

ICPMA Conference 2018: Building Futures

Risk-based Cost and Schedule Analysis for Megaprojects

London, June 5, 2018

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www.riskcon.at

- 1. Introduction**
- 2. Standard vs Integrated Approach**
- 3. Integrated Cost and Schedule Model**
- 4. Results and Alternative Delivery Methods**

1. Introduction

2. Standard vs Integrated Approach

3. Integrated Cost and Schedule Model

4. Results and Alternative Delivery Methods



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Megaprojects follow different rules, thus tailored processes and tools are required.

- Cost and Risk Management
- Team Alignment
- RAMS Analysis
- Software Development
- Training



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

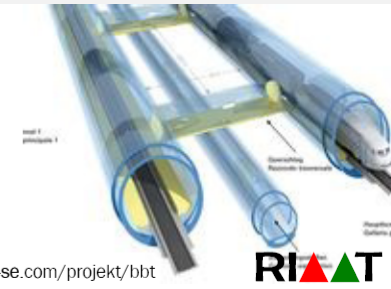


Selected Projects

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

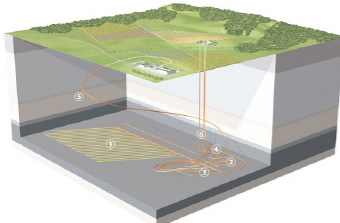
Flooding caused by Superstorm Sandy inundated the Canarsie Tunnel with seven million gallons of salt water. The rehabilitation includes upgrading of the Canarsie Tunnel facilities from 1st Avenue Station in Manhattan to Bedford Avenue Station in Brooklyn and three substations.

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

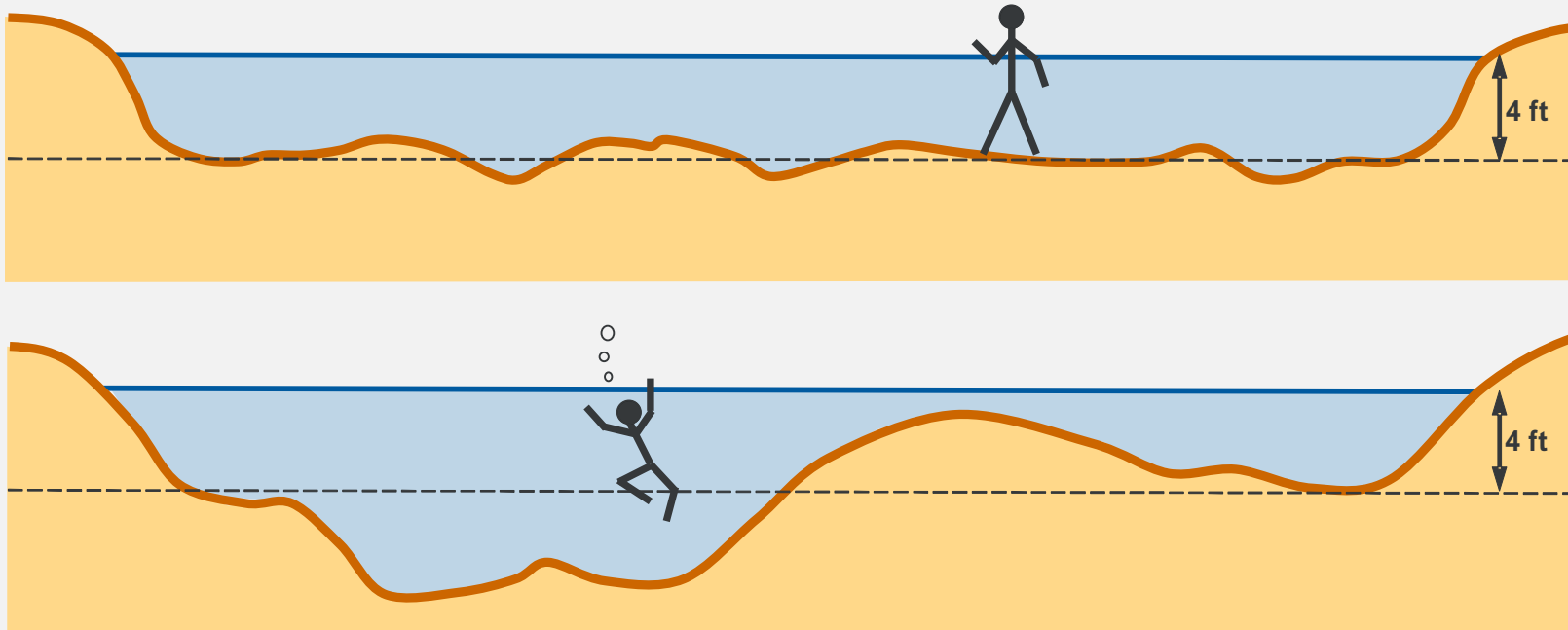
The German Ministry for Transport and Digital Infrastructure (BMVI) initiated the "Construction of Mega Projects" commission. Their task is to identify problems in the planning and construction phase of large projects and reveal reasons for cost increases and delays.

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



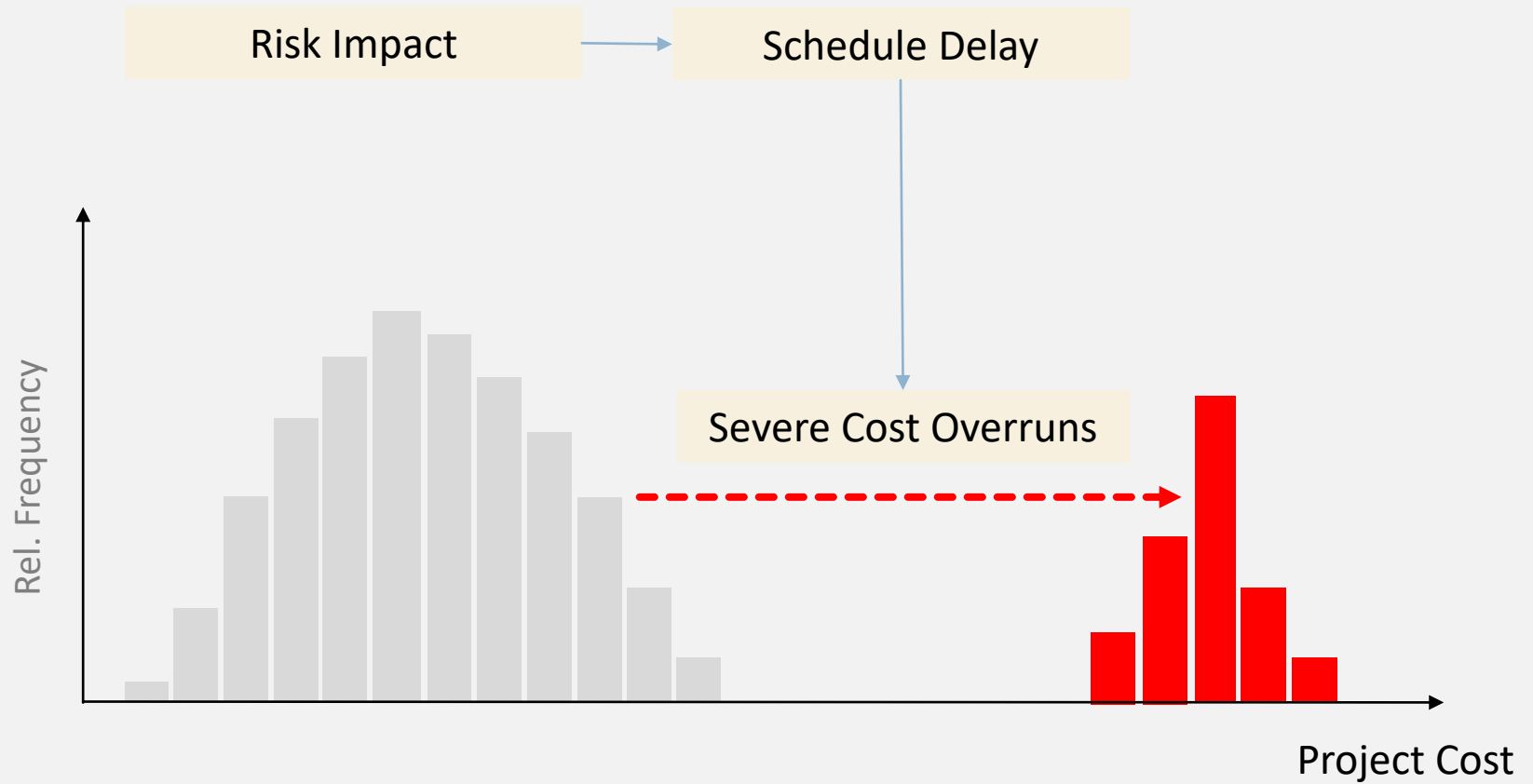
1. Introduction
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„Would you wade through a river
4 feet deep on average?”

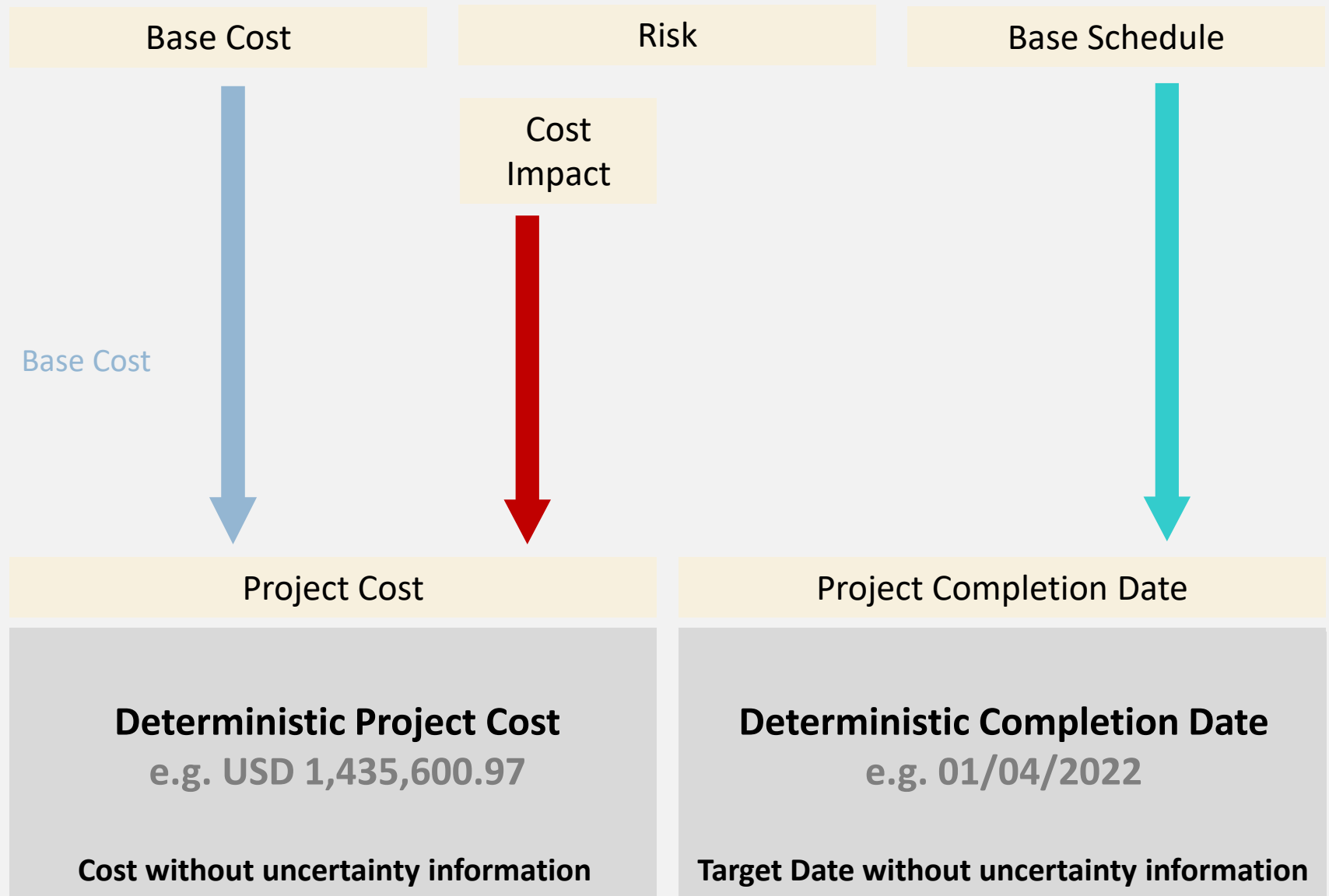


Information about uncertainty is necessary!

