UNIVERSAL LAWS OF TUNNELING

Major Tunnel Project?  DON’T TAKE THE BUS!
CUT AND COVER IS LOW RISK ...
GEOTECHNICAL RISK MUST BE MANAGED
STATE OF THE PRACTICE REVIEW

• Topics Covered
  Principles of risk management
  Risk registers and their use at all stages of a tunnel project
  Risk Allocation Report and its use in design, procurement and construction
  Quantitative Risk Analysis

• What is risk management?
  EVERYTHING YOU HEAR THIS WEEK!
CORRECTLY ASSESSING YOUR PROJECT RISKS IS IMPORTANT
PRINCIPLES OF RISK MANAGEMENT

1. AVOID
   Change tunnel alignment to avoid structures

2. MITIGATE
   Probe ahead and grout to mitigate risk from faults

3. ALLOCATE
   Provide clear contractual baselines to allocate residual risk
RISK MANAGEMENT IS A PROCESS

1. Identify Risks
   - What Could Go Wrong?

2. Assess Risks
   - Quantify / Rank

3. Identify Control Measures
   - Mitigation / Management / Control

4. Implement Control Measures

5. Monitor

6. Update Risk Register

- Risk Eliminated
- Risk Mitigated
- Residual Risk Acceptable?
- Risk Allocated
SOMETIMES THE RISKS ARE OBVIOUS TO ANYBODY
DON’T WORRY, THERE IS GUIDANCE FOR THE UNDERGROUND INDUSTRY

• Code of practice exists for underground risk management

• Particulars include:
  Experience most important aspect of project team
  Use risk registers to present and organize hazards
  Be open and transparent about awareness of project risks
TUNNEL PROJECT RISK MANAGEMENT

• US Practice established by this document
• Published and available online
• Rigorous industry review carried out prior to publication
• Published by UCA of SME
<table>
<thead>
<tr>
<th>Risk Description</th>
<th>Financial</th>
<th>Project Schedule</th>
<th>Social Environment</th>
<th>Regulatory/Legal</th>
<th>Health and Safety</th>
<th>Operating &amp; Maintenance</th>
<th>Natural Environment</th>
<th>Risk Score</th>
<th>Control Measures Implemented</th>
<th>Indicators or Metrics</th>
<th>Residual Likelihood - After Mitigation (Blank = Risk Closed)</th>
<th>Residual Consequence - Once Controls in Place</th>
<th>Residual Risk Score - After Mitigation Action</th>
<th>Action Item for Risk Mitigation</th>
<th>Action Item Completion Date (Target Date)</th>
<th>Responsible Party or Risk Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual ground conditions different to GBR baselines, due to unexpected changes in ground conditions, that leads to minor DSC claims, increased project costs, and/or project delays</td>
<td>4 4 4 16 4 4 2 4 4 8</td>
<td>Geotechnical investigation and laboratory testing</td>
<td>Distribution of lab test results</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>8</td>
<td>Create contractual baselines</td>
<td>see schedule</td>
<td>J. Doe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk Description</td>
<td>Risk consequence</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Actual ground conditions different to GBR baselines, due to unexpected changes in ground conditions, that leads to minor DSC claims, increased project costs, and/or project delays</td>
<td>4</td>
<td>3</td>
<td>4</td>
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<td></td>
<td></td>
<td>16</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
# Likelihood Ratings and Risk Score Table

<table>
<thead>
<tr>
<th>Probability Rating</th>
<th>AKA</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Probable</td>
</tr>
<tr>
<td>4</td>
<td>Likely</td>
</tr>
<tr>
<td>3</td>
<td>Possible</td>
</tr>
<tr>
<td>2</td>
<td>Unlikely</td>
</tr>
<tr>
<td>1</td>
<td>Improbable</td>
</tr>
</tbody>
</table>

### Probability vs. Consequence Matrix

- **Probability**: 1, 2, 3, 4, 5
- **Consequence**: 1, 2, 3, 4, 5

- **Red** indicates high risk score
- **Yellow** indicates moderate risk score
## Consequence Scoring Categories

<table>
<thead>
<tr>
<th>Risk Consequence Criterion</th>
<th>Consequence Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low 1</td>
</tr>
<tr>
<td>Financial</td>
<td>Less than $100k</td>
</tr>
<tr>
<td>Project Schedule Impacts</td>
<td>1 to 7 days</td>
</tr>
<tr>
<td>Social environment</td>
<td>Complaints from local public</td>
</tr>
<tr>
<td>Regulatory / Legal</td>
<td>Isolated non-compliance</td>
</tr>
<tr>
<td>Health &amp; Safety</td>
<td>Minor injury or near-miss (non-reportable)</td>
</tr>
<tr>
<td>Operating and Maintenance</td>
<td>Minor increase in expected O&amp;M activity (barely measurable)</td>
</tr>
<tr>
<td>Natural Environment</td>
<td>Minor short term local impact</td>
</tr>
<tr>
<td>Control Measures Implemented (actually in place today)</td>
<td>Indicators or Metrics (Measuring the effect of Control Measures)</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Geotechnical investigation and laboratory testing</td>
<td>Distribution of lab test results</td>
</tr>
</tbody>
</table>
USING THE RISK REGISTER TO MANAGE RISK

• Should be a single consolidated location for all foreseeable project risk
• Owner, designer, contractor must use the same risk register
• Forward-looking document to consider upcoming hazards
• Consider similarities to a project schedule

• NOT a checklist – don’t use the risk register to check a box
HAVE THE RIGHT TOOL FOR THE JOB

• Need a shift in thinking – similar to change in attitude to safety
RISK REGISTER DURING DESIGN BUILD PROCUREMENT

• Risk register should be a contract document
• Well established process
  Risk register requested as part of the bid used during one-on-one meetings
• Best value selection
  Allows the risk mitigation strategy to be used as part of selection
• Process can be molded to suit agency
RISK REGISTER THROUGH DESIGN BID BUILD PROCUREMENT

• Risk register should still be a contract document – but rarely used this way

• Remove fully mitigated risks
  Issues such as obtained permits, finance, design process risks etc.

