ILC
Tunnelling
- from TDR to Tender & Future Drivers

Matt Sykes & Yung Loo | ARUP
International Workshop on Future Linear Colliders 2014

Belgrade – 7th Oct '14

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Contents

- Risks and Opportunities
  - From TDR to Tender
  - Site Investigation
- Project Case Studies, ILC parallels
- Future drivers and legislation
  - Building Information Management (BIM)
  - Carbon

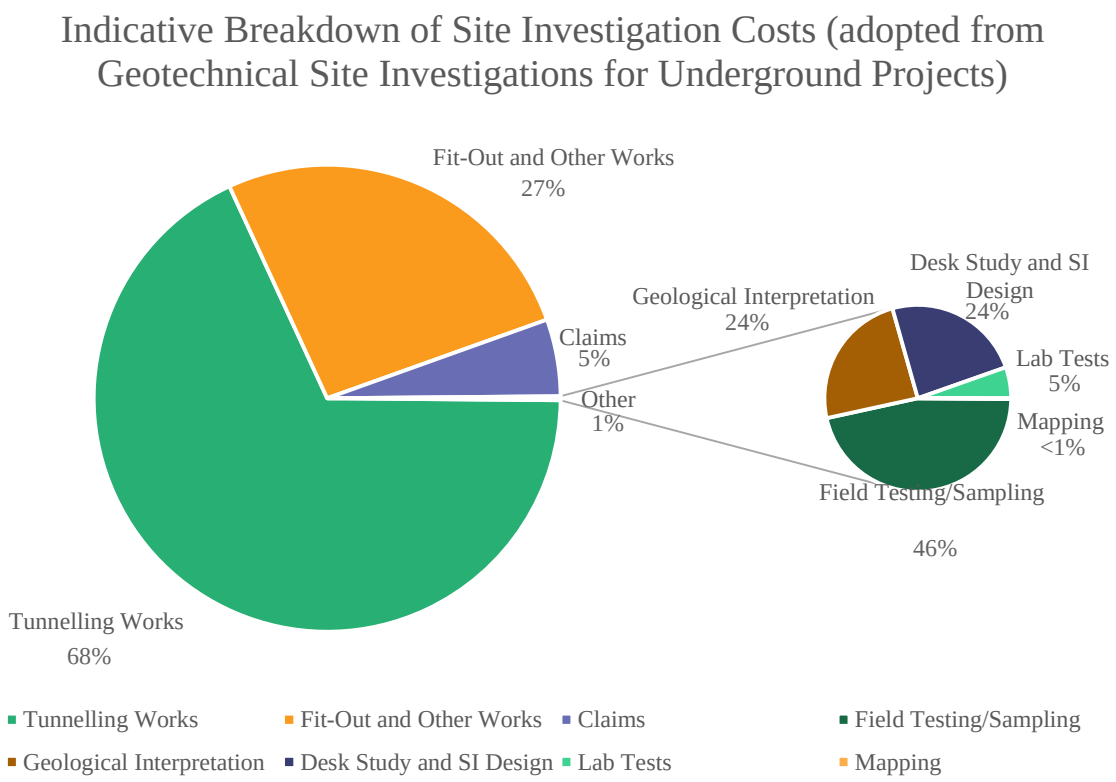
Site Investigation Process

STAGED

Stage 1: Preliminary Appreciation of Site and Site Conditions

Stage 2: Site Investigation before Construction

Stage 3: Site Investigation during Construction



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Typical Project Examples

- Tunnel Projects: ~1.5% of Project Cost (Buildings: ~0.2% of cost)

Project	Length of Tunnel, km	Length of Holes Bored, km	Bore length /m of tunnel
Lake Mead, USA	4.7	2.9	0.6
Koralm, Austria	32.9	21.0	0.6
Glendoe, UK	6	1.4	0.2
YPL, UK - Stage 1	36.0	3.3	0.1
Point 1, Point 5, LHC	-	2.8	-

- BH Length:Tunnel Length - (0.5 to 1.5)
  - Generally considered the level at which risk of cost overruns are reduced to an acceptable level
  - Need to a/c for deep-drilled boreholes / borehole spacing

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GI: Total Estimated Construction Cost

Geological Complexity	Construction Complexity: Low	Medium	High	V. High
Low	<0.2%	<0.4%		
Med		<0.8%	<1.2%	
High			<1.8%	<3%
V. High				>3%

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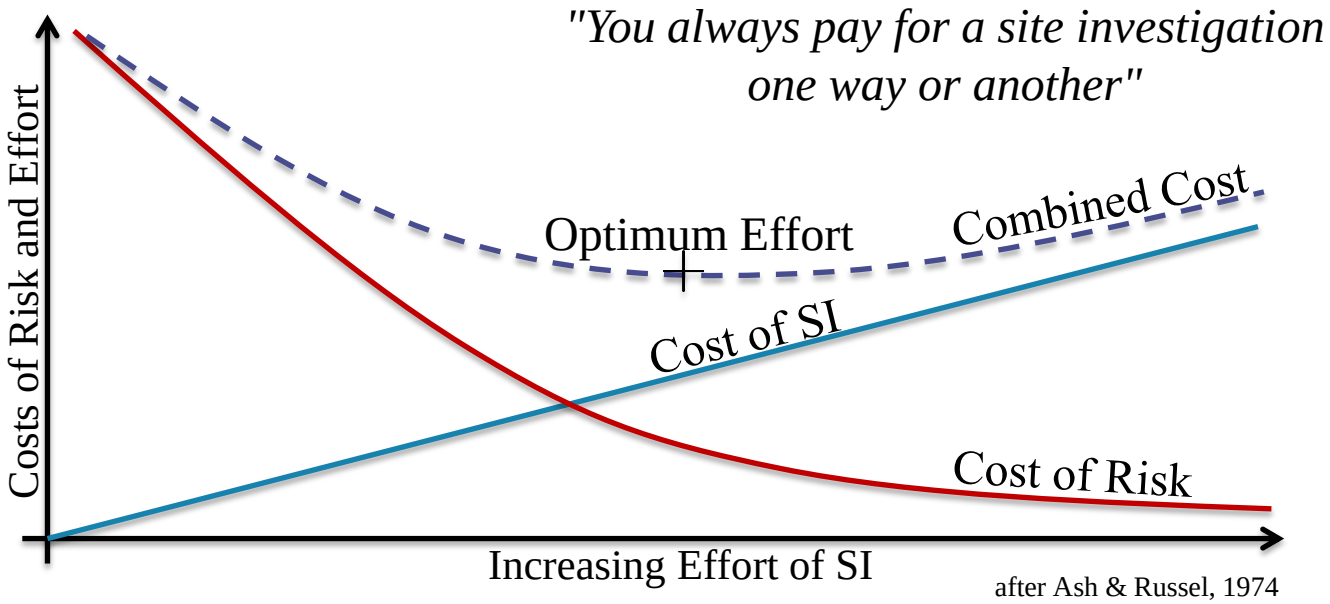
Cost vs Risk



Site investigation costs as % of tender price	Increase in costs of construction (%)	
	Range	Mean
<1	0 - 100	26
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after Whyte, 1998

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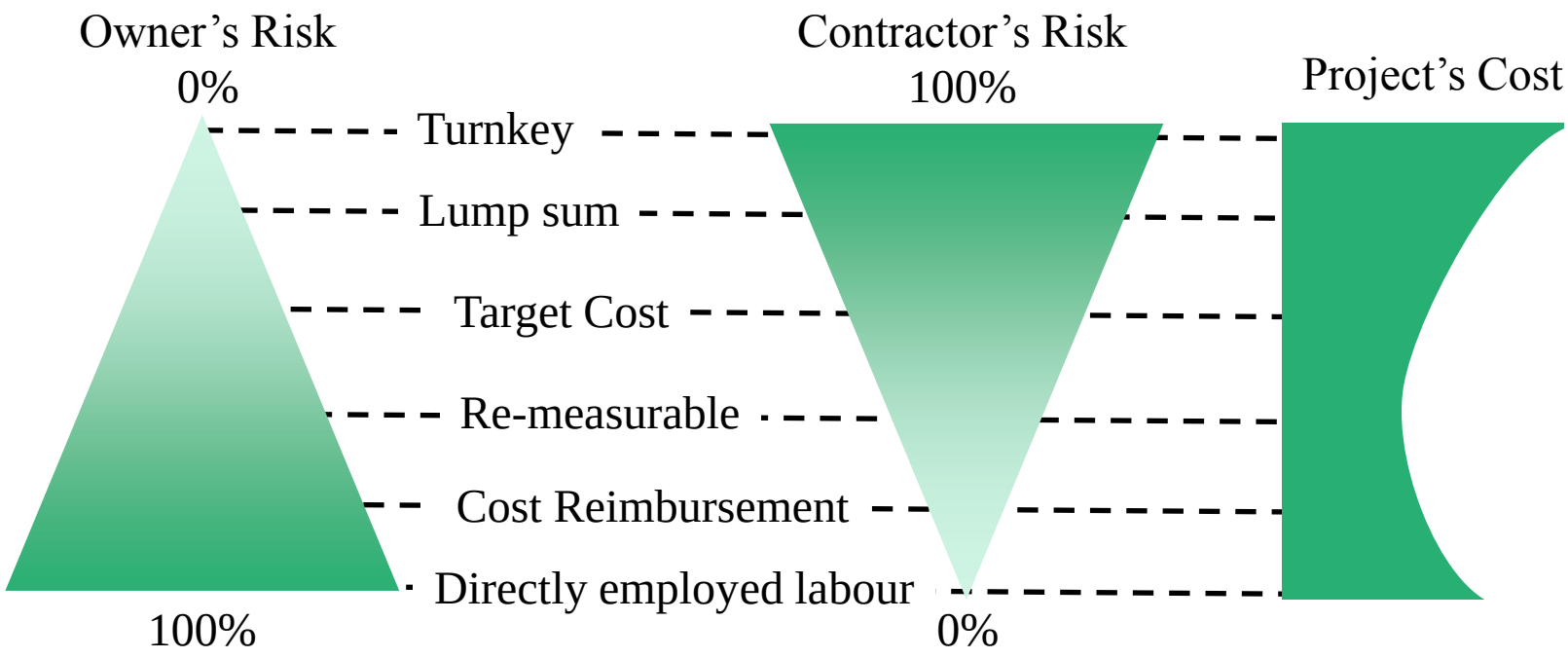
Contract models



