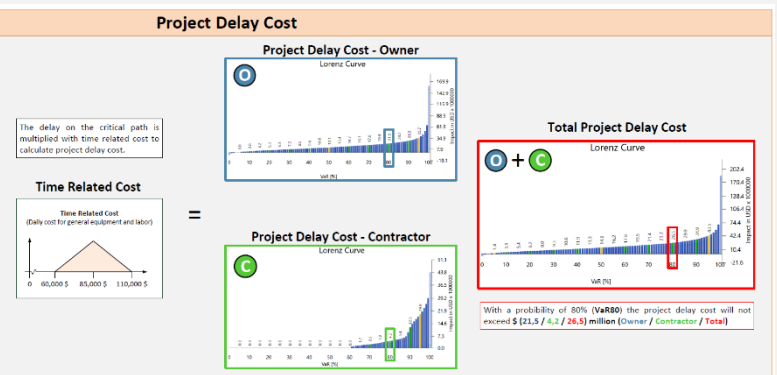
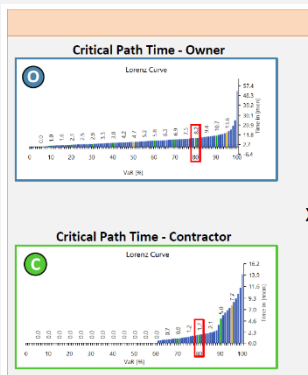
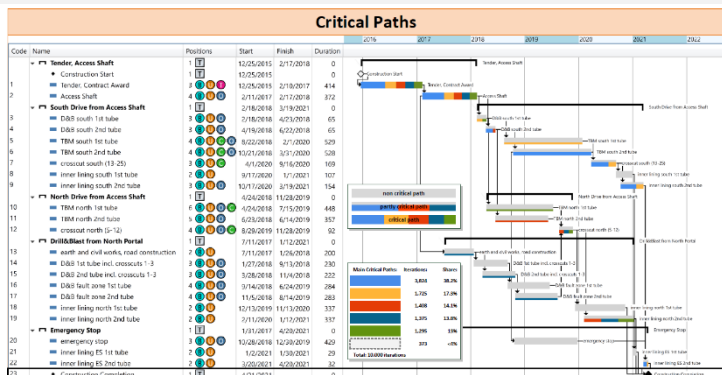
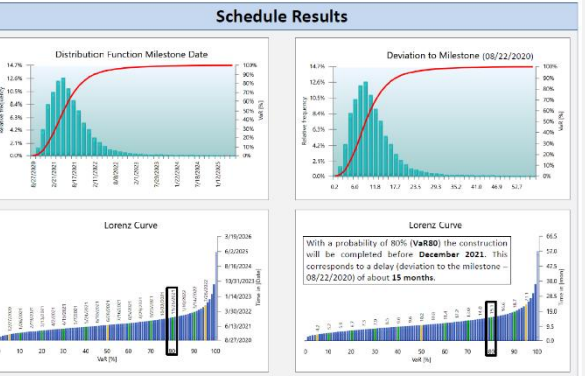