Impact of Delays on Project Cost



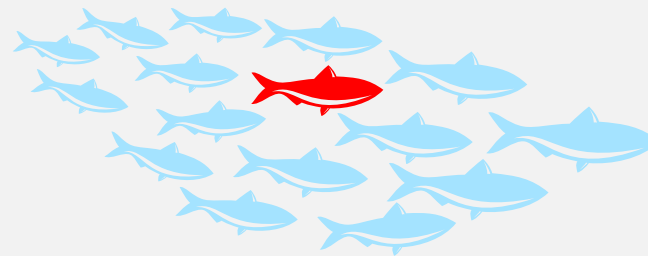
Standard Approach



Large-Scale Projects Follow Different Rules

→ Complex entities cannot be understood by breaking them down into independent parts.

Even at the simplest level, studying a fish cannot explain how a school of fish works.



complexity

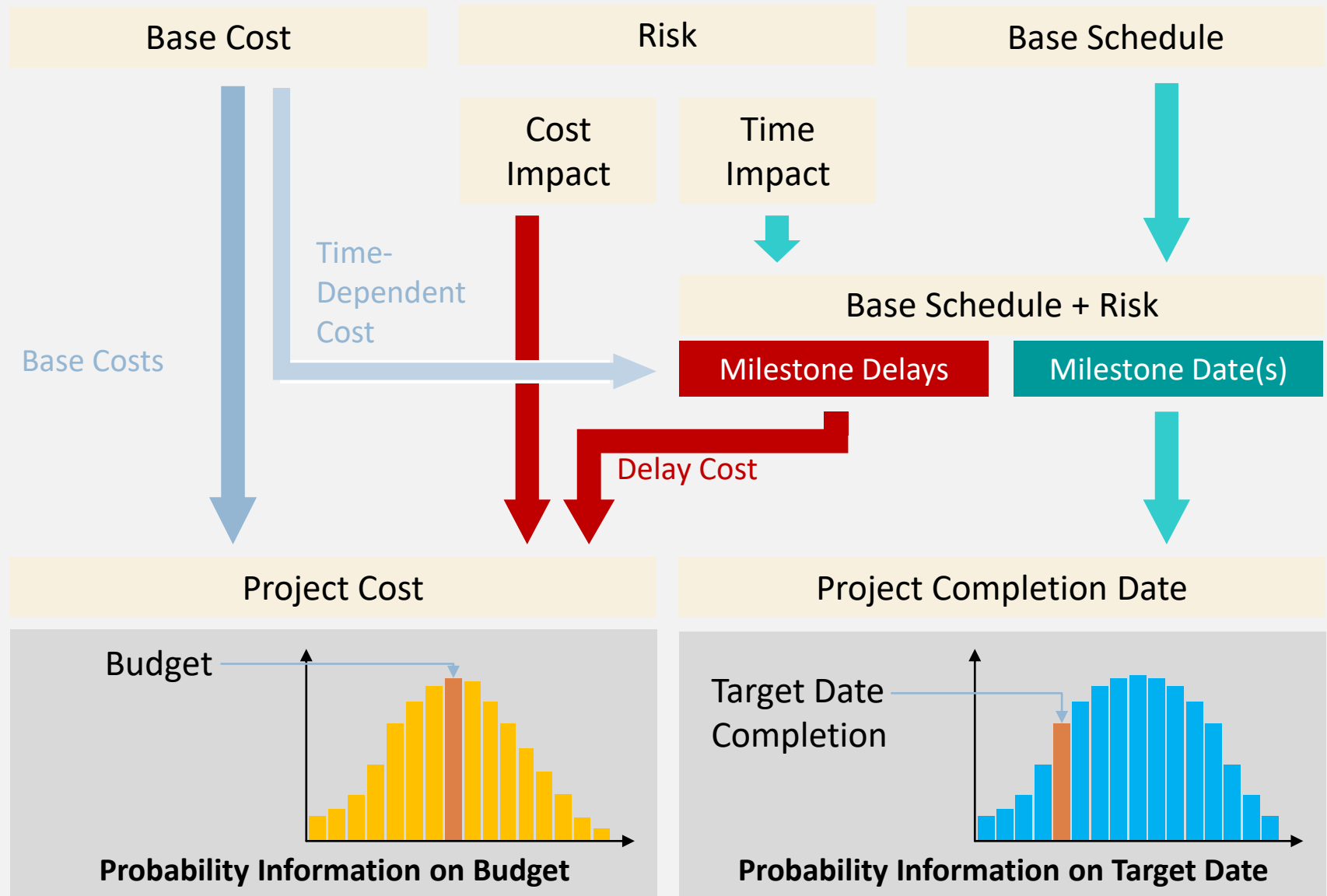
dynamics

Statement

→ Integrate cost and schedule.

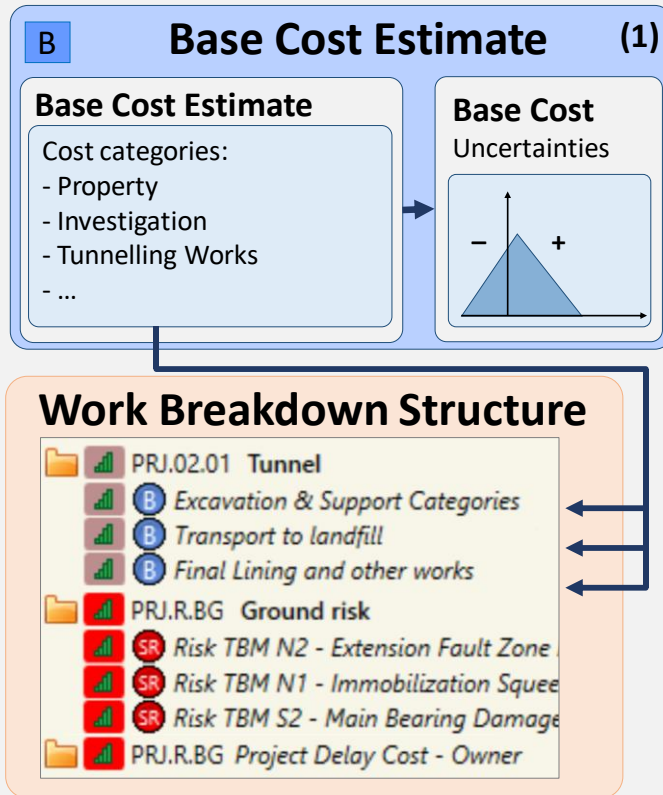
→ Consider **uncertainties**.

Integrated Cost & Schedule Model



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Integrated Cost and Schedule Analysis - Process



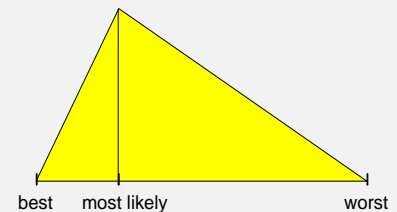
Validation of Base Cost Estimate

- Assign cost elements to WBS structure
- Review relevant Base Cost elements (quantities, prices, completeness)
- Add Base Cost variabilities (uncertainties)