After Kleivan, 1988

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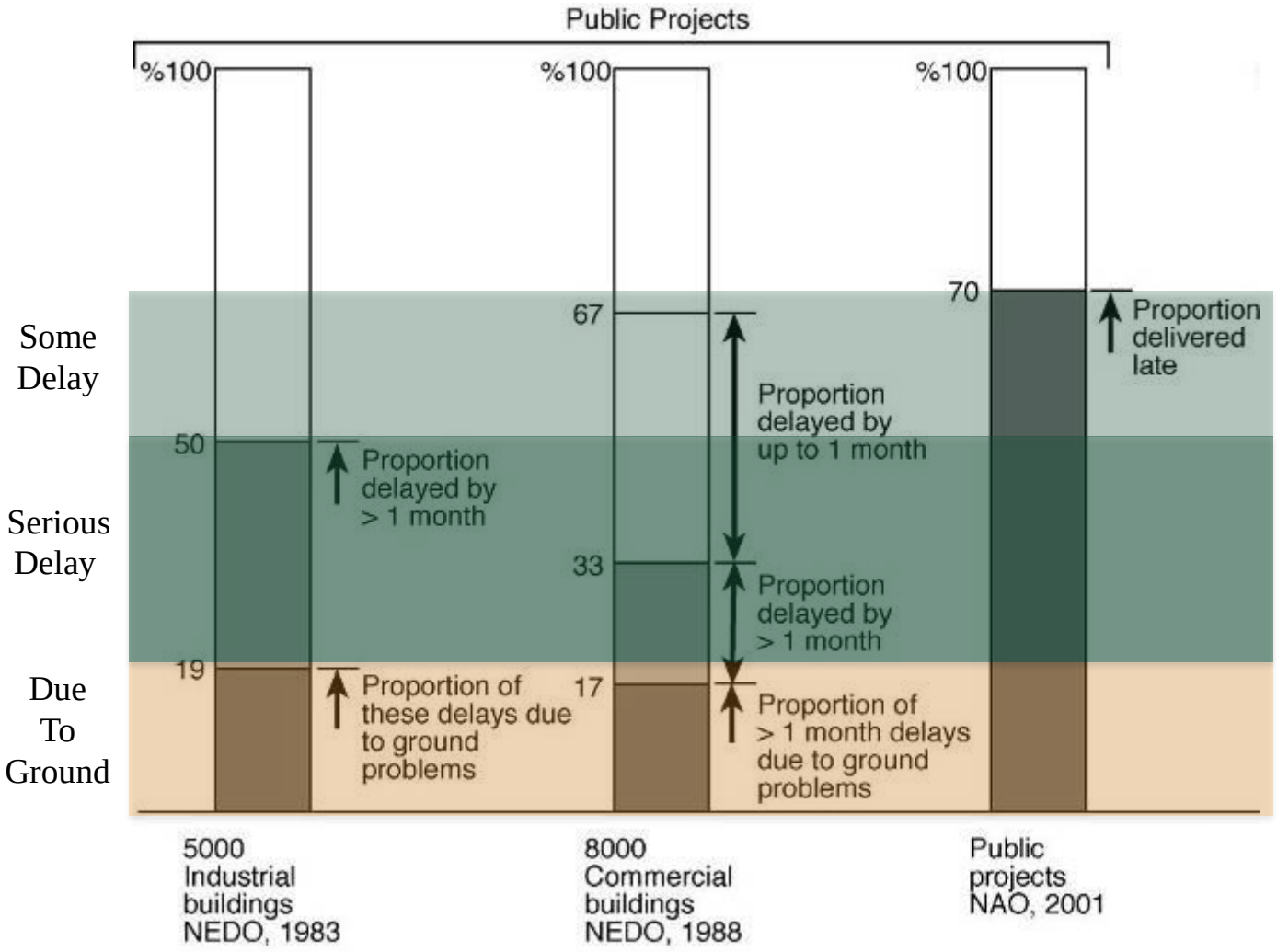
Project Overruns



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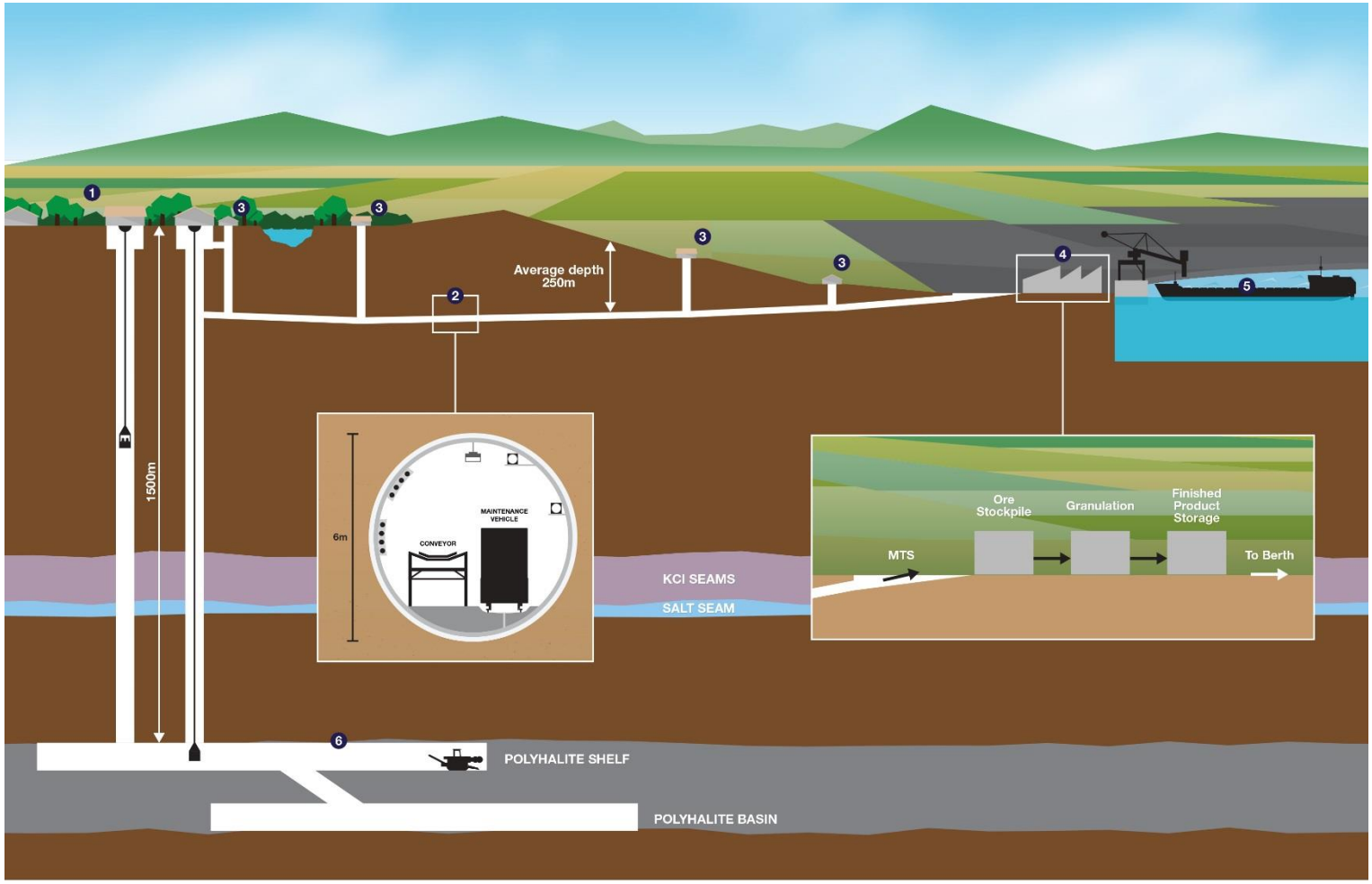
Rock Tunnel – Causes of Delay

- Littlejohn et al (1994) identified the following causes for these problems for rock tunnels:
  - Unforeseen man-made obstructions
  - Inappropriate support systems for the rock encountered
  - Unforeseen difficulties in handling and removal of spoil due to lack of durability data
  - Excessive groundwater ingress and instability
  - Excessive overbreak and collapse of blocky and “slabby” rock
  - Poor TBM/Drill & Blast performance

Remote Working Considerations

- Cost of access and mobilisation of resource and equipment
- Making and maintaining access to drilling site (helicopter)
  - Avoid construction of environmentally damaging access roads
- Small diameter pilot tunnel

Case Study: York Potash



1 MINE SITE
2 MINERAL TRANSPORT SYSTEM
3 MAINTENANCE, VENTILATION AND EMERGENCY ACCESS
4 TEESSIDE GRANULATION AND STORAGE
5 PORT INFRASTRUCTURE
6 CONVENTIONAL UNDERGROUND MINING

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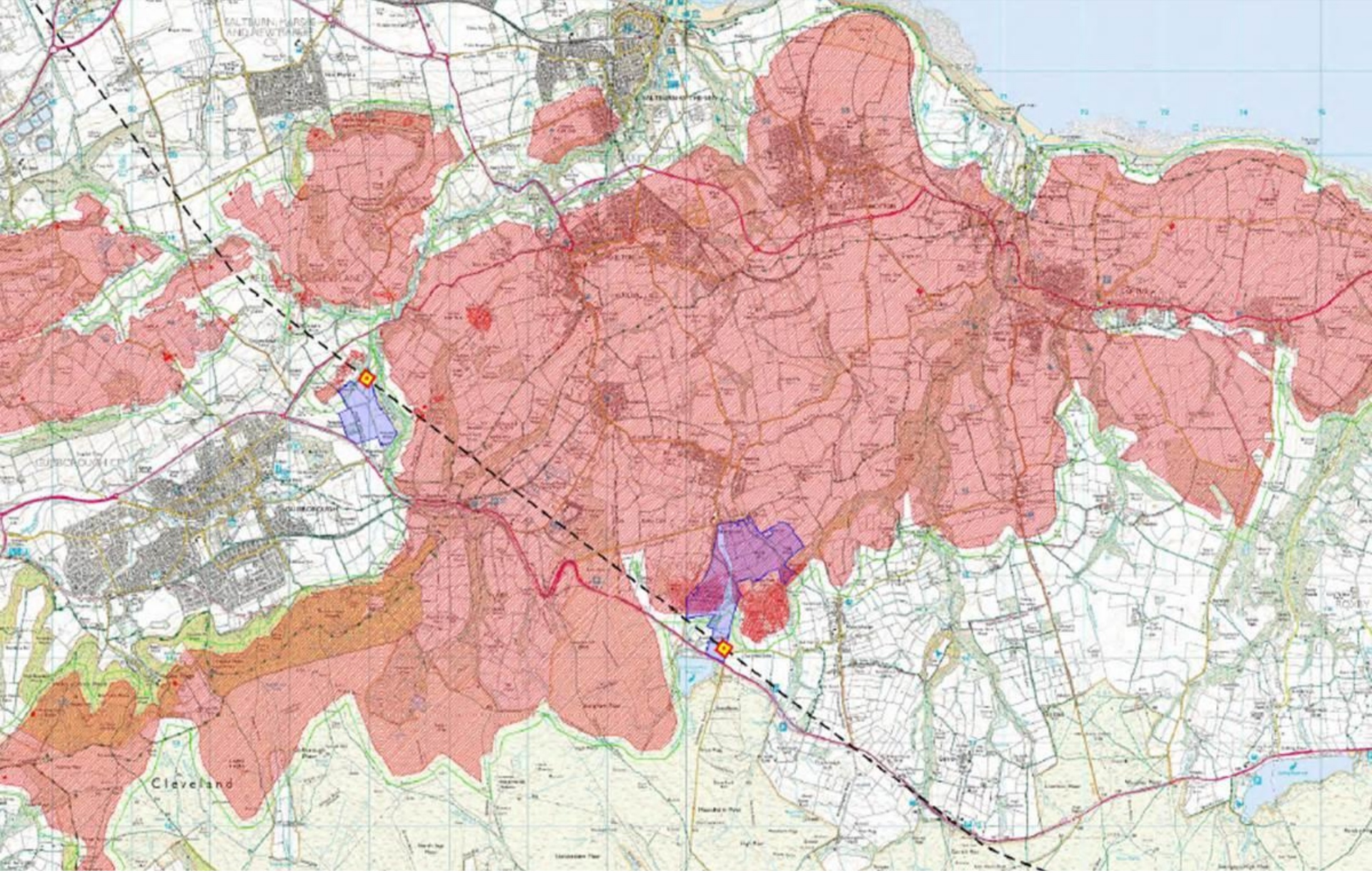