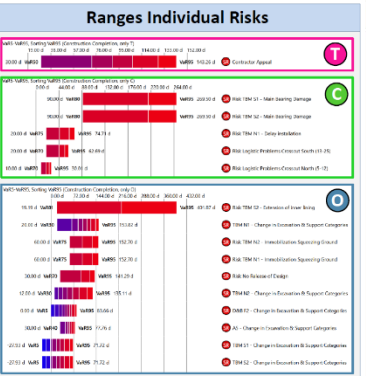
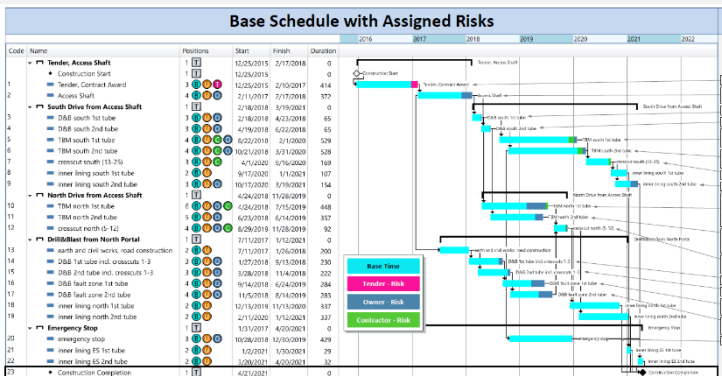
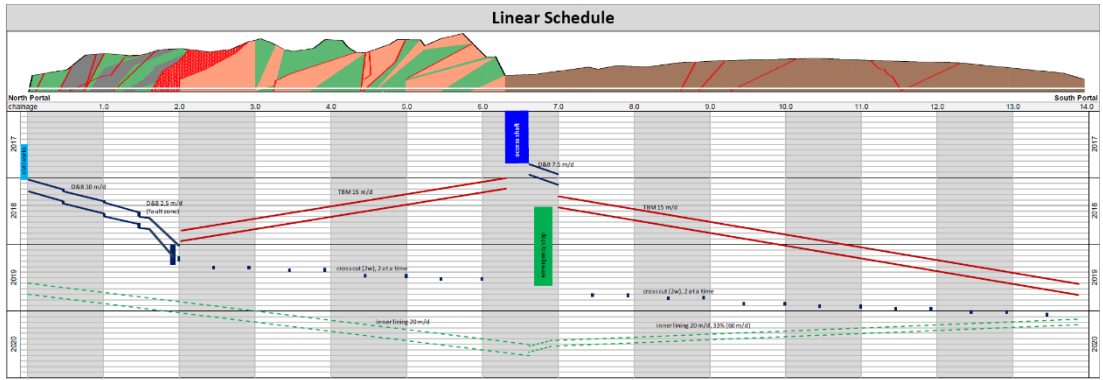
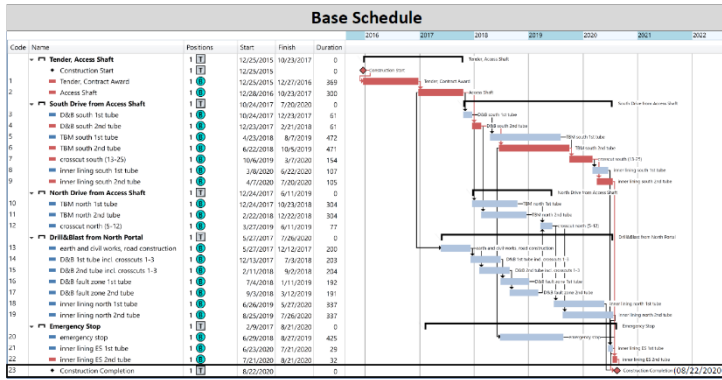