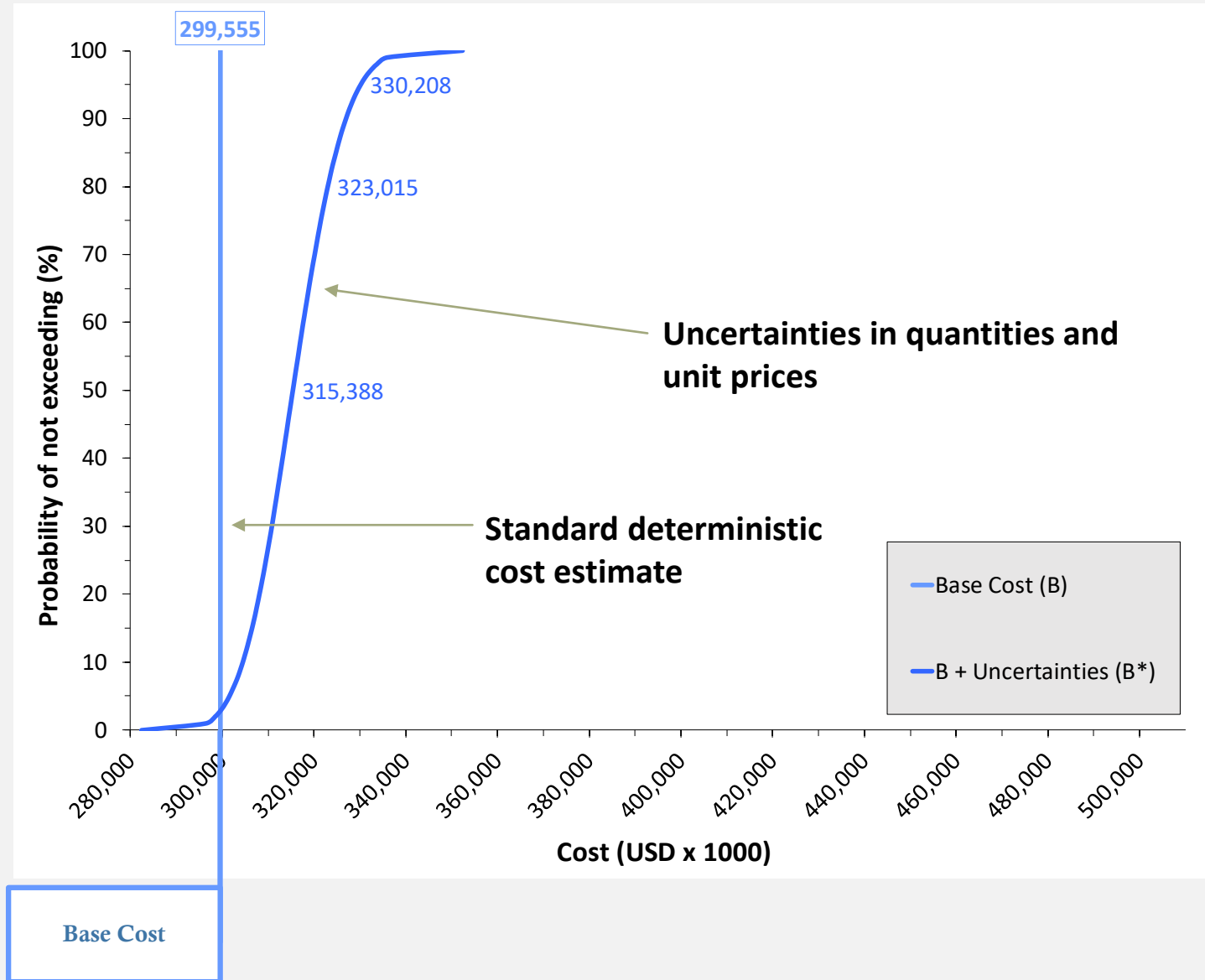
3-Point Estimate

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

Triangle Distribution

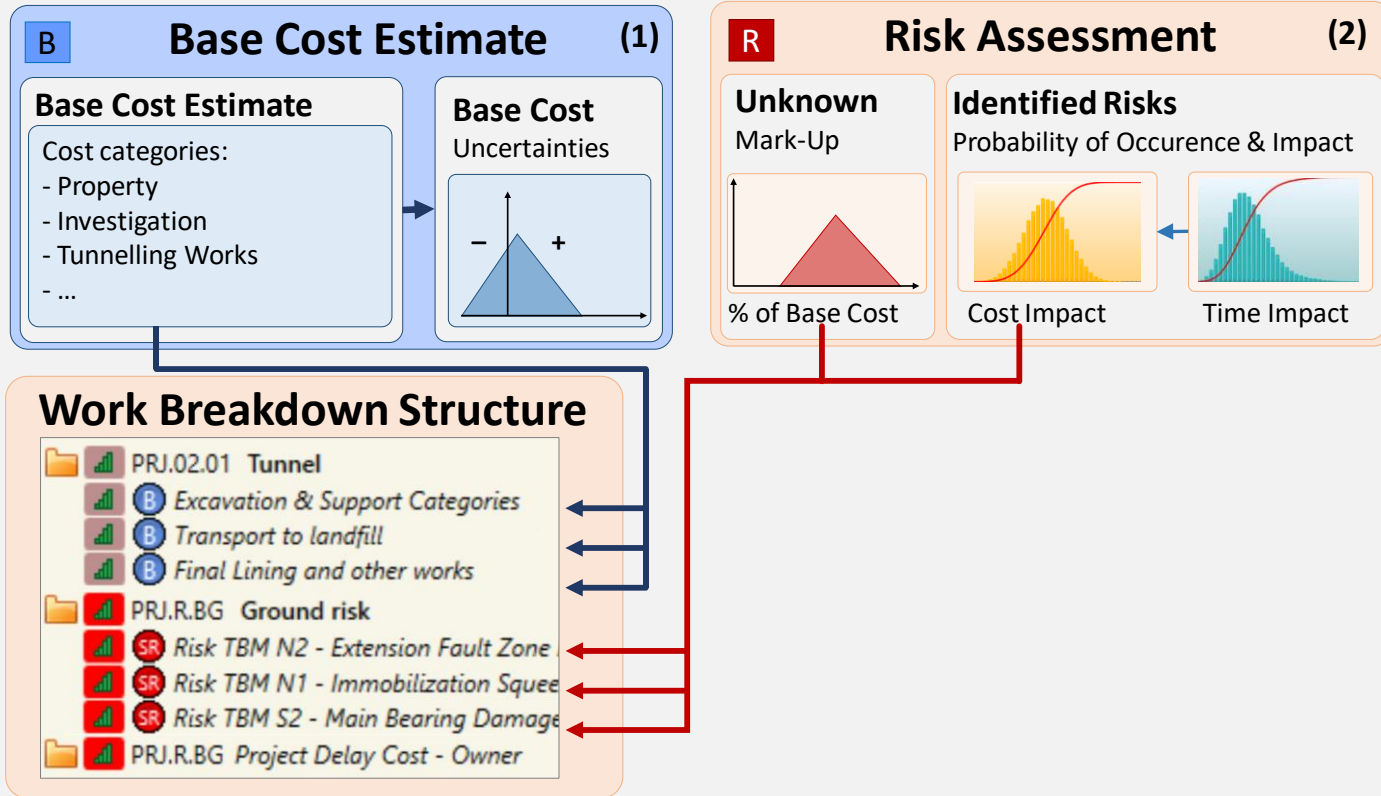


Base Cost + Base Cost Uncertainty



Base Cost

Integrated Cost and Schedule Analysis - Process



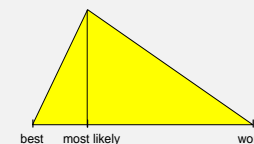
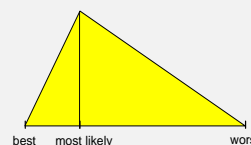
Risk Assessment Workshops



- Facilitated interdisciplinary workshops
- Identification and quantification of risks
- Populate risk register
- Supported by appropriate tools

Impact (cost and time)

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



#	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

RIAA v2.7.0.3092 - [2.6.0.3023, I:\Meine Ablage\01 Arbeit\02...\Project Tunnel & Approaches_V25_F02.riat]

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 67.136 MS 1.136

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

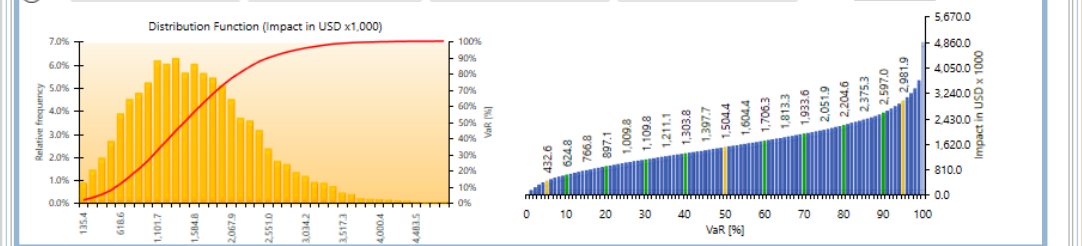
Workbook: [Tree Input Gantt Value adjustment]

Tree Input Gantt Value adjustment

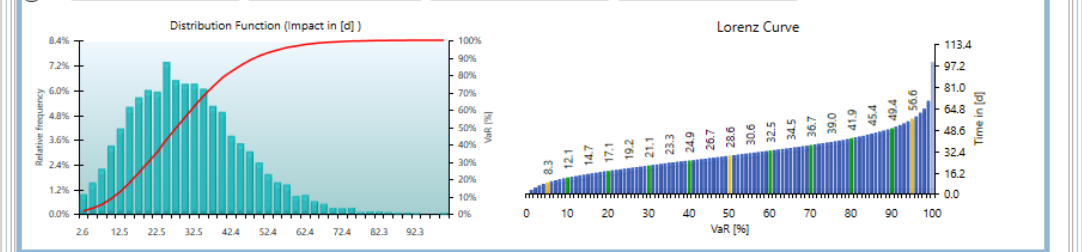
Cost element : Risk TBM N2 - Mountain water inflow > 40L/s 2450