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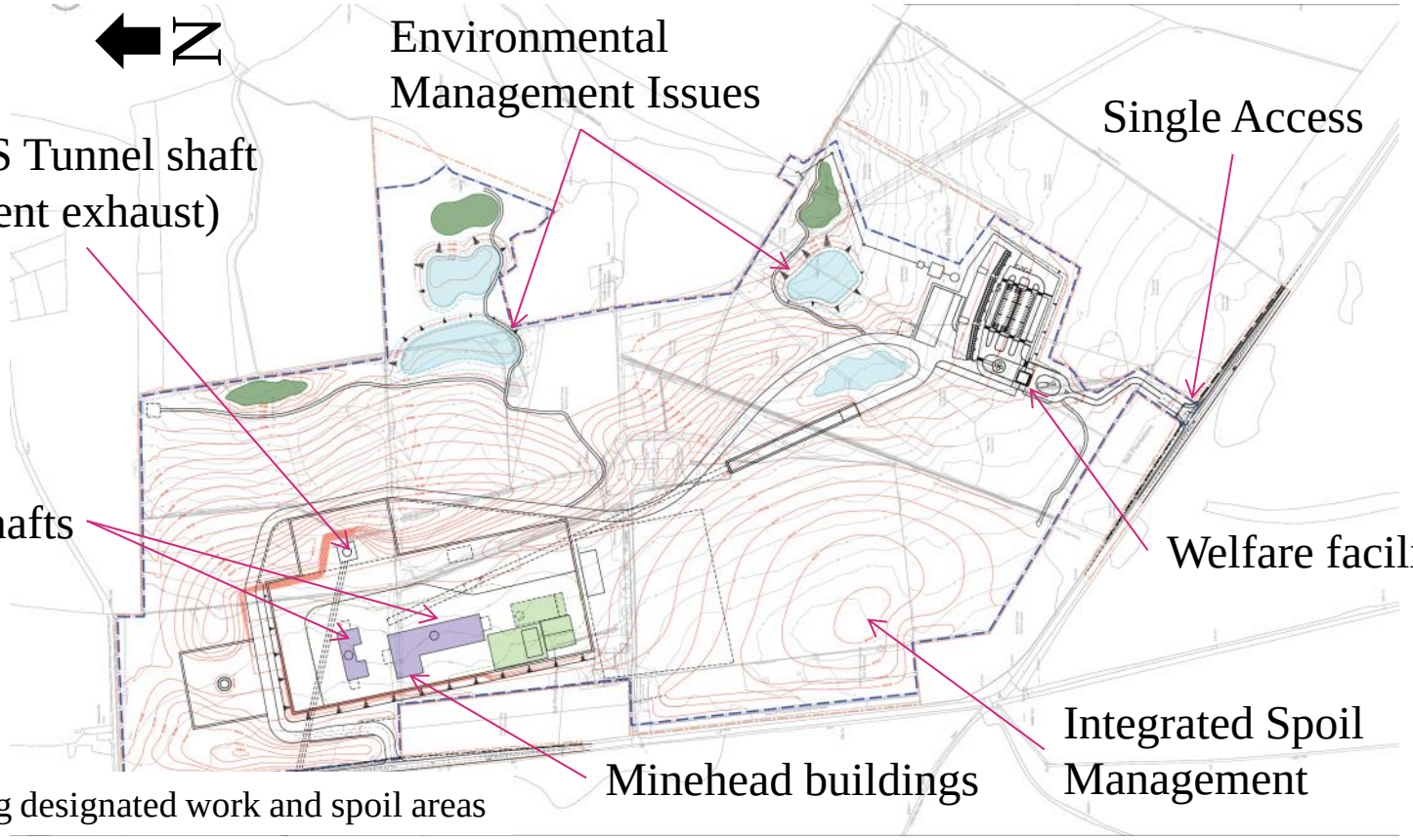
Mine Site – Permanent Configuration



Anticipating designated work and spoil areas

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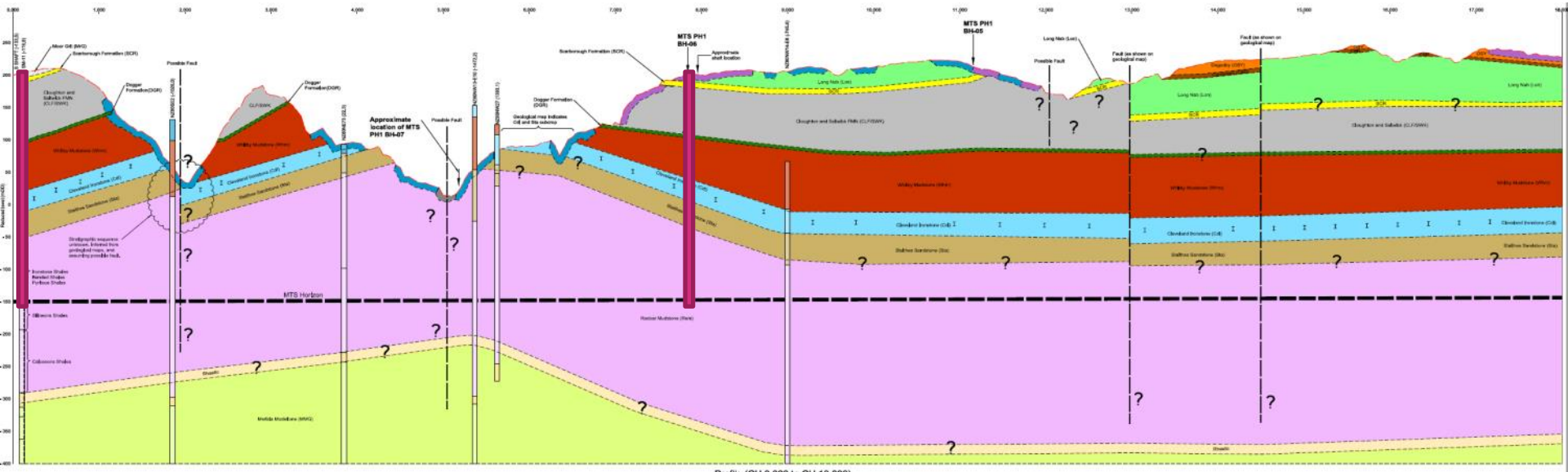
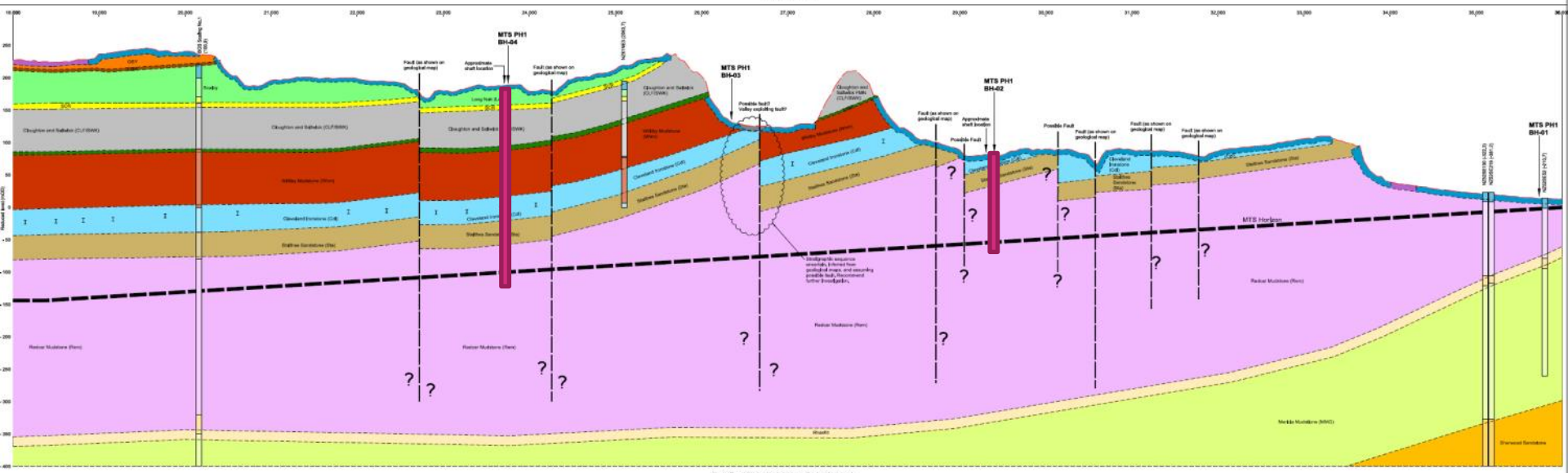


Profile (CH 0.000 to CH 18.000)



Profile (CH 18.000 to CH 36.000)

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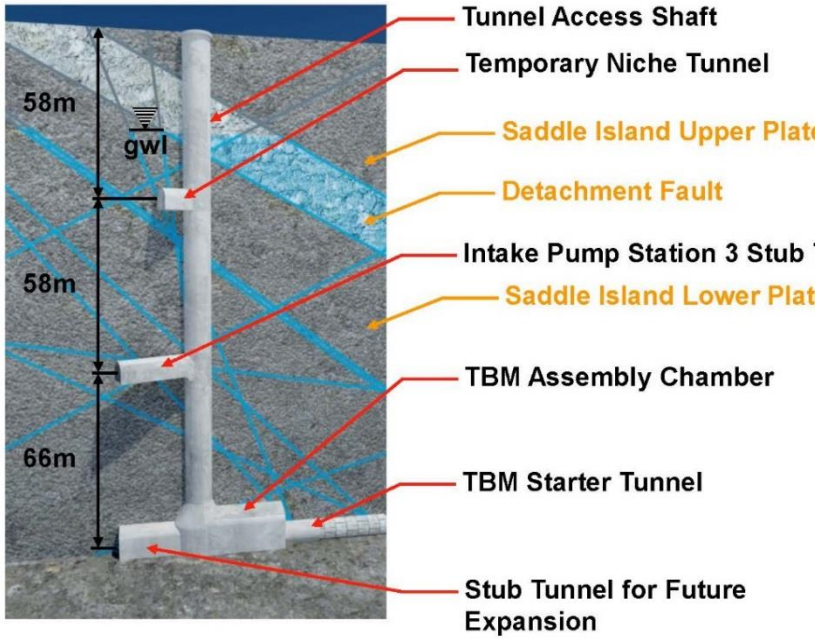
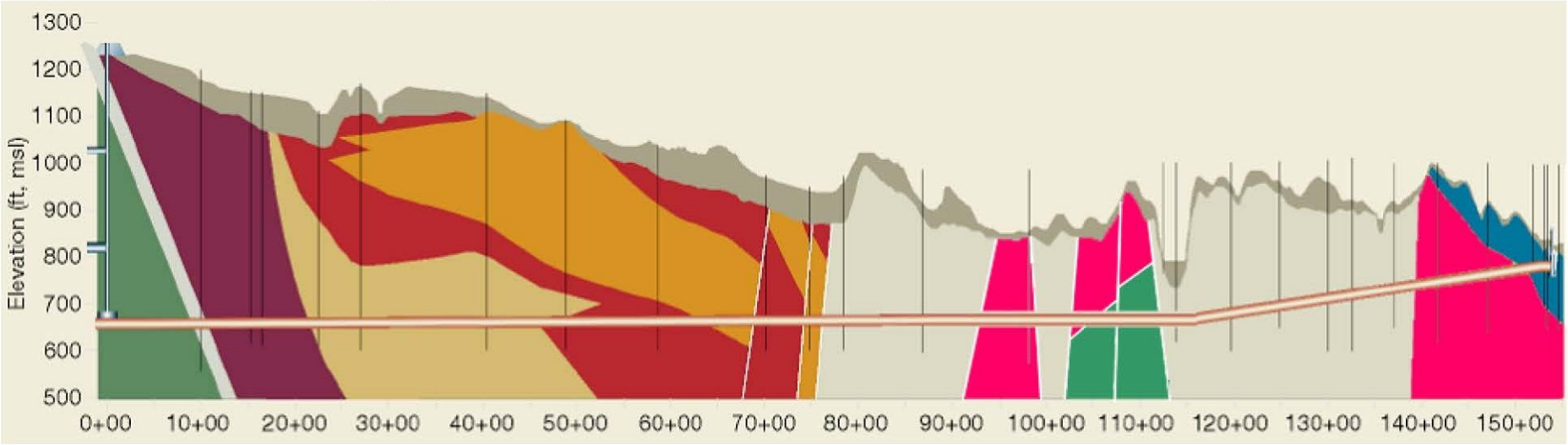
Group	Parameter	Test method	Comments
Material properties (laboratory)	Axial compression, σu	UCS laboratory test on core	Soaked or as received
	Axial Compression, σp	PLT laboratory test on core	
	Tensile Strength σt	Brazilian laboratory test on core	Or by calculation derived from UCS (σ_u/10)
	Modulus (E)	UCS with stress/strain laboratory test on core	ISRM method?
	Shear modulus (G)	By calculation	Derived from E and ν
	Modulus of deformation (Erm)		
	Poisson's Ratio (ν)	UCS with stress/strain laboratory test on core	
	Density (ρb, ρd and ρp)	Laboratory test on core	
	Porosity (η)	Laboratory test on core	
	Moisture content (w)	Laboratory test on core	
	Plasticity (Ip)	Laboratory test on core	Mincing required (see Atkinson et al 2003 Tunnelling in Mercia Mst QJEGEH)
	Swelling	Laboratory test on 'minced' core samples in an oedometer	
	Slake durability tests	Laboratory test on core	
	Abrasivity tests	Laboratory test on core	
	Clay fraction	Laboratory test on core	BS methodology
	Clay fraction (XRD)	Laboratory test on core	Clay fraction
	Clay mineralogy (SEM)	Laboratory test on core	Clay mineralogy
	Clay mineralogy (microscopy)	Laboratory test on core	Clay mineralogy
	pH and sulphate	Laboratory test on core	
	Waste Classification Leachability/WAC	Laboratory test on core	
	Shear wave velocity (Vp and Vs)	In situ downhole geophysics	
	Gamma-Gamma, natural gamma, neutron, resistivity,	In situ downhole geophysics	
	Caliper and verticality	In situ downhole geophysics	
Groundwater (in situ and laboratory)	Fluid flow, temperature conductivity	In situ downhole geophysics	
	Water pressure (ρw)	In situ groundwater monitoring	
	Permeability (k)	In situ packer tests	
	pH and sulphate	In situ and laboratory test on groundwater	Other geochemical tests may be required
Mass properties (in situ)	Vertical in situ stress (σv)	By calculation and HPDT in situ testing	Derived from γ.z
	Horizontal in situ stress (σH and σh)	HPDT in situ testing	σh = k.σv (where k=ν/1-ν) (Hoek p165)
Mass strength (laboratory)	Cohesion c' and cr	Shear box / triaxial laboratory test on core	Saw cut or joint?
	Mass strength Phi ϕ' and ϕr	Shear box / triaxial laboratory test on core	Saw cut or joint?
	Shear stress (τ)	Shear box / triaxial laboratory test on core	Saw cut or joint?
Mass strength (in situ)	Fracture index (iF)	Field test on core	
	RQD (RQD)	Field test on core	
	Dip (D)	In situ downhole geophysics	Optical / acoustic televiewer
	Dip direction (DD)	In situ downhole geophysics	Optical / acoustic televiewer