Base Schedule + Risk

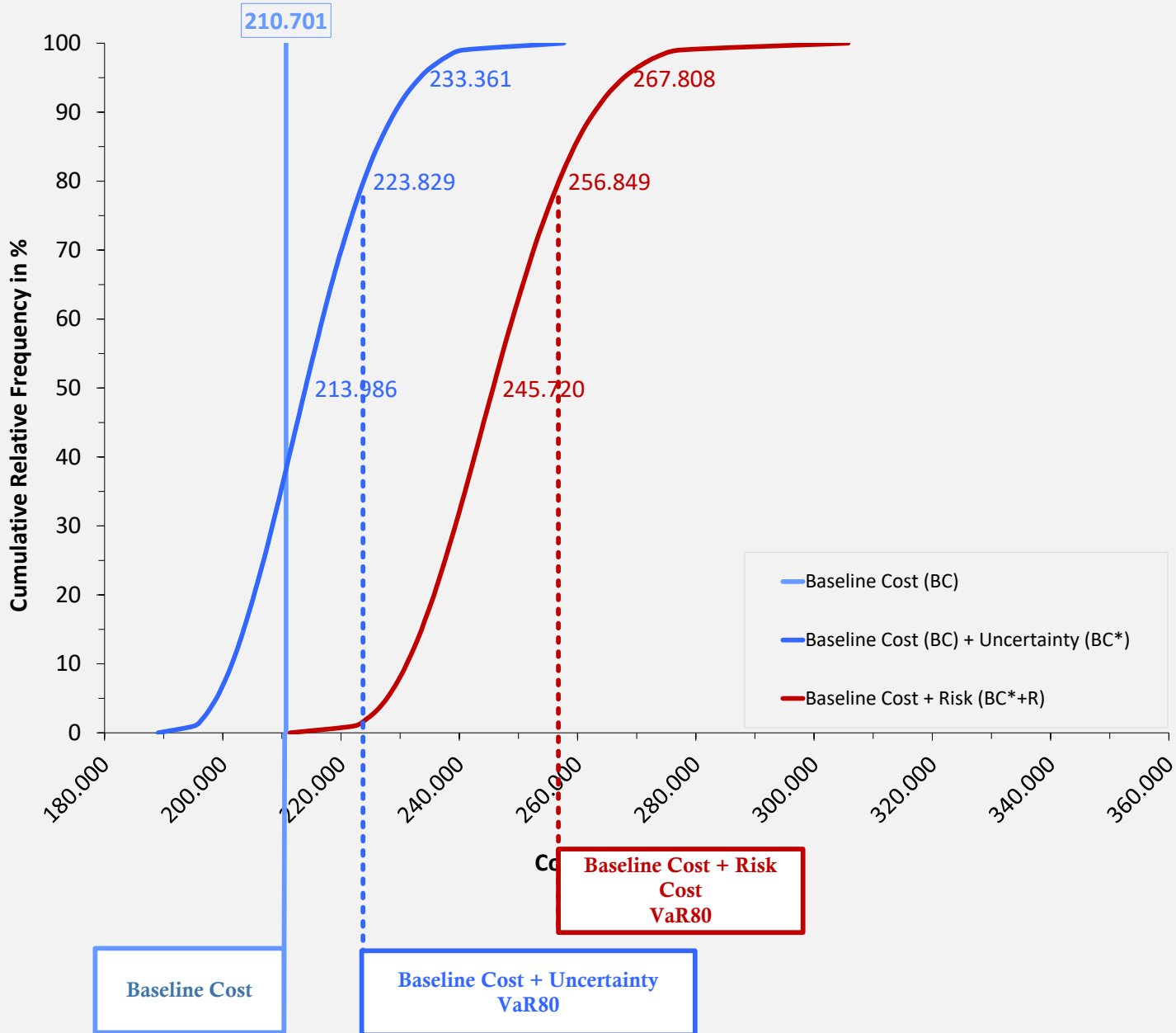


Critical path is changing to ATC tower