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

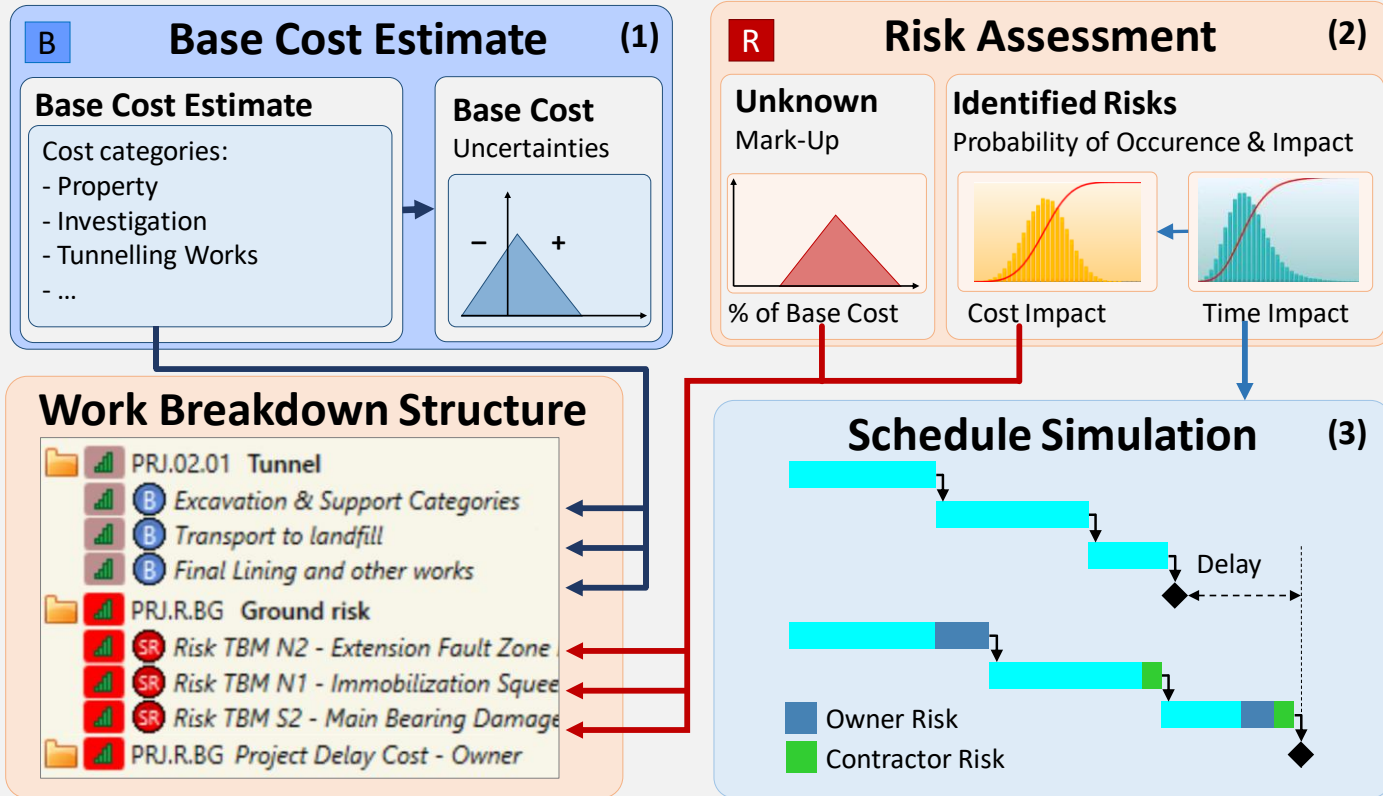


Probability of Occurrence 5 Zeroize negative fractiles

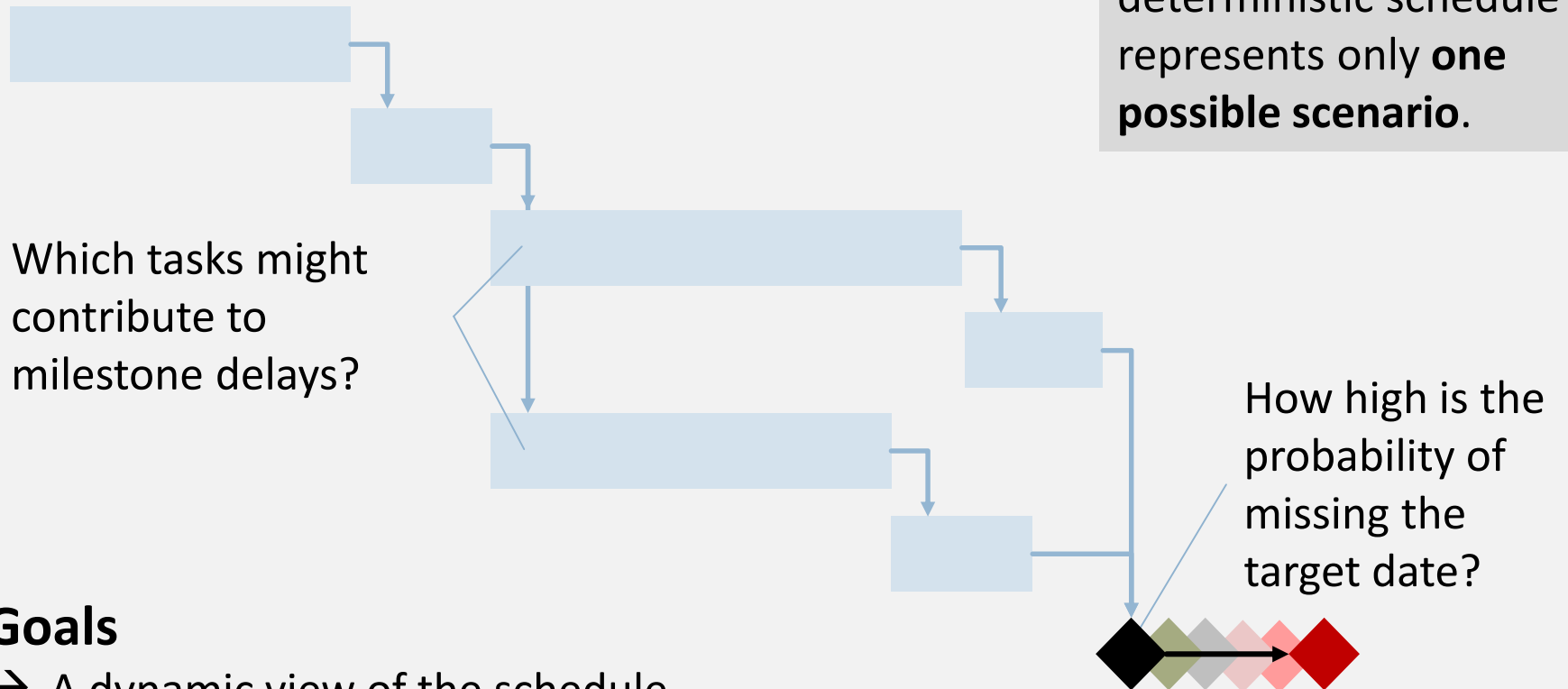
Subcomponent (4 positions)

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 - Process



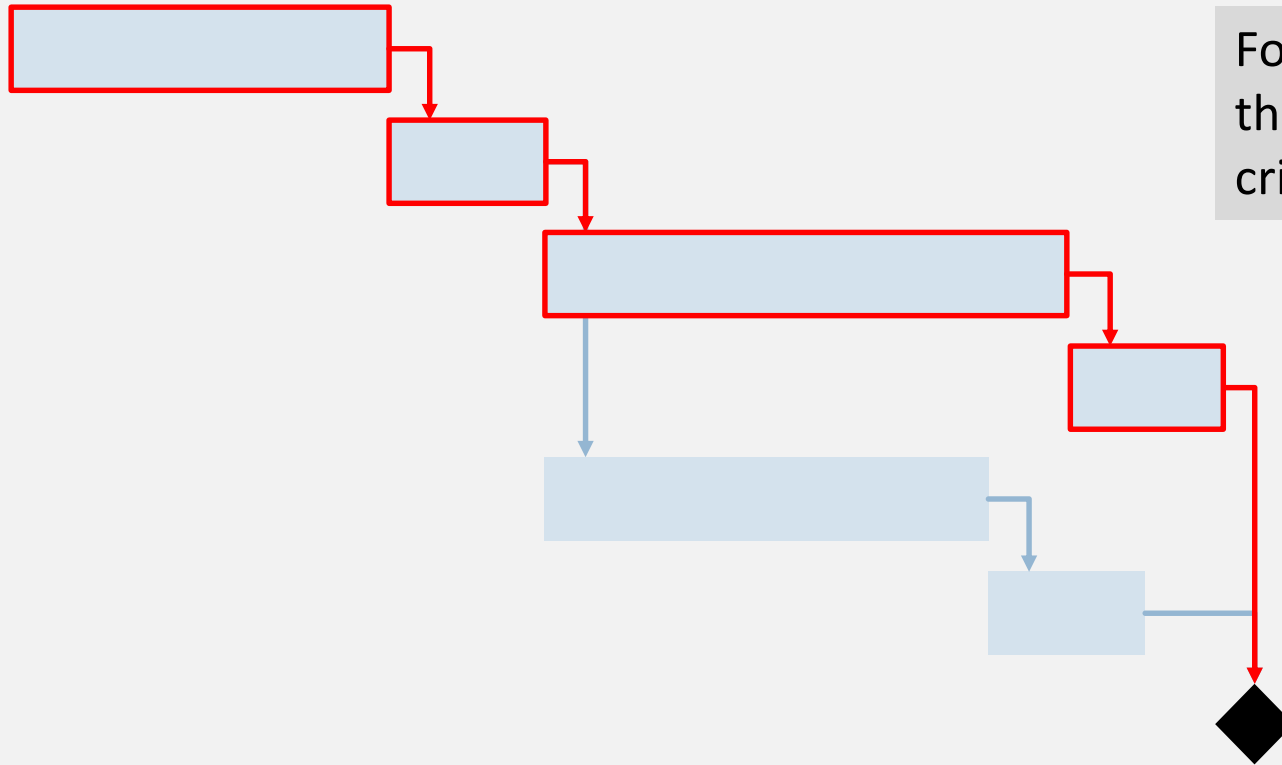
Deterministic Schedule Approach



Goals

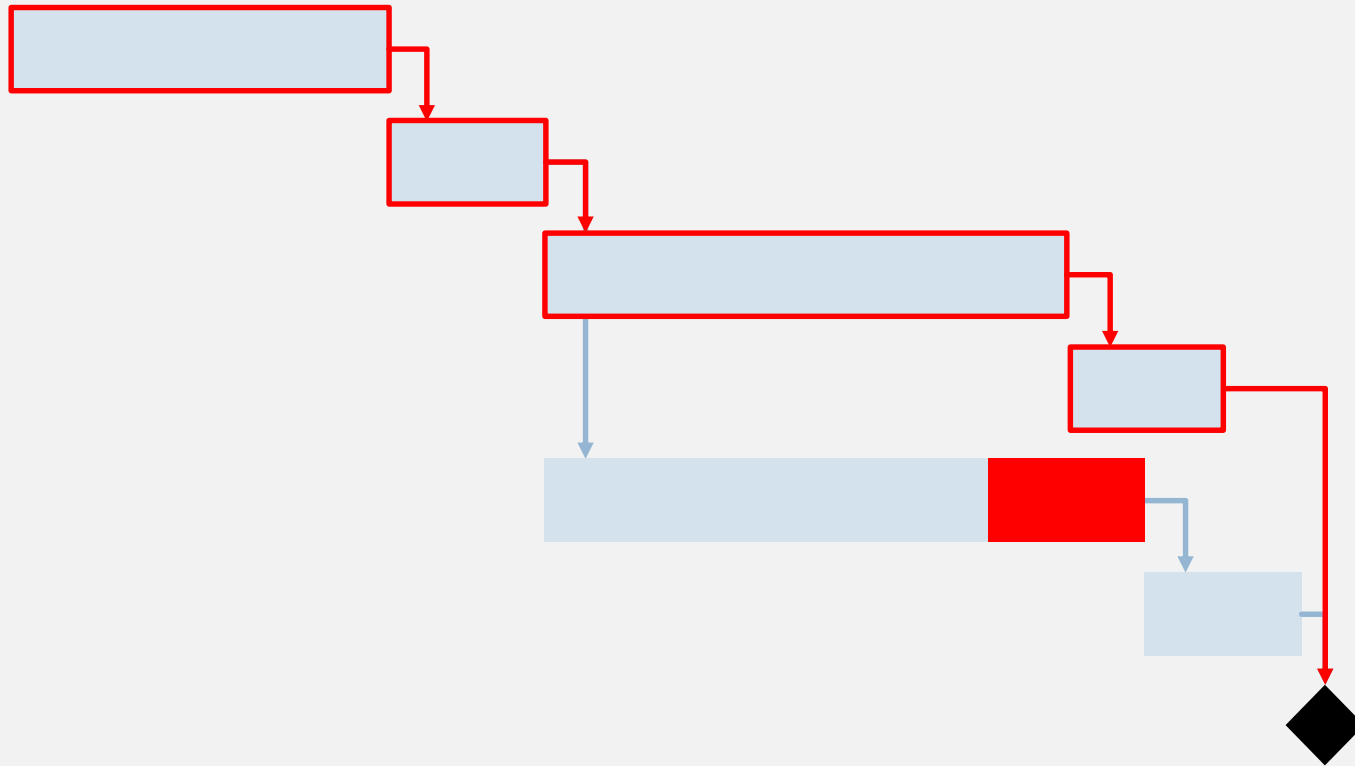
- A dynamic view of the schedule
- Integrate risks – link them to tasks
- Implement risk mitigation measures based on results of the schedule analysis
- Optimize construction processes