Case Study: Lake Mead





Overburden, alluvium

Muddy creek formation: Gypsiferious mudstone

Muddy creek formation: Interbedded siltstone, sandstone, mudstone conglomerate

Muddy creek formation: Conglomerate

Muddy creek formation: Conglomeratic breccia

Callvilla mesa formation: Basalt

Red sandstone unit: Conglomeratic breccia

Saddle Island upper plate: Schist, amphibolite, gniess, pegmatite, dacite intrusives

Saddle Island lower plate: Amphibolite, schist, gniess

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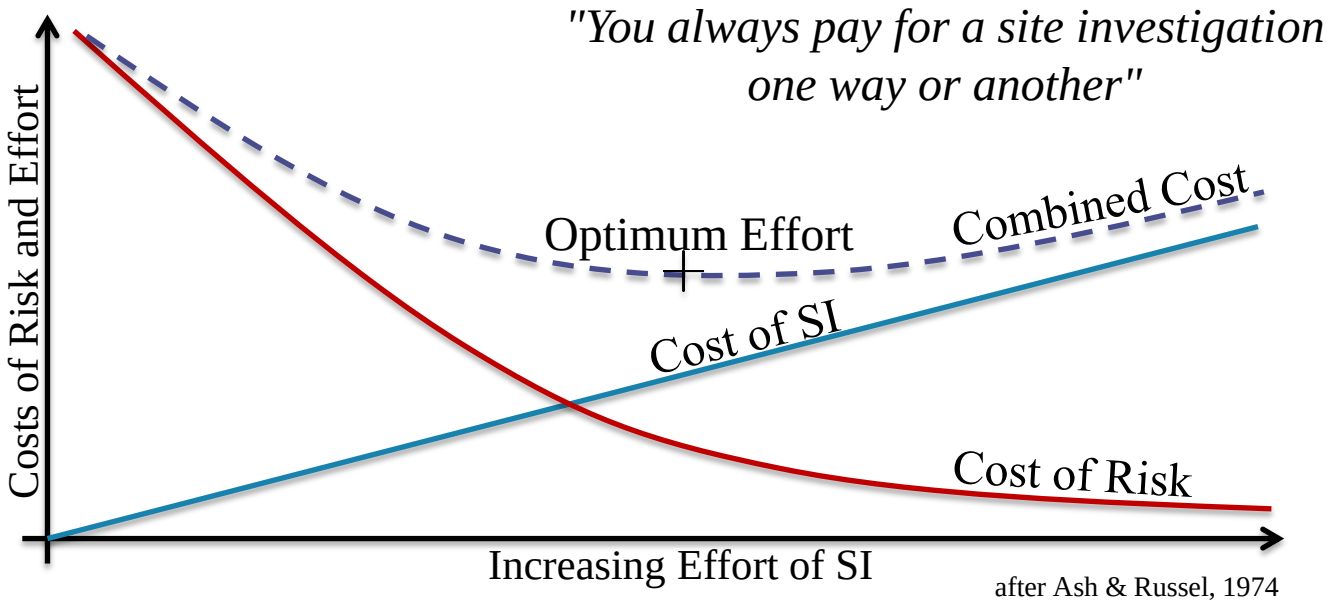
Cost vs Risk



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after Whyte, 1998

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Up Front Costs

- Site Investigations in remote areas
  - Accept fewer boreholes, but greater data volume
  - Hitting the risk areas for highest design value
  - Contract mechanisms to deal with uncertainty
  - **1 to 3%** of build cost, early money more difficult to get?
  - Don’t forget access costs
- Design
  - Level to suit approvals and funding
  - Approximate split for design and build (UK)
    - **2%** for early engineering (feasibility, fatal flaw, investigations)
    - **6%** for design
    - **8%** for client costs
  - Early costs (SI and Early eng) up to 5% of build costs……

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Carbon Management

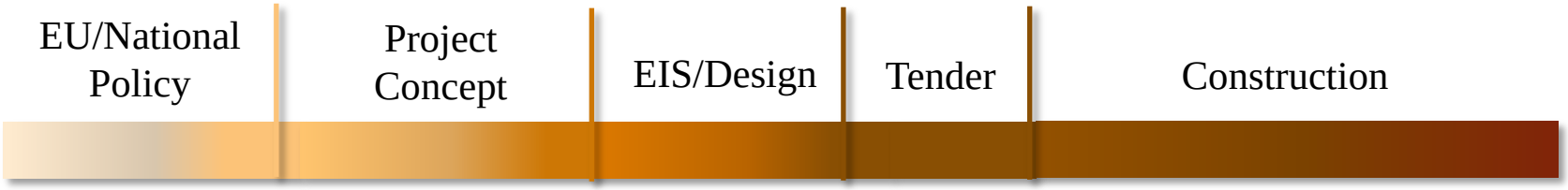
Aspiration

- Doing the right thing
- Corporate responsibility
- Public perception
- Early legislation
- Industry aspiration

Taxation

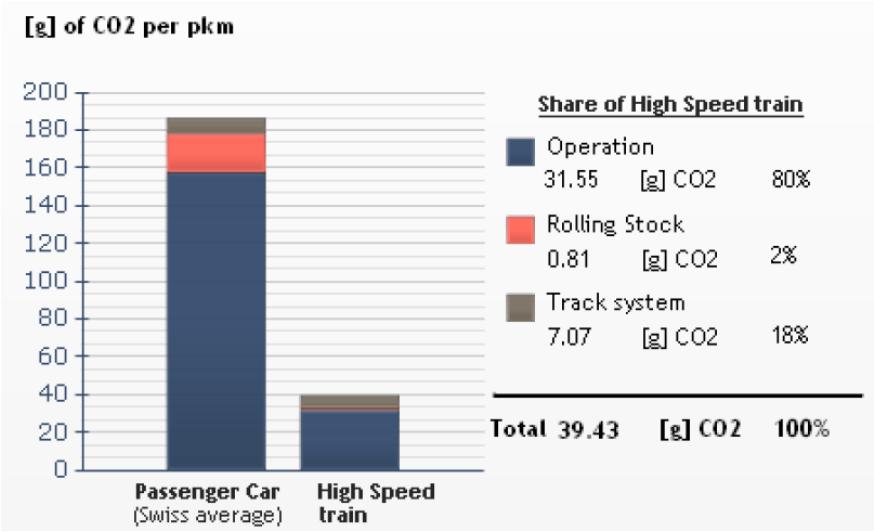
- Carbon taxes on the use of **fossil fuels** based on greenhouse gasses produced.
- Duties on **imported goods** containing significant non-ecological energy input
- Severance taxes on **extraction** of mineral, energy, and forestry products.
- Specific taxes on **technologies and products** which are associated with negative effects
- Waste **disposal** taxes and refundable fees
- Taxes on effluents, pollution and other **hazardous waste**
- Site valuation taxes on the unimproved **value of land**

The Early Effects



The Early Effects

EU/National Policy	Project Concept	Design	Tender	Construction



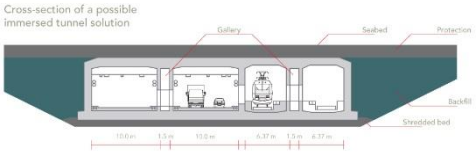
UIC Dec 2009

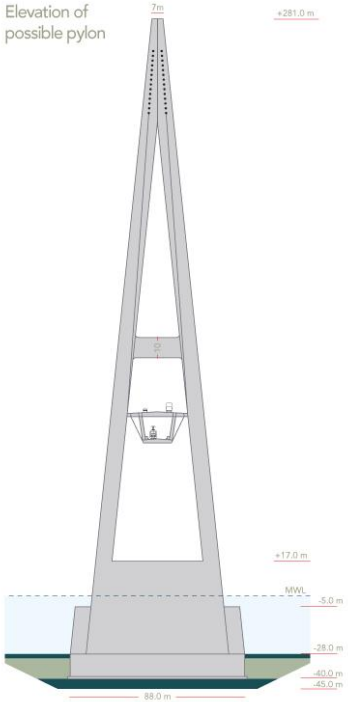
"Transport is the only sector in which greenhouse gas emissions are growing in the EU and this is not compatible with long-run targets for overall emissions levels" CER 2009

- 2008, the European Commission proposed a revision to the Eurovignette directive which allows charges to reflect congestion, local air pollution and noise