due to risk impact

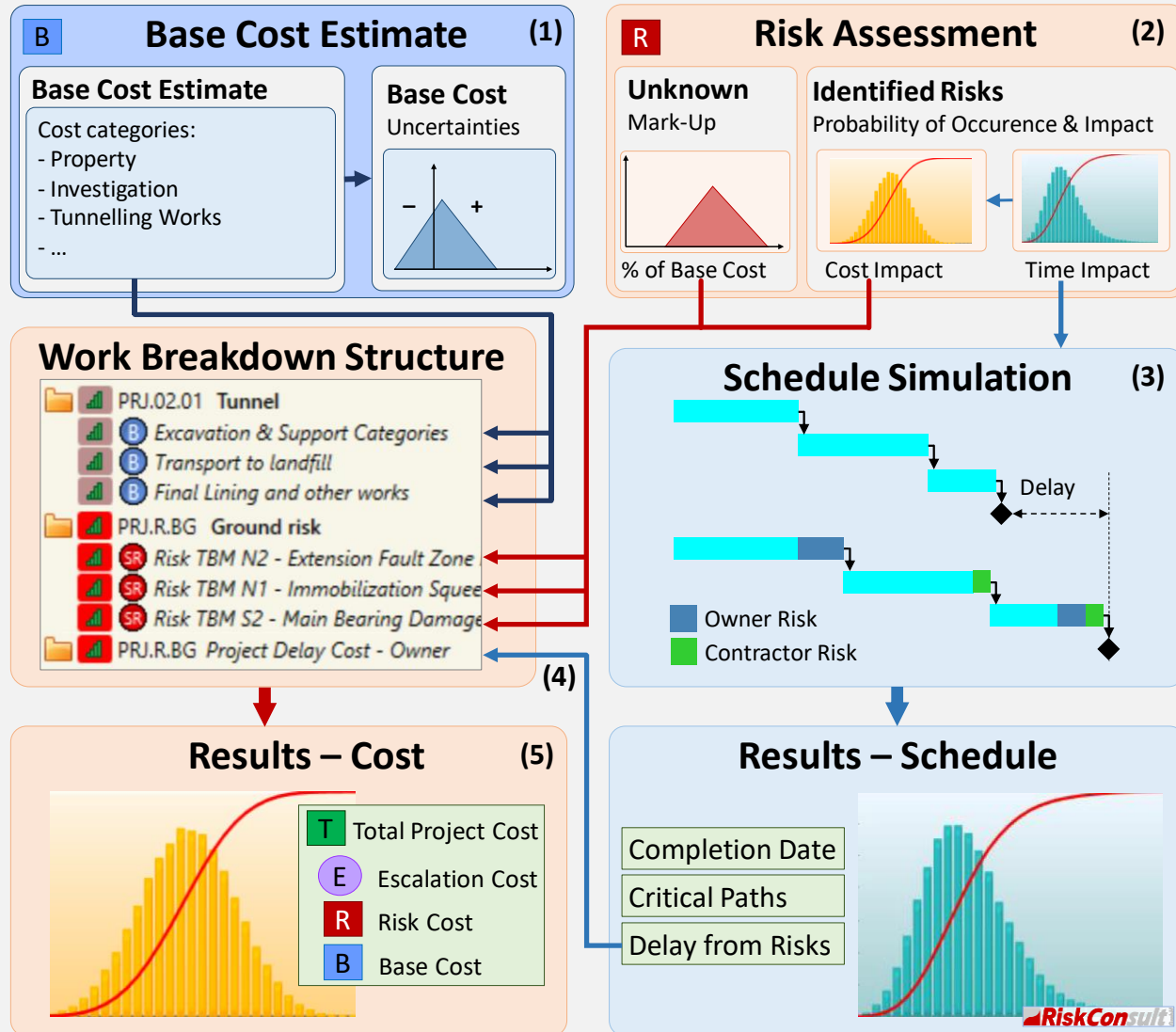
Summary Integrated Cost and Schedule Model