CPM in Deterministic Schedule



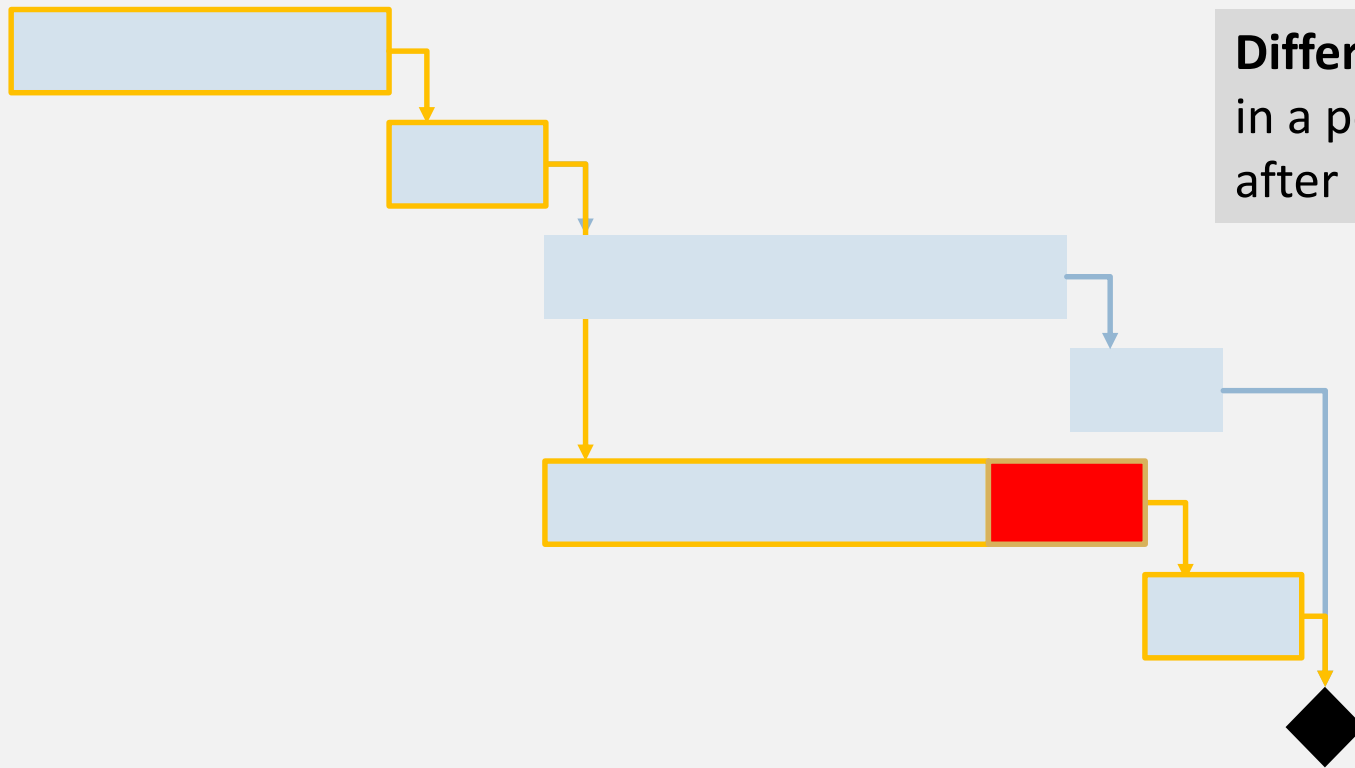
For **one** scenarios there is only **one** critical path.

Critical Path Shifting due to Risk Impact



What If
risk impacts
change task
durations?

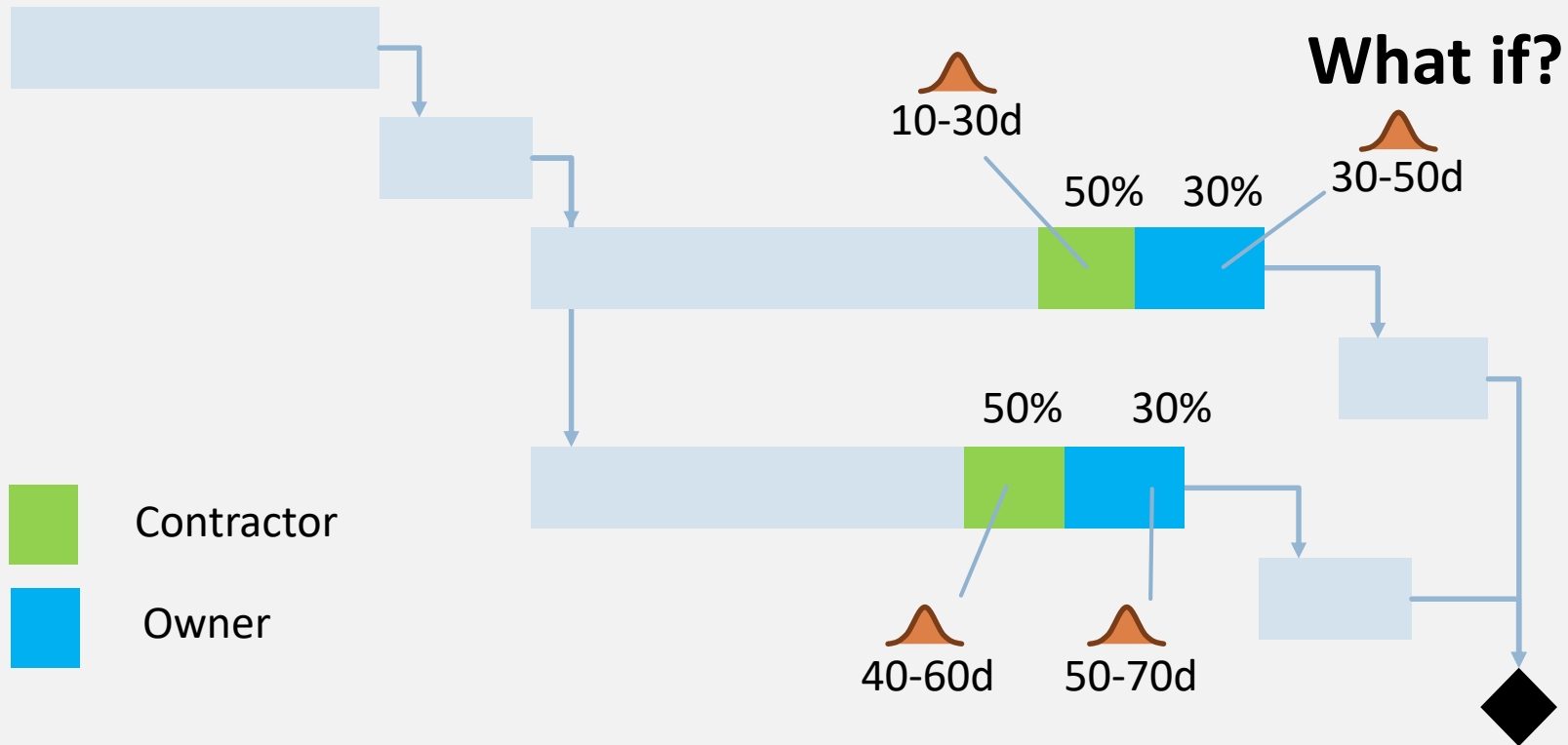
Critical Path Shifting due to Risk Impact



Different critical path
in a possible scenario
after risk impact(s).

Assigning Risks to Tasks

#	Identified Risk	Probability of Occurrence	Rate of Occurrence	time impact (d)		
				best	most likely	worst
1	TBM S2 - Main Bearing Damage	20%	-	90	180	400



→ Monte Carlo simulation will generate thousands of realistic scenarios, each depicting a possible project outcome.

Application: Assigning Risks to Schedule Activities

Workbook

Tree Input Gantt Value adjustment

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

- 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
 - Risk 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 0.048
 - 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
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 - Risk CC N - Mountain water inflow > 40l/s MS 0.886 MS 0.492
 - Risk Cave-ins of 5m² to 20m² MS 0.578 MS 0.505
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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

Workbook

Tree Input Gantt Value adjustment

Diagram: Schedule+links, uncertainties

Planning Ranges

2017 2018 2019 2020 2021 2022

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	7/11/2017	200
14	D&B 1st tube incl. cross	1/27/2018	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

Time in [d]	Var [%]
328.9	0.00
343.1	1.11
356.7	2.22
380.6	3.33
396.8	4.44
414.7	5.56
427.6	6.67
438.5	7.78
448.0	8.89
457.2	10.00
467.4	11.11
477.8	12.22
500.0	13.33
514.3	14.44
532.9	15.56
555.7	16.67
582.8	17.78
621.4	18.89
636.6	20.00
659.9	21.11
686.8	22.22
712.7	23.33
738.9	24.44
763.9	25.56
789.0	26.67
811.4	27.78
831.4	28.89
849.0	30.00
863.6	31.11
875.7	32.22
885.0	33.33
891.2	34.44

Baseline Time 304.00 d 100.00 % 304.00

Uncertainty 0.00 d 100.00 % -20.00 0.00 40.00

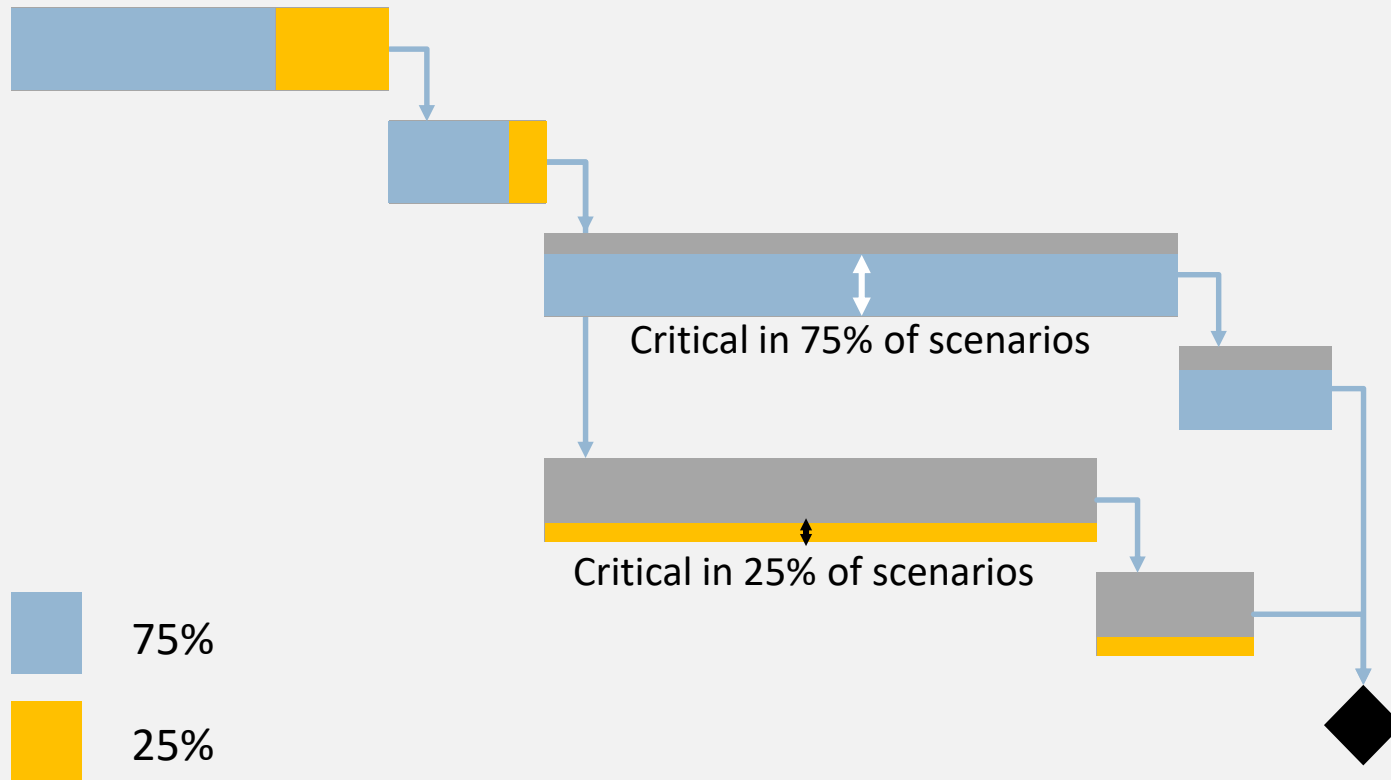
Owner 30.00 d 0.00 d 0.00 d 152.70 d from Risk TBM N1 - Immobilization Squeezing Ground 2436 Risk Owner