The Early Effects

EU/National Policy	Project Concept	EIS/Design	Tender	Construction





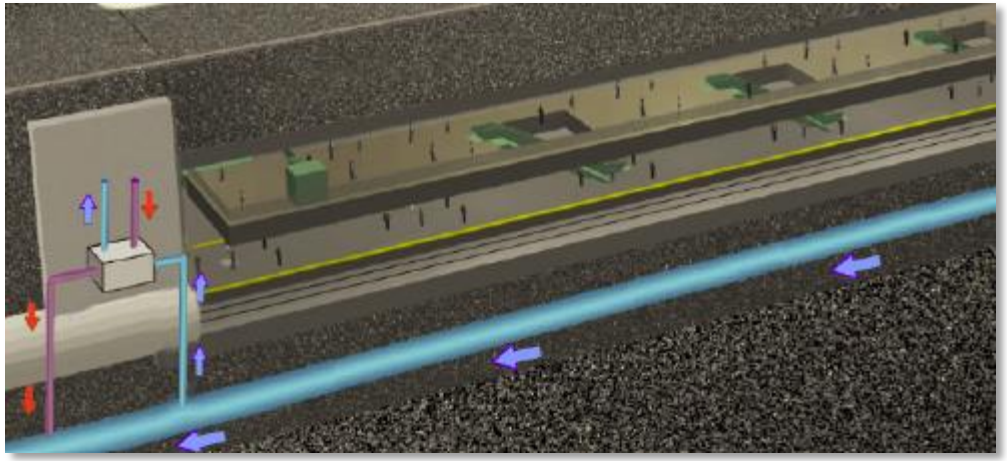
Bridge versus Tunnel

- Fehmarnbelt
- Forth Crossing
- Tappan Zee
- Antwerp
- Alaskan Way

Level out € and CO_2 becomes critical

The Early Effects

EU/National Policy	Project Concept	EIS/Design	Tender	Construction



<u>Public view/Approvals</u>

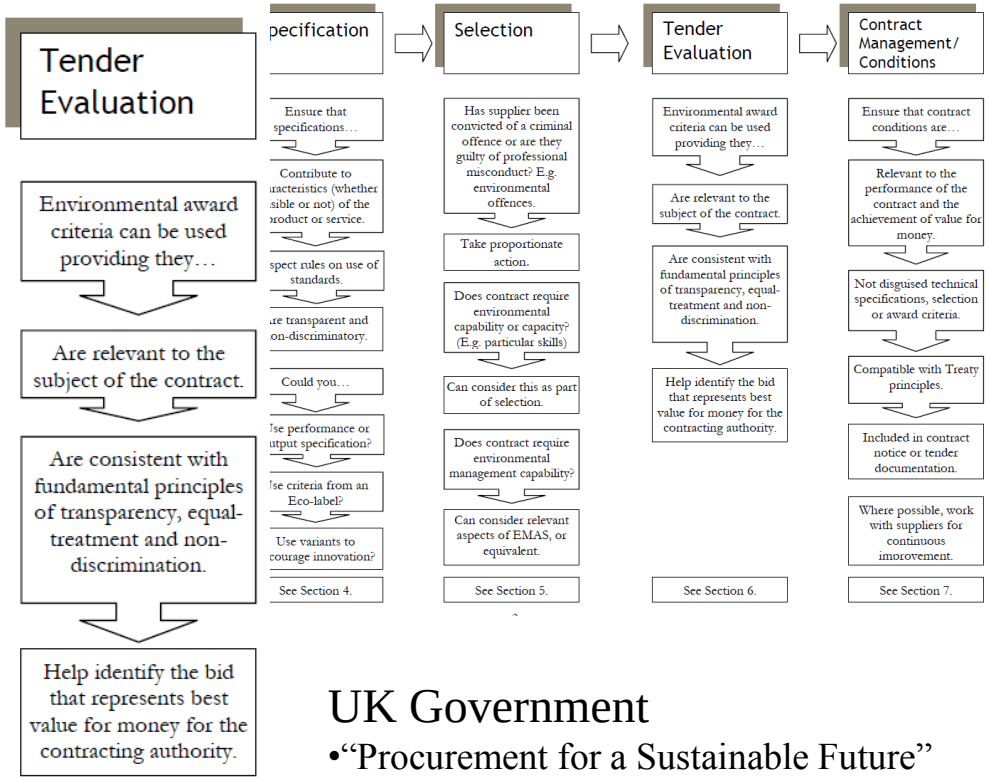
- Realising efficiency and project responsibility
- Written into Design & performance requirements

<u>Initiatives</u>

- Energy savings….operation Rehau, Janbach….Crossrail
- Lean Design

The Early Effects

EU/National Policy | Project Concept | EIS/Design | **Tender** | Construction



Tender and Prequal Requirements

- Generic Corporate policy statements
- Transition to proof that proposals "meet the mark"

UK Government

•"Procurement for a Sustainable Future"

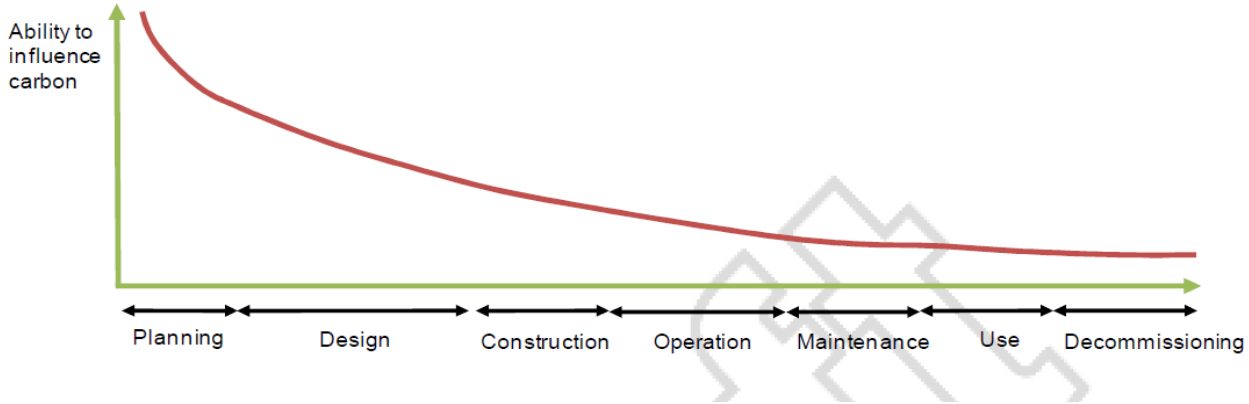
•Centre of Expertise in Sustainable Procurement (CESP)

The Early Effects

EU/National Policy	Project Concept	EIS/Design	Tender	Construction

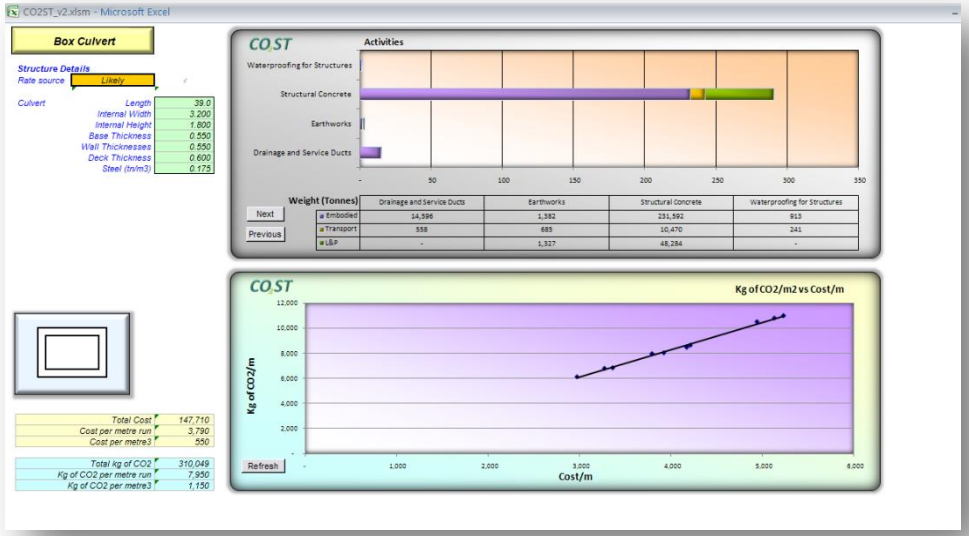
The realisation of a better end result?

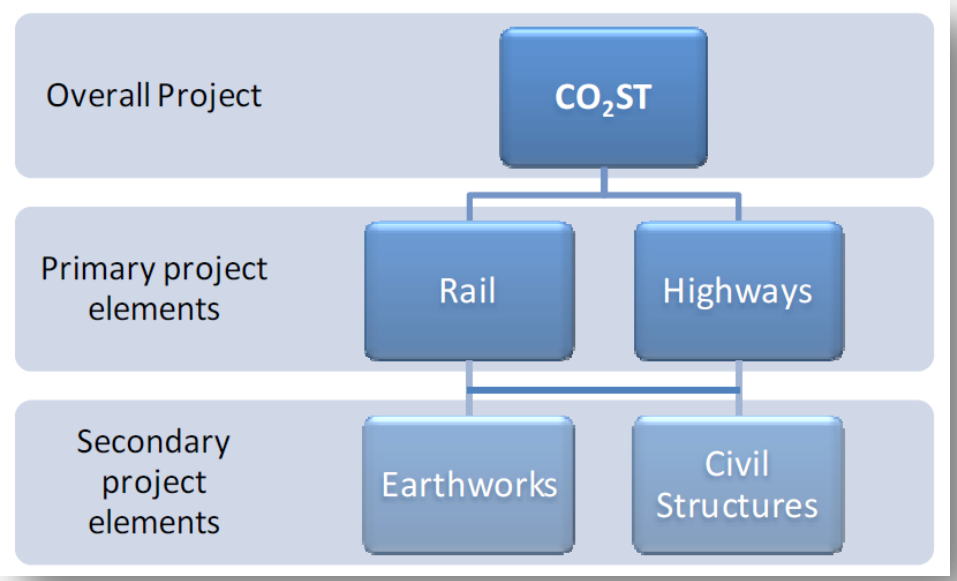
- Aspiration
- Efficiency
- Profit?

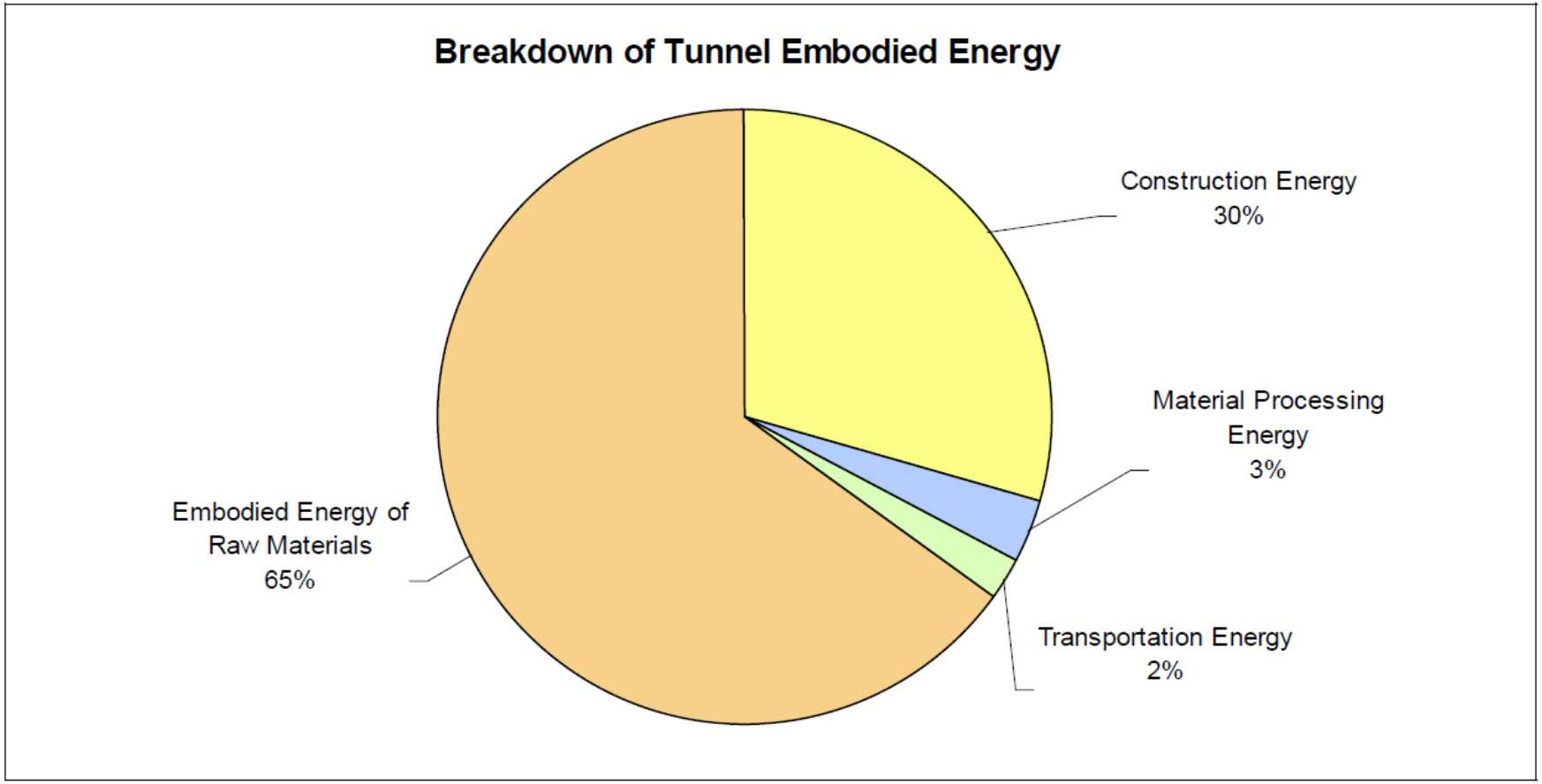


CO_2ST

- A tool for top-down estimates for cost and carbon
- Based on research in association with Cambridge
- Growing database of BoQs from various projects
- Allows rapid assessment of CO_2 for projects at early stages






Breakdown of Tunnel Embodied Energy
Construction Energy
30%
Material Processing
Energy
3%
Transportation Energy
2%
Embodied Energy of
Raw Materials
65%