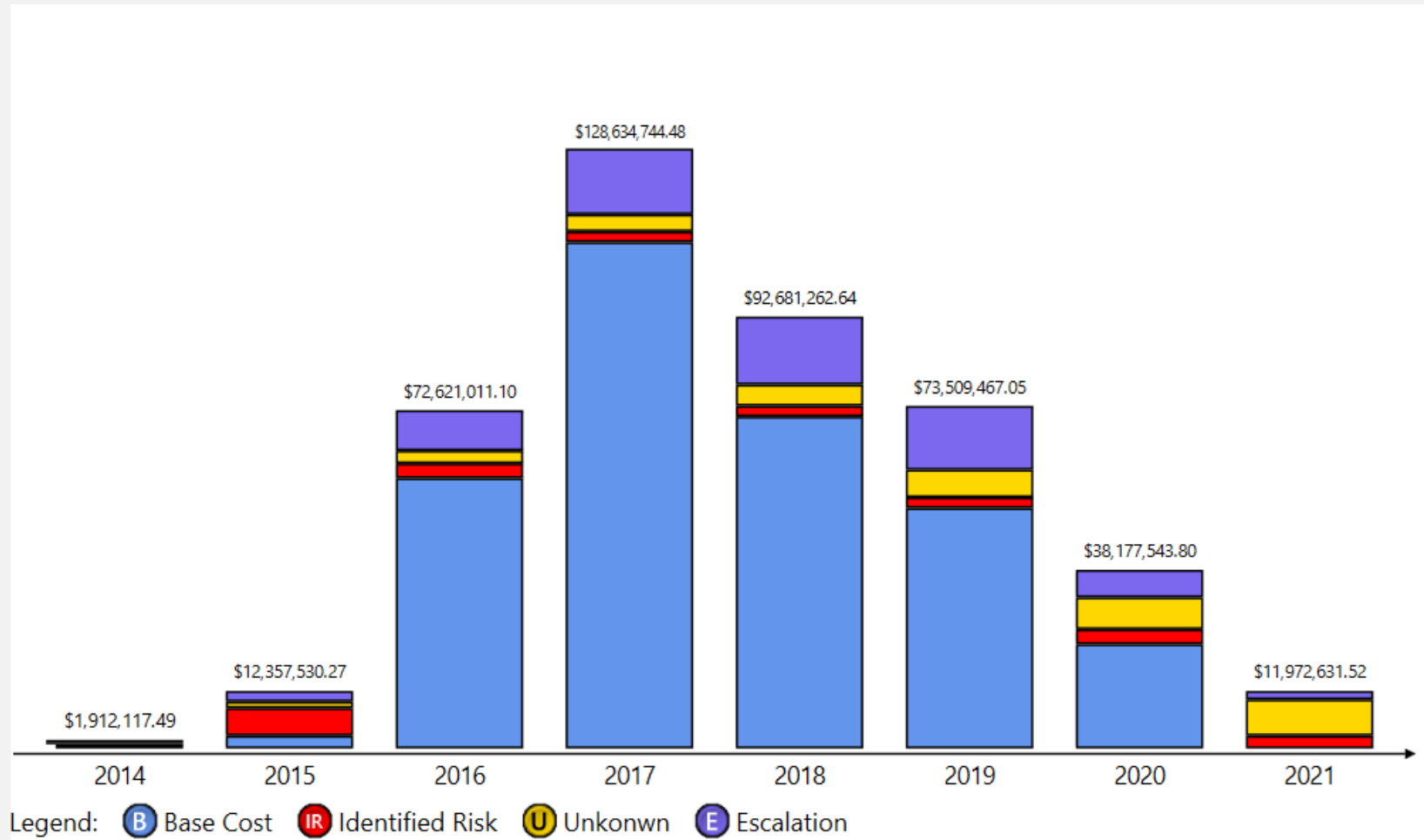
Uncertainty Baseline Cost + Risk



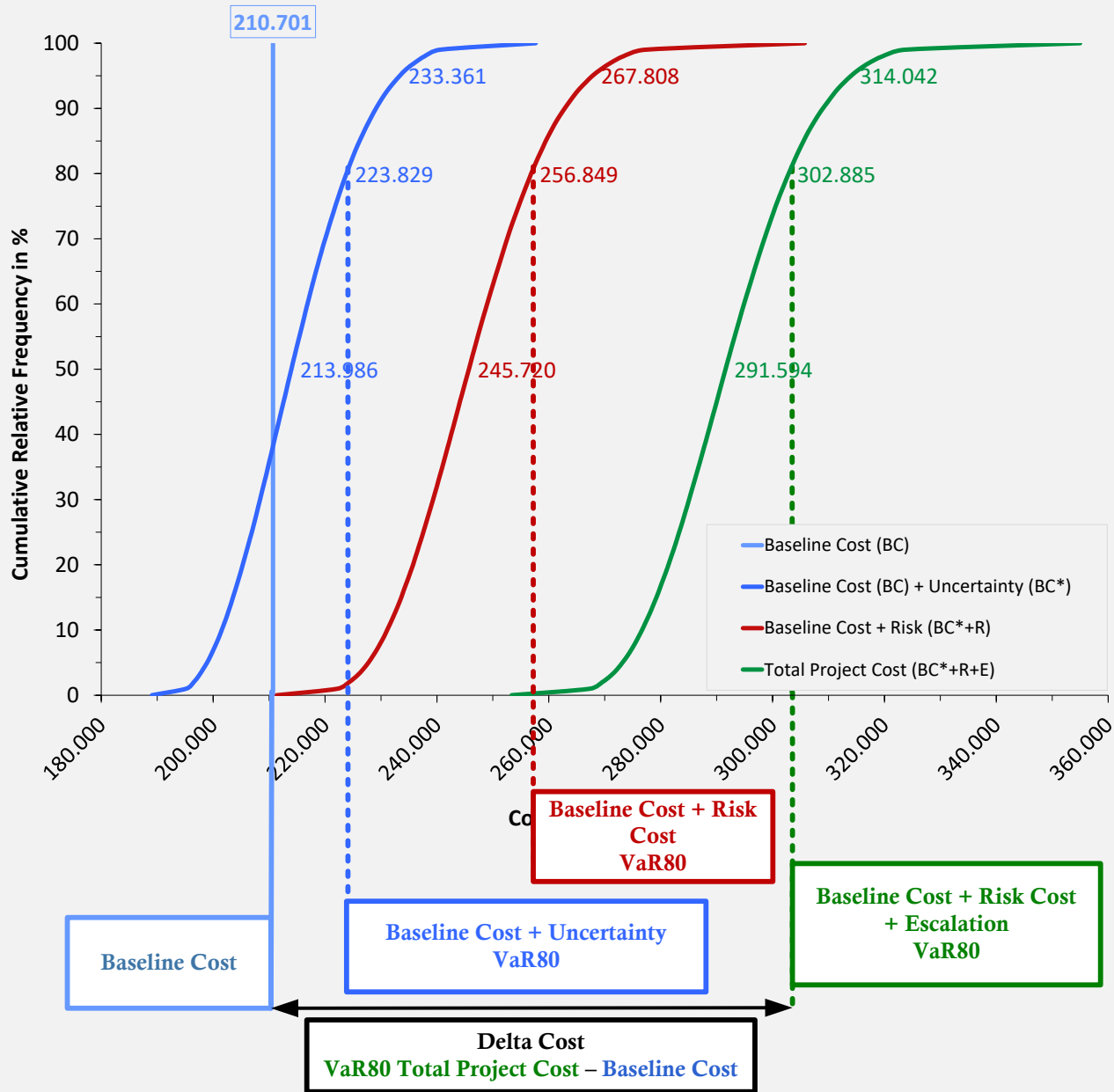
Integrated Cost and Schedule Analysis



Escalation



Depiction Baseline Cost, Total Cost, Delta Cost



Summary RIAAT – Risk Administration and Analysis Tool



Cost Estimate • Risk Management • Cost Control

Further Information: <http://riaat.riskcon.at>

➤ Hierarchical Project Tree Structure

➤ Cost Components

➤ Probabilistic Methods

➤ Risk Analysis Process

➤ Schedule Analysis

➤ Cash Flow Functions

➤ RAMS Analysis - Reliability, Availability, Maintainability, Safety

➤ Numerous visualization options

➤ Custom reports with tables and graphics

➤ Various import/export options for MS Excel