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

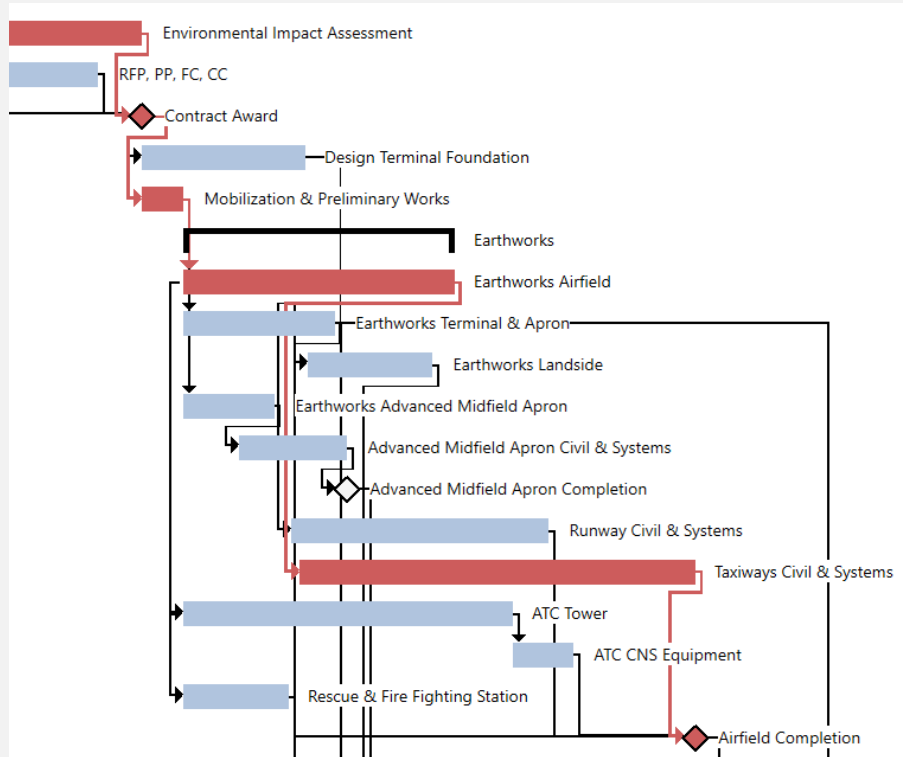
Critical Paths after Monte Carlo Simulation



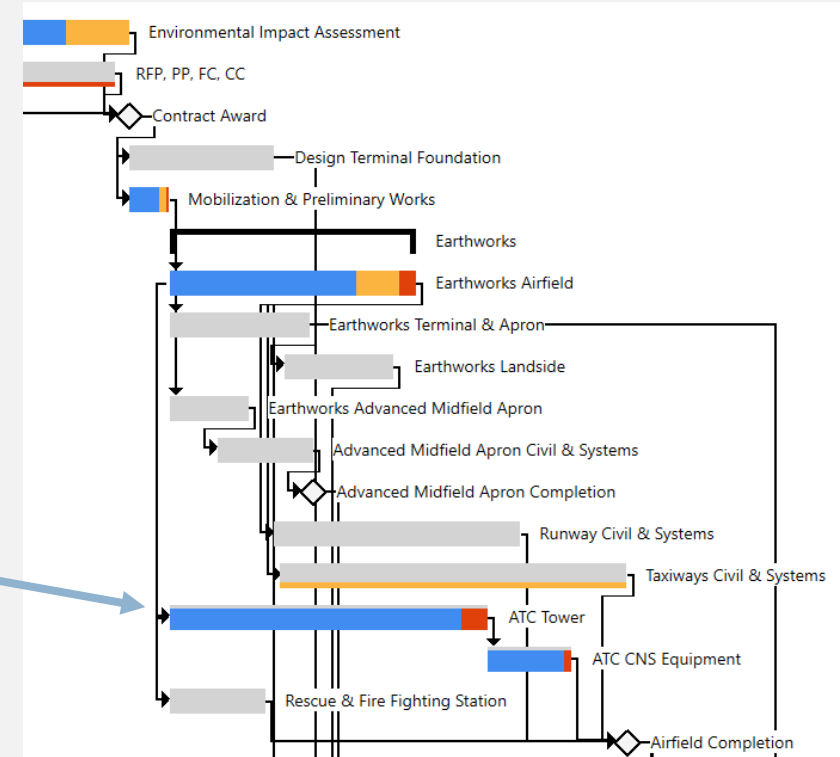
→ Due to uncertainties, **numerous** critical paths become possible, each with a different probability.

Example: Lima Airport Extension Project

Base Schedule



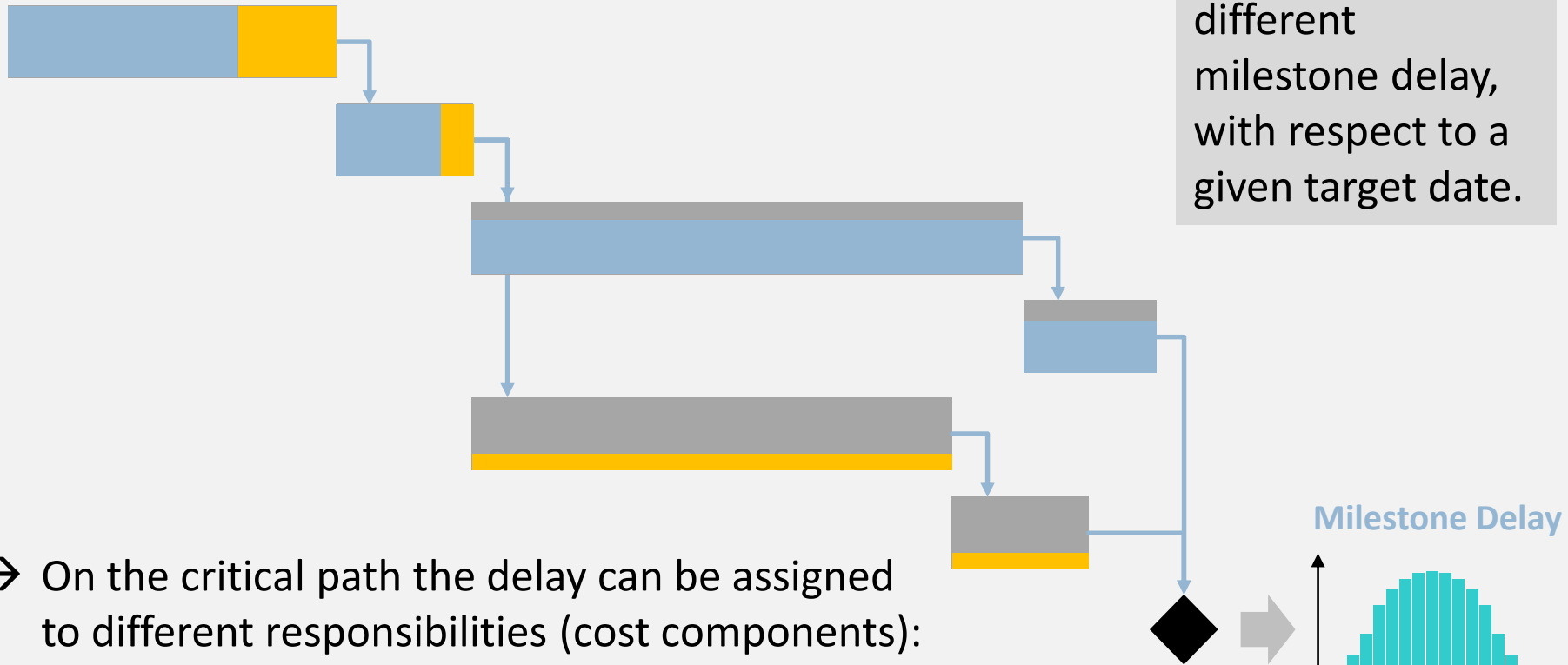
Base Schedule + Risk



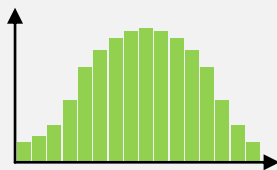
Main critical path is changing to ATC tower due to risk impact

Milestone Results after Monte Carlo Simulation

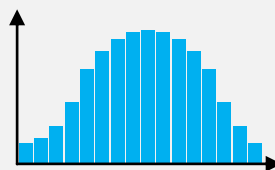
Each simulated scenario yields a different milestone delay, with respect to a given target date.