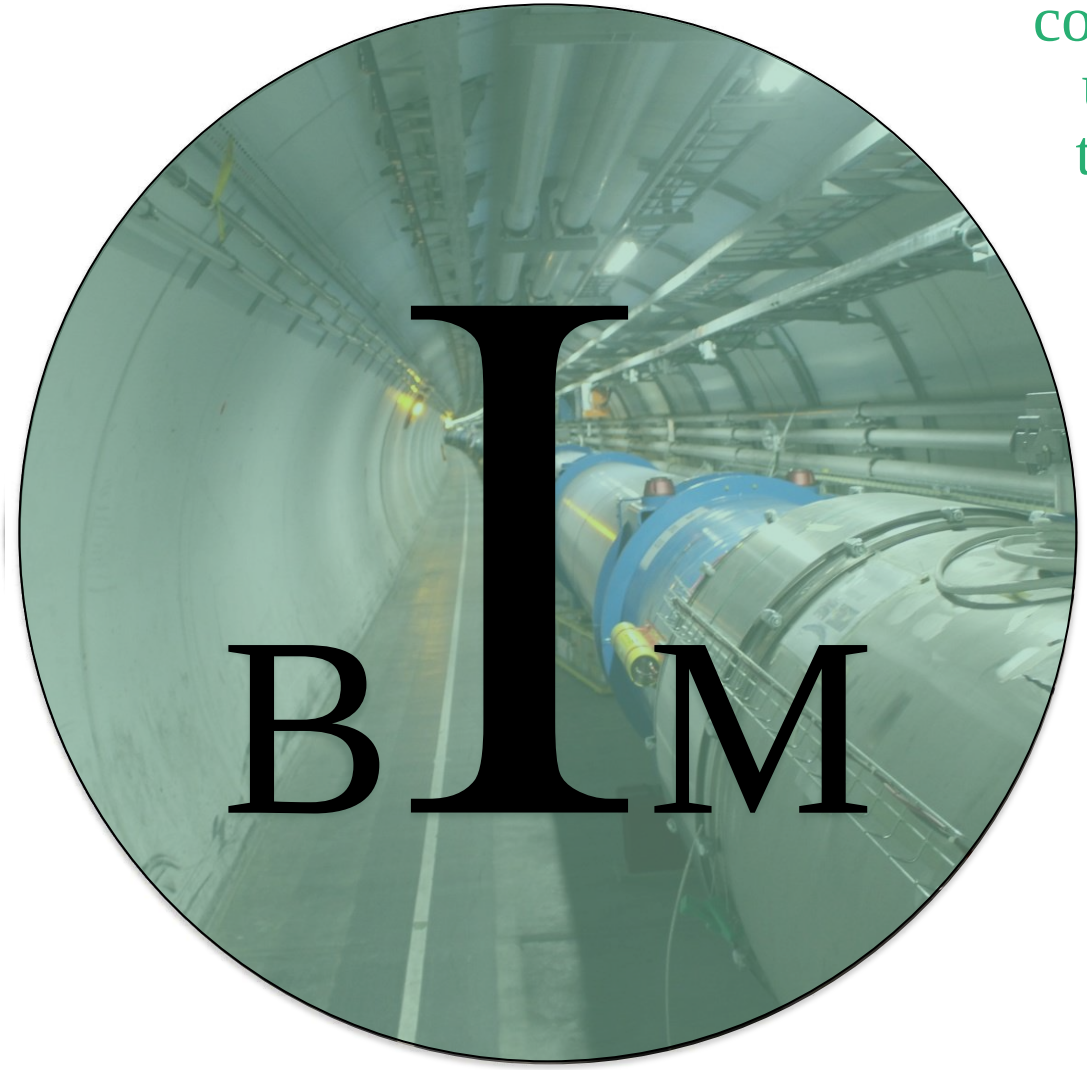
- Cost sensitivity
  - To local market
  - To economic cycle
  - To political influences
  - To good business

Cost / CO_2ST

Which is the better measure of efficiency?

- Cost is volatile……CO_2 isn't
  - We can now compare multiple projects to see if design and construction are efficiently carried out
  - Contractors can assess projects outside fluctuation of unit prices and across different markets
  - Clients and funding agencies can understand value and efficiency from another perspective

BIM



Construction Industry Council, CIC - Growth through BIM (2013)

"Building Information Modelling (BIM) is a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets."

BIM

- Design
- Build
- Operation & Maintenance
- Asset & Organisational Performance
- Social Performance

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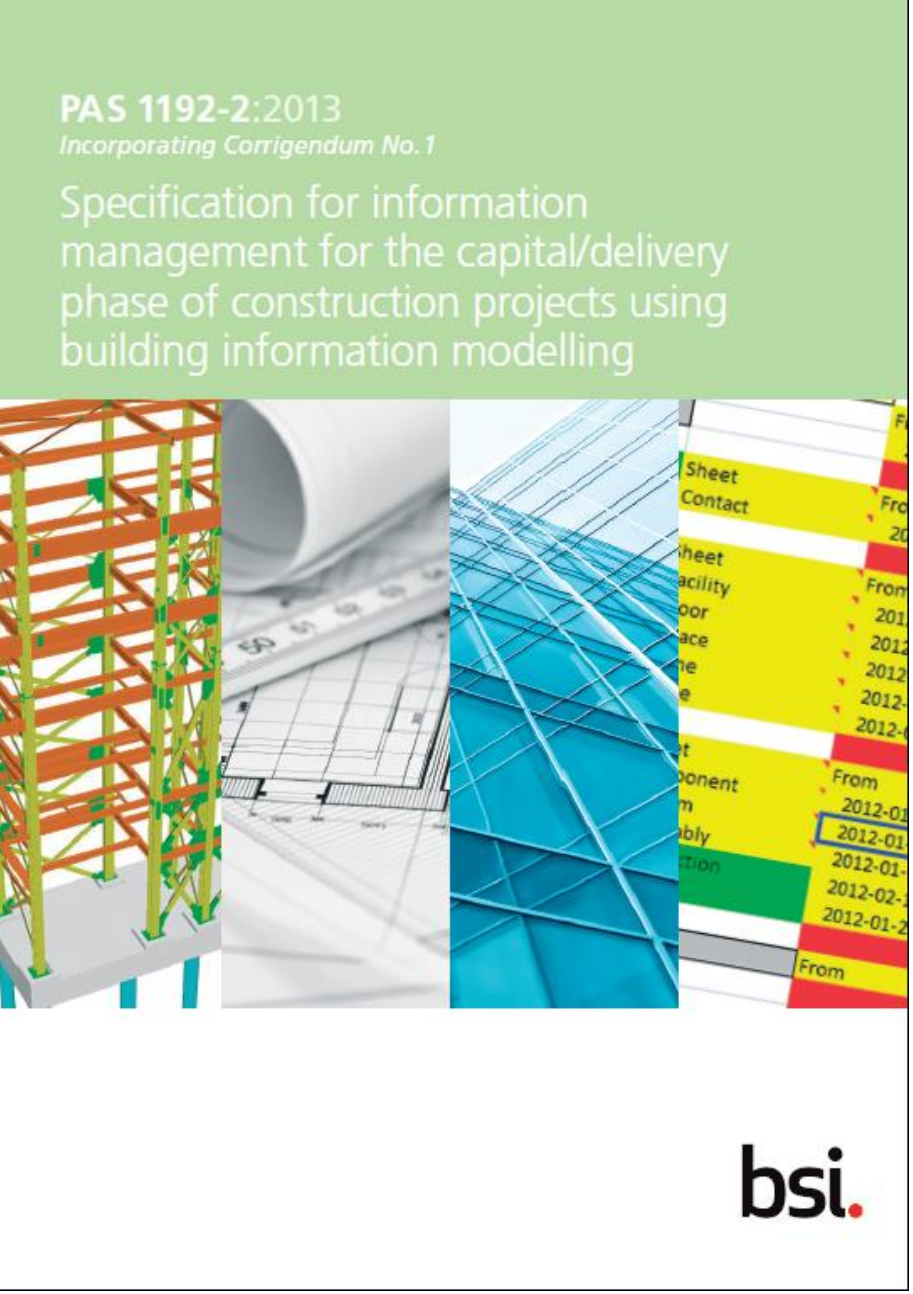

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All construction companies tendering for Government work required to achieve level 2 BIM by 2016

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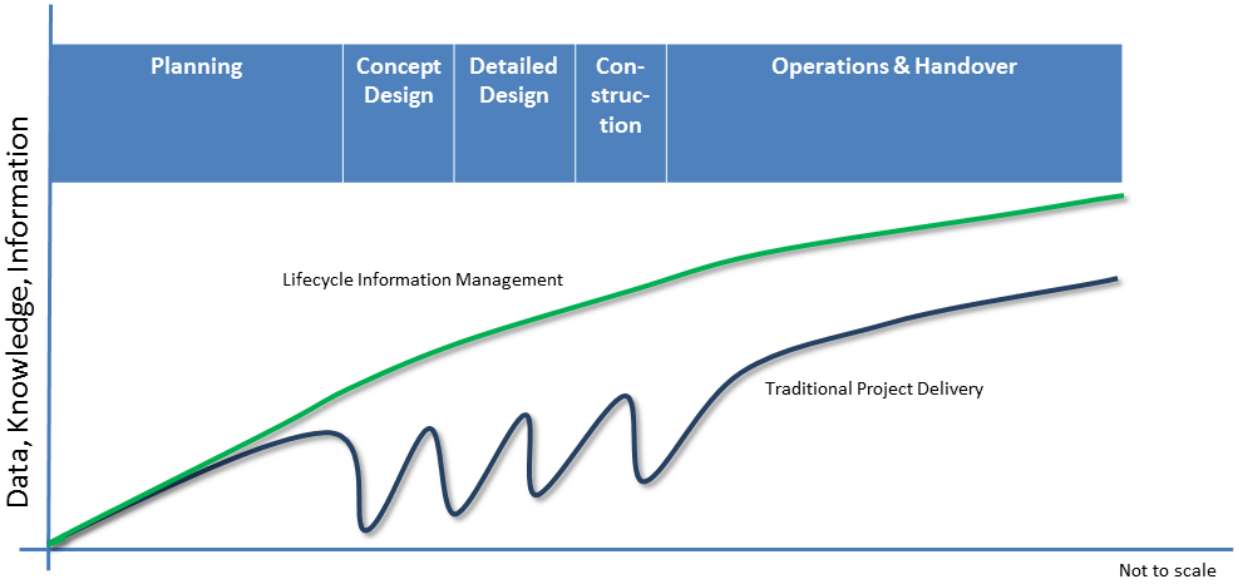

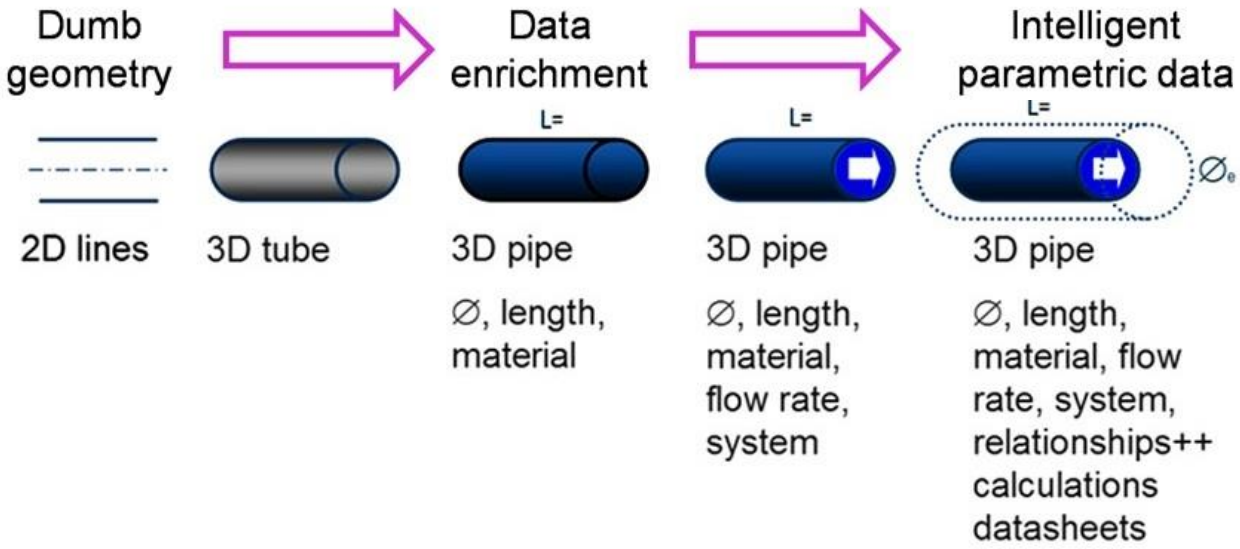

MLIT, Ministry of Land Infrastructure, Transport and Tourism in **Japan**, executed 38 BIM pilot projects for Infrastructure last year.

USA – National BIM Standards

Korea – BIM Roadmap and Application Guide

Australia – National Building Information Modelling Initiative and Guide

Singapore – BIM Regulation Pilot Guidelines

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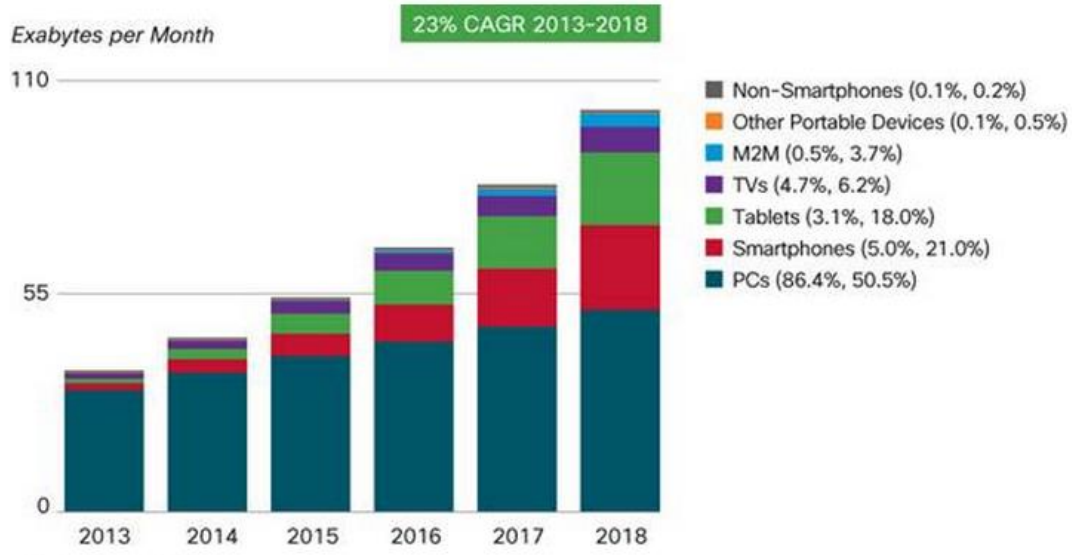
Better Information Management

- International Association of Engineering Insurers (IAEI)
  - €570M of economic losses incurred in 18 tunnelling projs (1994-2005)
  - Av. delay in completion – 19mths
- Failures in ground-related construction projects are mainly due to shortcomings in the **use of available data and knowledge** as opposed to uncertainty due to unknown factors. - Cardenas et al (2013)



Source: Cisco VNI, 2014
The percentages in parentheses next to the legend denote the device traffic shares for the years 2013 and 2018, respectively.

Cisco® Visual Networking Index (VNI) Global Internet Traffic

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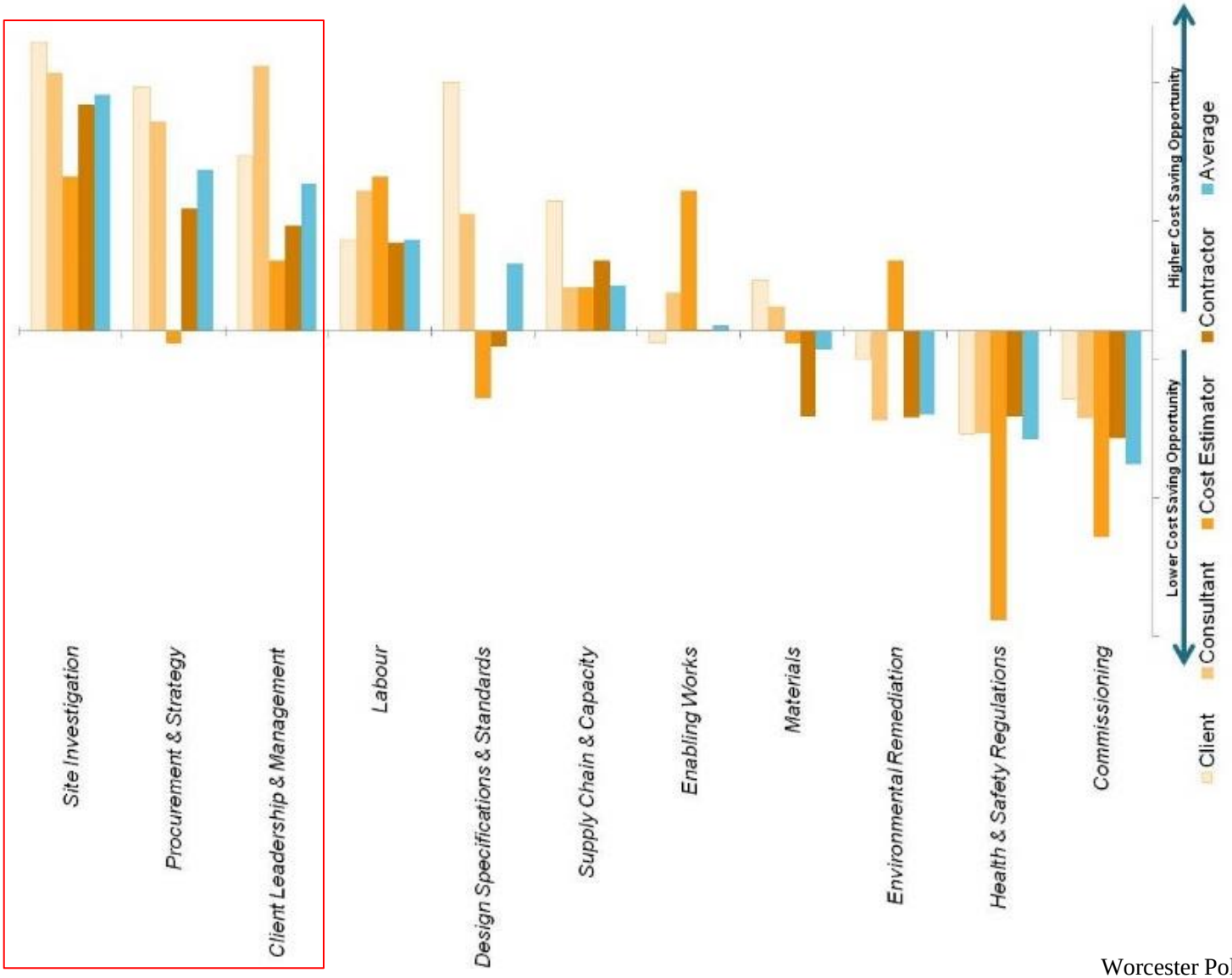
Better Information Management



Worcester Polytechnic Institute, 2012

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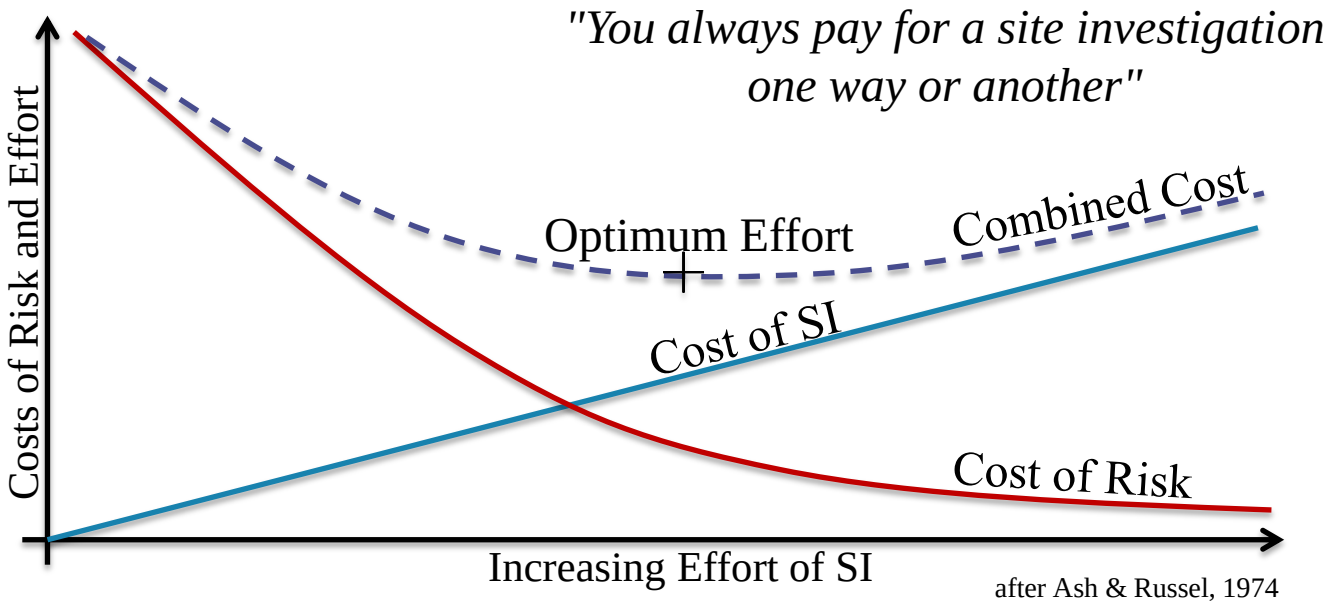
Cost vs Risk



after Whyte, 1998

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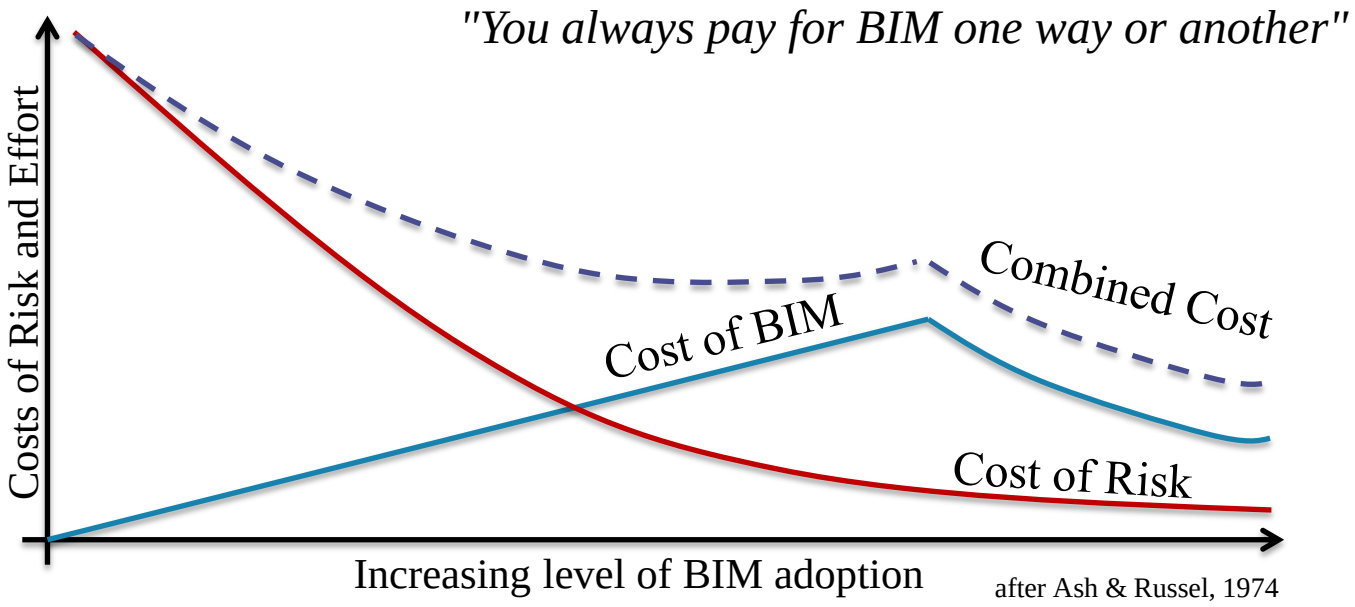