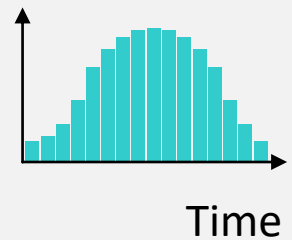
Contractor Delay



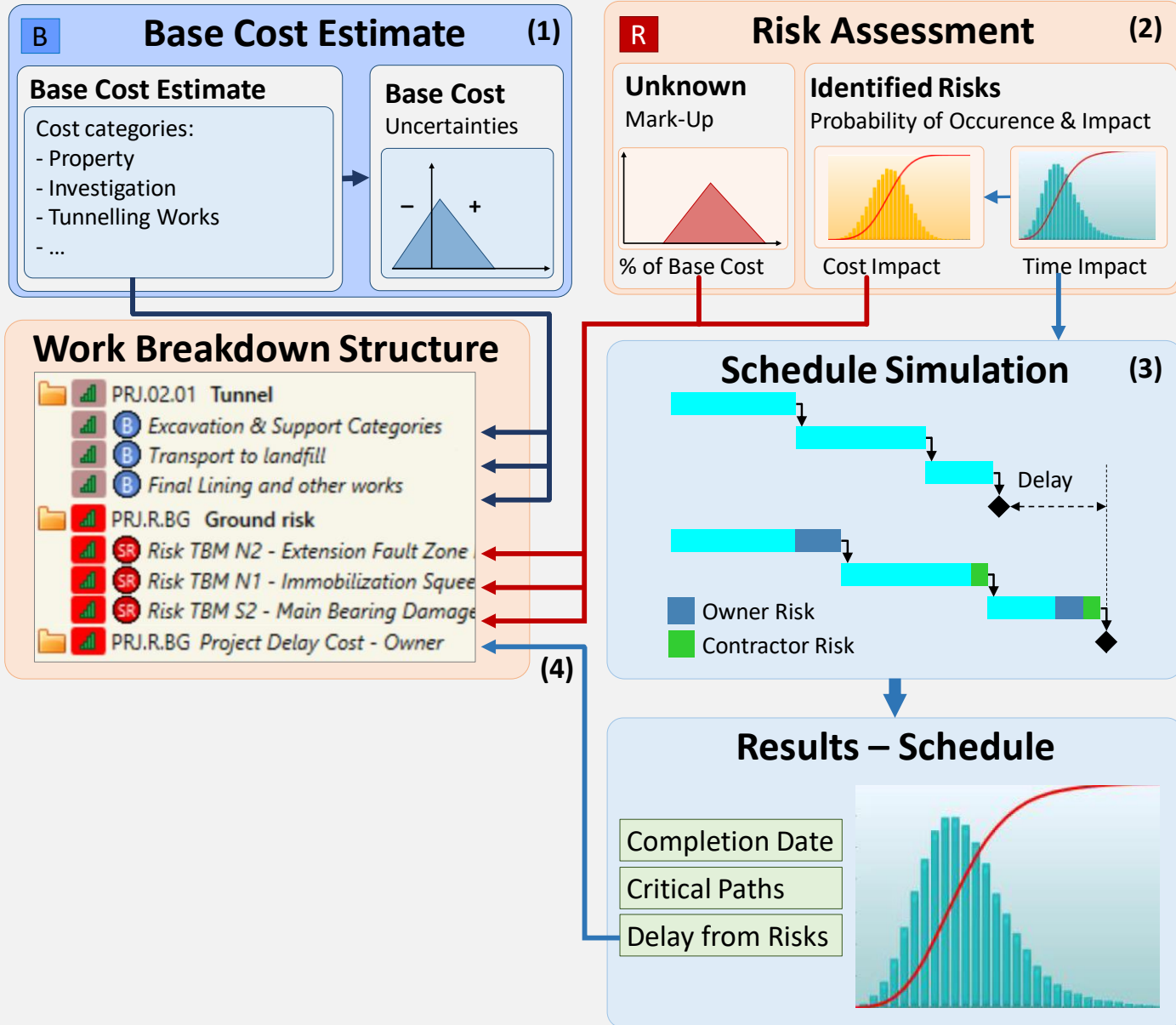
Owner Delay



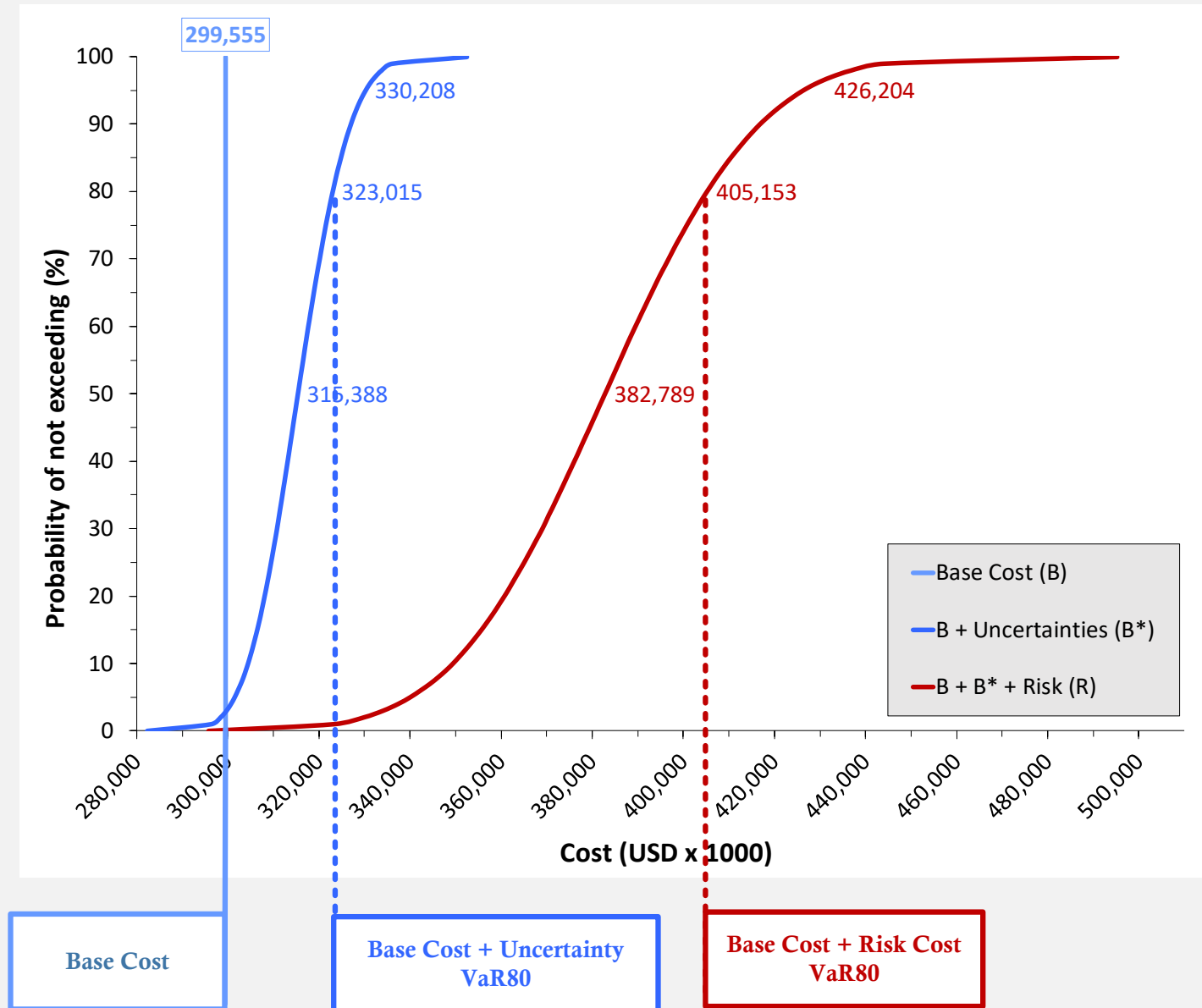
Milestone Delay



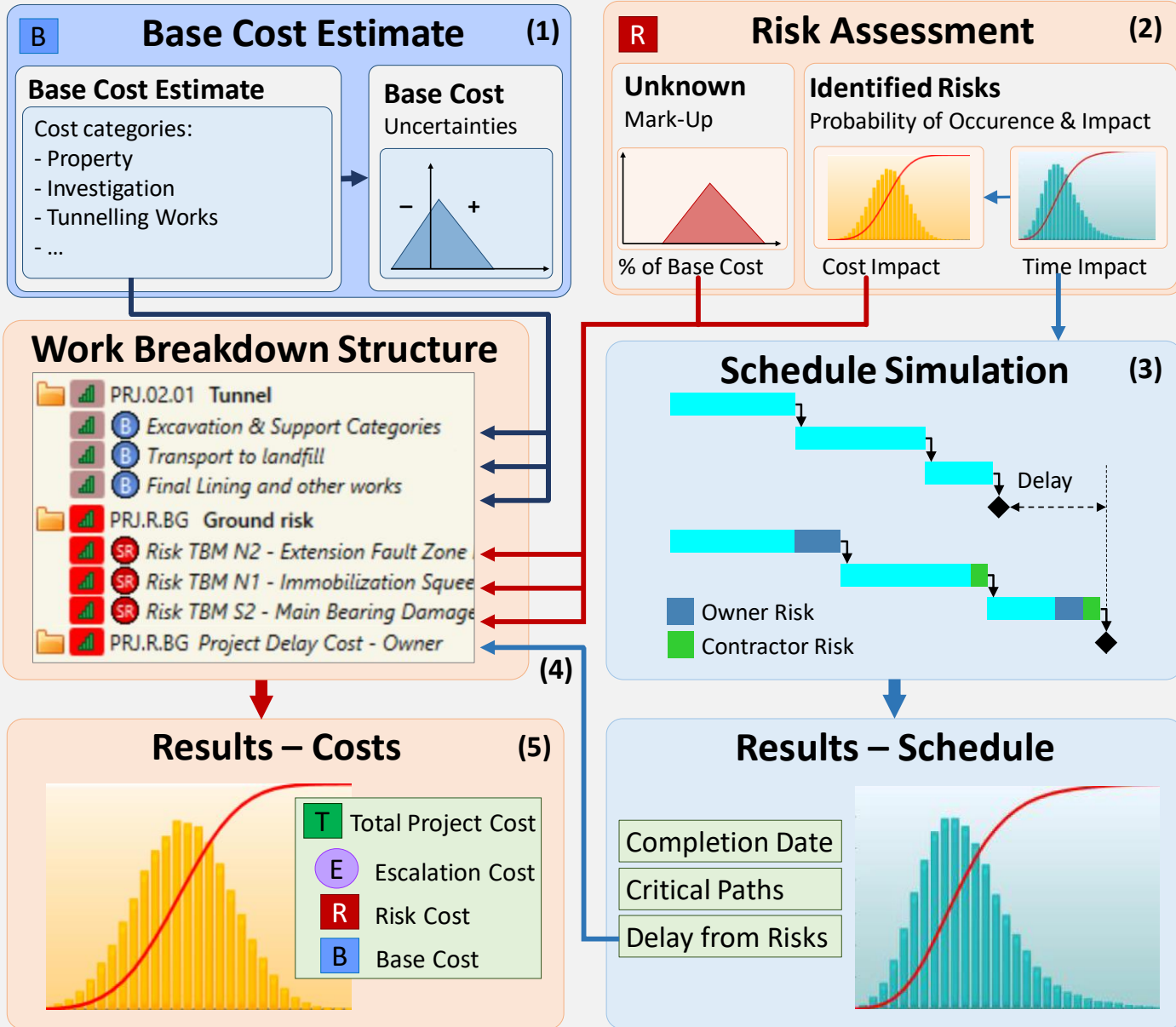
Integrated Cost and Schedule Analysis - Process



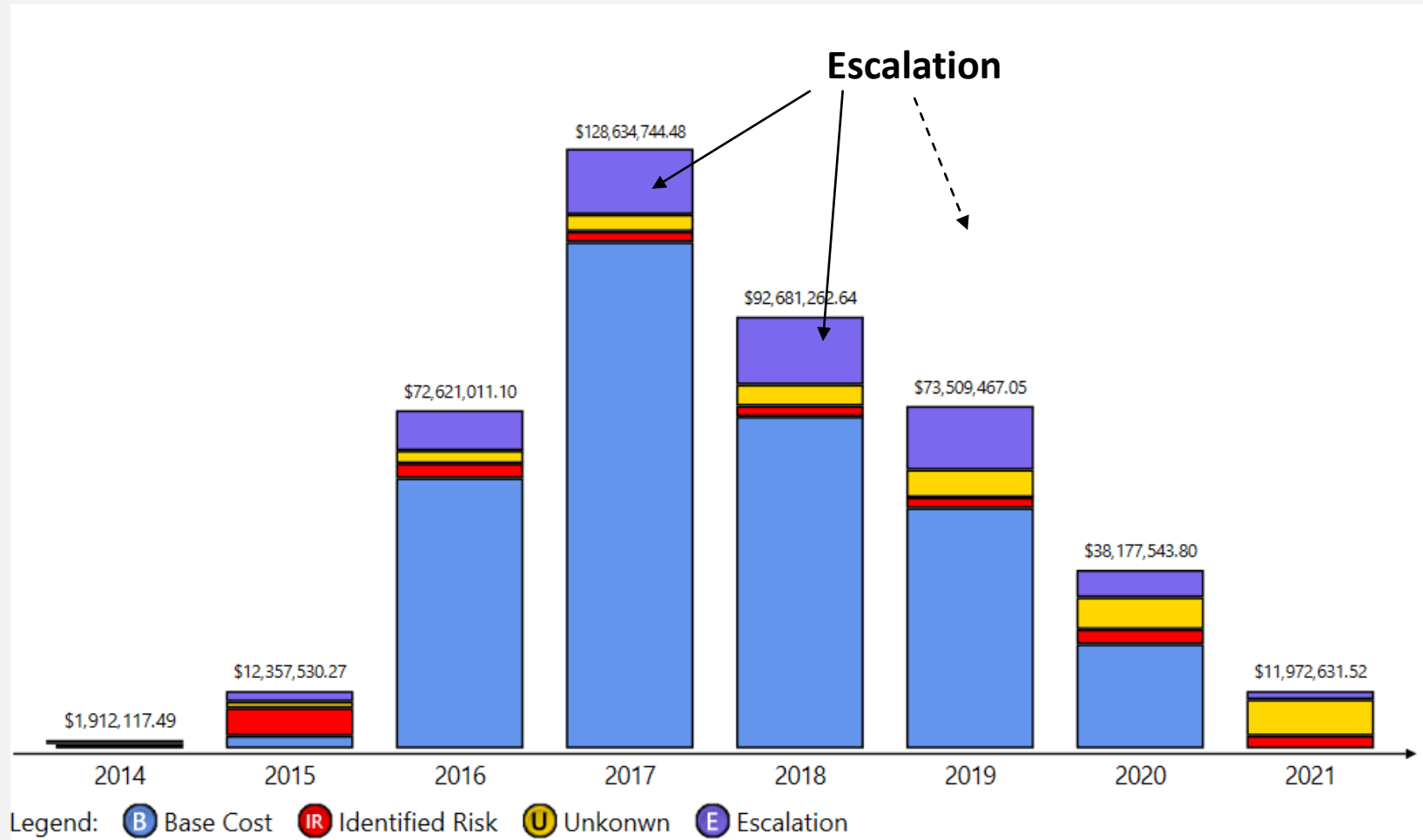
Base Cost + Base Cost Uncertainty + Risk