after Whyte, 1998

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Virtual Modelling

Hong Kong: Admirality Station

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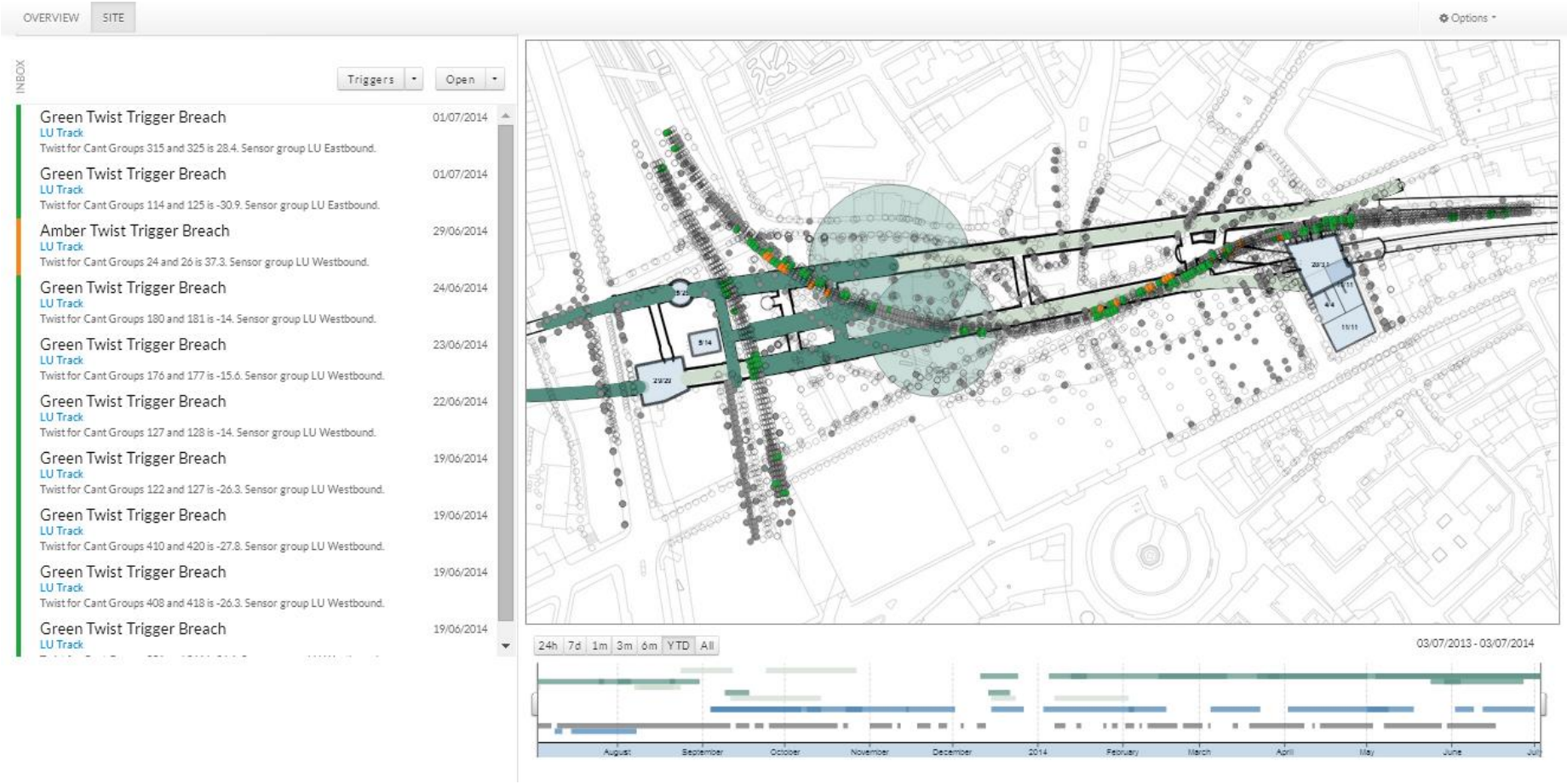
Crossrail: Adaptive I&M



www.crossrail-aim.com

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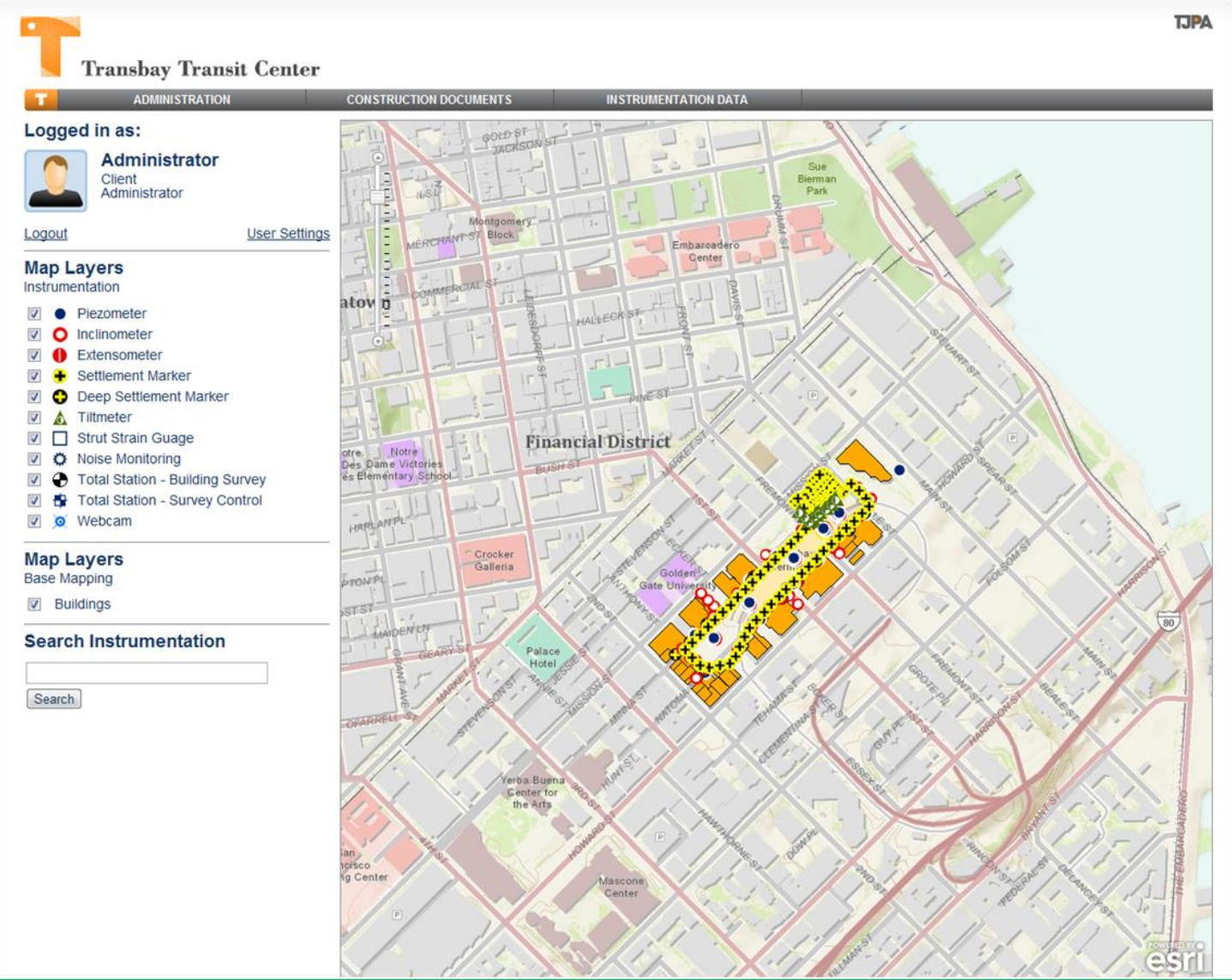
Transbay Transit Centre – Global Analyzer



http://ga.arup.com/

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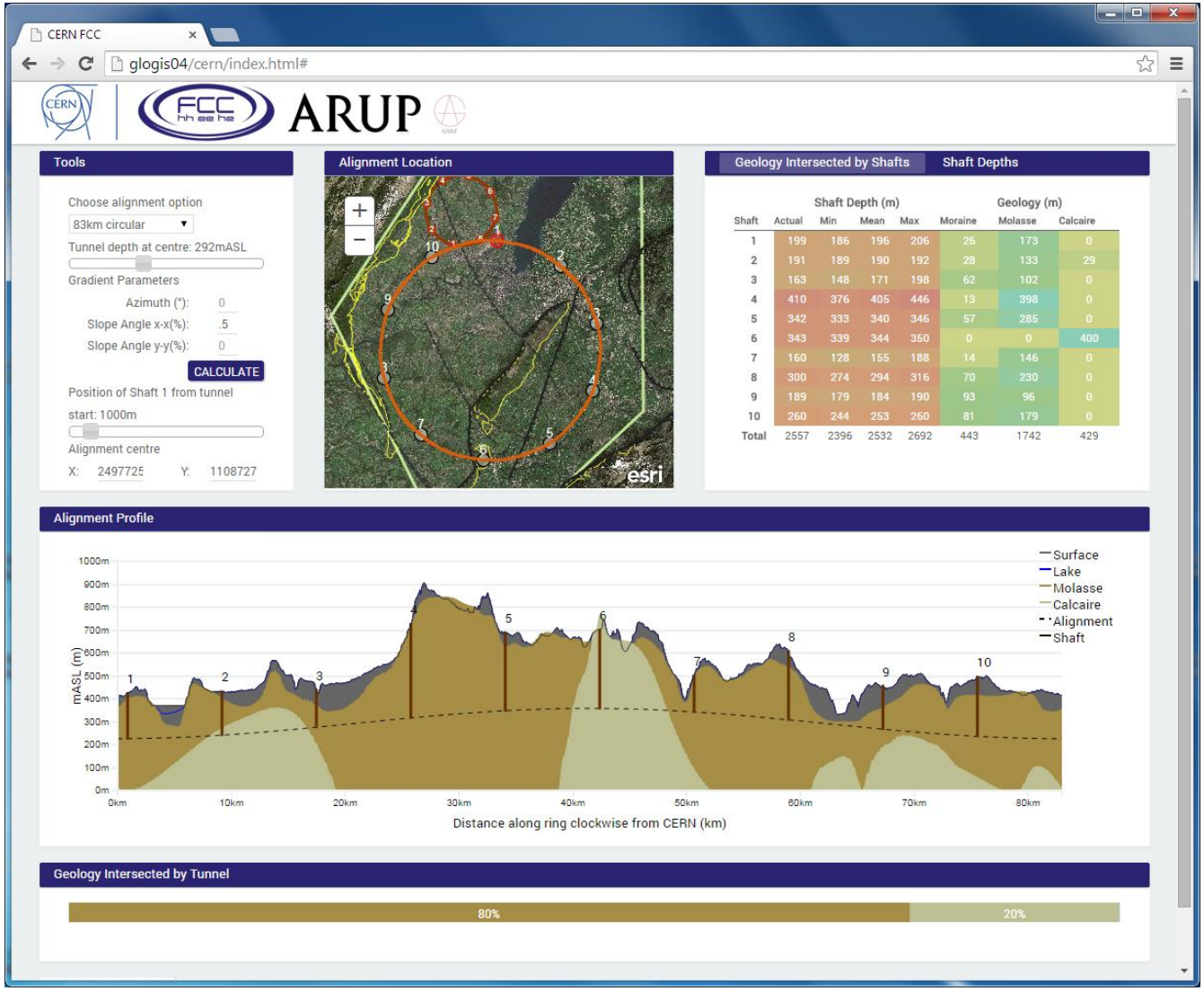
BIM Tool – Tunnel Optimisation Tool (TOT)



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McGraw Hill Smart Market Report 2014 - The Business Value of BIM for Construction in Major Global Markets

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Summary

- Ground Investigation
  - Risk vs Cost needs to be understood and baselined
  - Needs to be understood in context of whole project design
  - Opportunities and savings to be made if done well
- Information is key
  - BIM and technology will drive efficiencies and reduce cost
  - Embodied through whole life costs: Design -> O&M
  - Drivers: Legislation and Innovation for increasingly changing technological and global societal landscapes

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