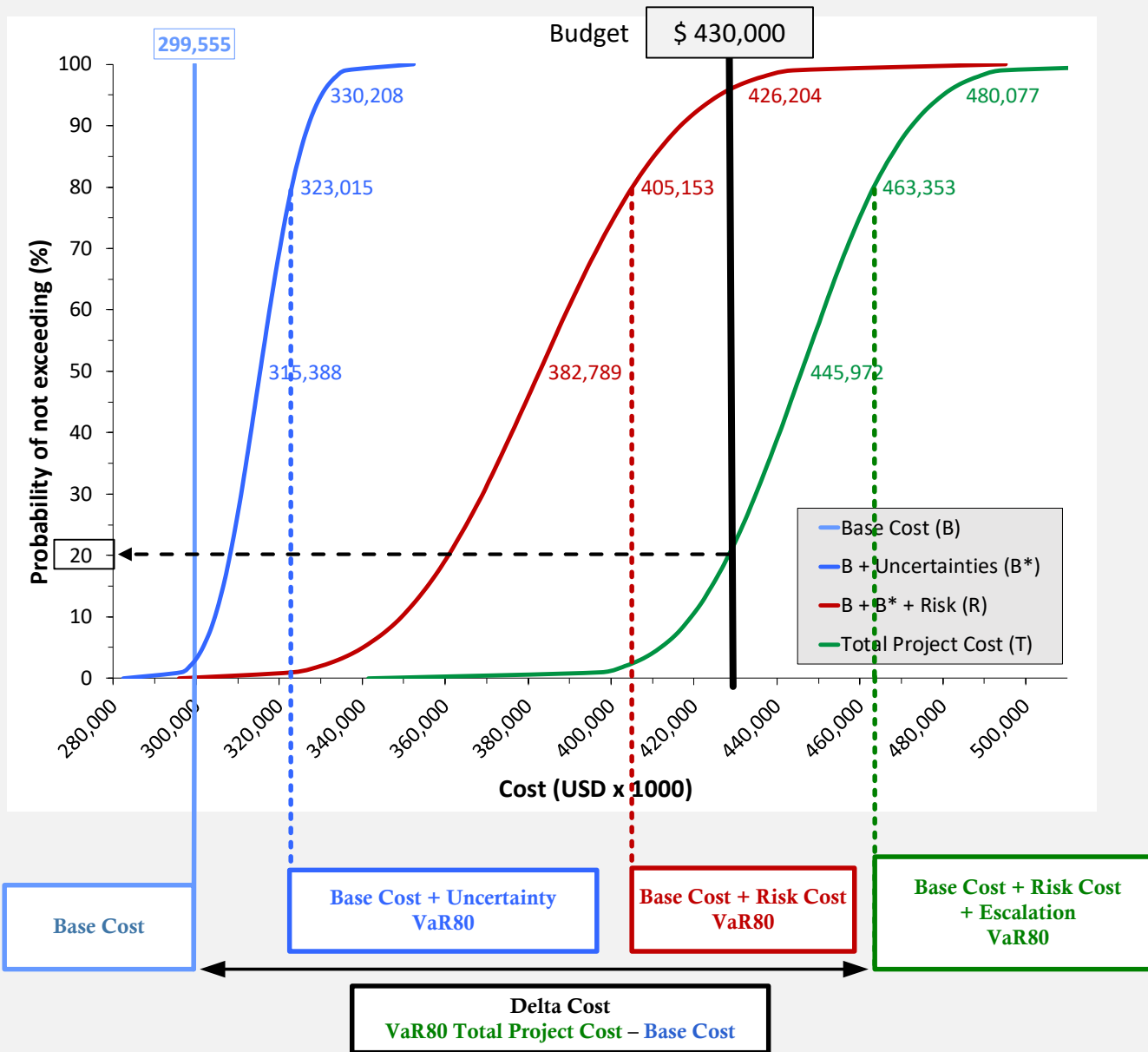
Integrated Cost and Schedule Analysis - Process



Escalation calculated from Cash Flow



Total Project Costs



Results in 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

Total	Det.	\$78,588,591.74	VarS	\$72,026,656.00	VarS0	\$83,933,360.00	VarR95	\$95,852,360.00
Escalation	Det.	\$10,568,249.38	VarS	\$9,617,237.00	VarS0	\$11,815,277.00	VarR95	\$14,250,380.00

Distribution Function (Impact in USD x1,000)

9.8172	10.0721	10.3957	10.6507	10.8795	11.0812	11.2730	11.4594	11.6398	11.8153	11.9864	12.1773	12.3655	12.5678	12.7848	13.0388	13.3260	13.6684	14.2504
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Risk

Risk	Det.	\$11,336,723.73	VarS	\$1,101,082.00	VarS0	\$12,657,875.00	VarR95	\$24,231,580.00
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Distribution Function (Impact in USD x1,000)

1.1011	1.0859	5.9382	7.3264	8.4191	9.4103	10.2889	11.1214	11.9023	12.6579	13.4498	14.2490	15.0887	15.9972	16.9534	18.0673	19.4262	21.2304	24.2316
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Base Cost

Base Cost	Det.	\$56,683,618.63	VarS	\$57,733,660.00	VarS0	\$59,392,368.00	VarR95	\$61,140,540.00
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Distribution Function (Impact in USD x1,000)

57.7317	58.0919	58.3269	58.5024	58.6947	58.8464	58.9680	59.1253	59.2584	59.3824	59.5034	59.6283	59.7687	59.9466	60.0882	60.2785	60.4984	60.7555	61.1465
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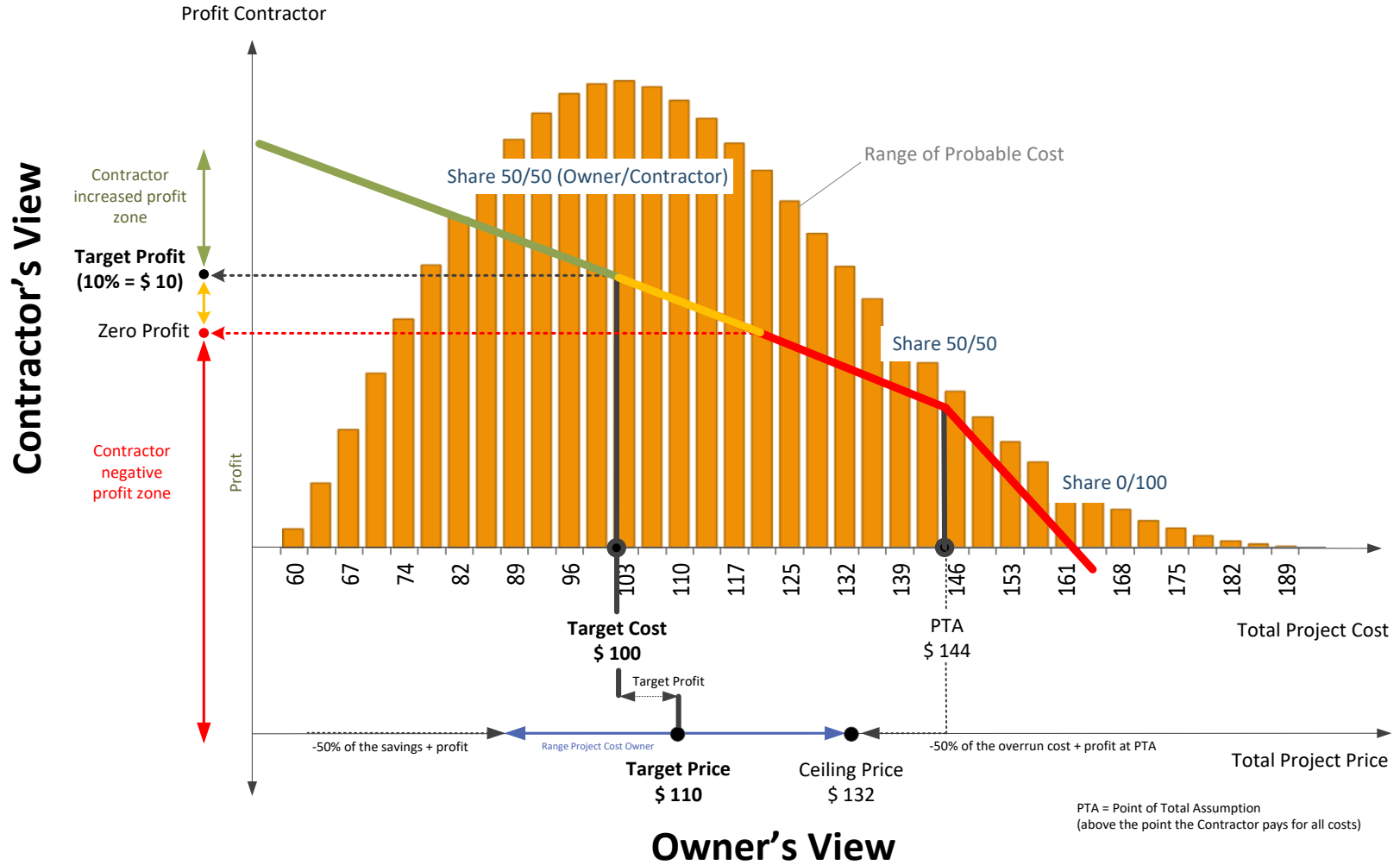
1 Version(s) Version 1 Version 1

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

1. Introduction
2. Standard vs Integrated Approach
3. Integrated Cost and Schedule Model
- 4. Results and Alternative Delivery Methods**

- The delivery method is a critical determinant
- We need to match the delivery process to the project environment (considering risk, applicable regulations, agency practice, experience and capability)
- Delivery procedures generally used for Infrastructure:
 - Design-Bid-Build (DBB) – most common
 - Design-Build (DB) – substantial number of projects
- Newer delivery procedures being used or of interest:
 - Early Contractor Involvement
 - **Fixed Price Incentive Fee**
 - Alliancing / Relationship / Consensus Contracting
- Other international contract applications (FIDIC, NCE-3c, PPC2000 Docs)

Alternative Delivery Methods – Fix Price Incentive Fee (FPIF)



Alternative Delivery Methods – Fix Price Incentive Fee (FPIF)