• Be clear on contractual allocation of residual risk
  Location in contract where risk considered

• Use a Risk Allocation Report
Prepare, Review, and Revise Design Risk Register → Prepare Contract Documents

Pre-Advertisement Open Day to Discuss Project Risks, Procurement Risk Register and Risk Allocation Report

Advertise Contract → Receive Bid Questions → Pre-Bid Meeting

Bid Award → Pre-Construction Meeting(s)

Notice to Proceed → Regular Progress Meetings - Include Risk Register Discussions

Include in contract: Procurement Risk Register; Risk Register Modification Process in Front End Documents; and Risk Allocation Report

Include Discussion of Risk Register and Risk Allocation Report

Include Risk Register Workshop to Define Construction Risk Register

Review and Revise Construction Risk Register
WHAT IS A RISK ALLOCATION REPORT?

- Purpose: clarify how risks are considered in contract document
- Assists contractor with familiarization of contract documents
- Narrative support to risk register
  References contract clauses
  Explains how risks are allocated
  States mitigation action necessary
  Considers all sources of potential conflict
DO YOU KNOW THE RISKS YOU ARE TAKING?

That wasn't chicken.
WRITING A RISK ALLOCATION REPORT?

• Written at 90% design stage
• Should contain no new information
• Most risks require a single simple reference to the contract
• Some risks need a more detailed narrative to describe fully
• Writing report is similar to claim analysis

In depth analysis of each major risk issue
Narrative description of that issue
USING A RISK ALLOCATION REPORT

• Does not supersede any other contract document
  Contains no new information
• Helps to promote a well thought out design
  Documentation of use of good engineering and management practices
• Subject of discussion during procurement
  Pre-advertisement workshop
  Pre-bid meeting
• Assists with administration of contract during construction
## QUANTIFICATION RISK RATING TABLE

<table>
<thead>
<tr>
<th>Rating Scale</th>
<th>Rating Description</th>
<th>Evaluated Probability</th>
<th>Percentage (Single occurrence = mean)</th>
<th>Poisson (Recurrence Possible)</th>
<th>Minimum Cost</th>
<th>Most Likely Cost</th>
<th>Maximum Cost</th>
<th>Minimum Delay (mo)</th>
<th>Most Likely Delay (mo)</th>
<th>Maximum Delay (mo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Probable</td>
<td>&gt;50%</td>
<td>75.0%</td>
<td>1.37</td>
<td>$500,000,000</td>
<td>$750,000,000</td>
<td>$1,000,000,000</td>
<td>12</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>Likely</td>
<td>25-50%</td>
<td>37.5%</td>
<td>0.45</td>
<td>$100,000,000</td>
<td>$300,000,000</td>
<td>$500,000,000</td>
<td>6</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>Possible</td>
<td>25-50%</td>
<td>17.5%</td>
<td>0.20</td>
<td>$50,000,000</td>
<td>$75,000,000</td>
<td>$100,000,000</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Unlikely</td>
<td>5-10%</td>
<td>7.5%</td>
<td>0.09</td>
<td>$5,000,000</td>
<td>$27,500,000</td>
<td>$50,000,000</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>Improbable</td>
<td>&lt;5%</td>
<td>2.5%</td>
<td>0.03</td>
<td>$-</td>
<td>$2,500,000</td>
<td>$5,000,000</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
</tr>
</tbody>
</table>
BASE COST TEMPORAL DISTRIBUTION

<table>
<thead>
<tr>
<th>Year</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
<th>Year 10</th>
<th>Year 11</th>
<th>Year 12</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage Allocated by Year</td>
<td>4%</td>
<td>8%</td>
<td>12%</td>
<td>14%</td>
<td>16%</td>
<td>14%</td>
<td>12%</td>
<td>8%</td>
<td>6%</td>
<td>4%</td>
<td>2%</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Mega Project QRA Post-Mitigation

Outflow parameters: Local input

To distribute: 100.00, 9,603,221,504.00, 9.60
Distributed: 100.00, 9,603,221,504.00, 9.60
Yet to distribute: 0.00, 0.00

Year | Target [%] | Share [%] | Outflow Value |
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>2017</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>0.00</td>
<td>4.00</td>
<td>384,128,86</td>
</tr>
<tr>
<td>2019</td>
<td>0.00</td>
<td>8.00</td>
<td>768,257,72</td>
</tr>
<tr>
<td>2020</td>
<td>0.00</td>
<td>12.00</td>
<td>1,152,386,58</td>
</tr>
<tr>
<td>2021</td>
<td>0.00</td>
<td>14.00</td>
<td>1,344,451,01</td>
</tr>
<tr>
<td>2022</td>
<td>0.00</td>
<td>16.00</td>
<td>1,536,515,49</td>
</tr>
<tr>
<td>2023</td>
<td>0.00</td>
<td>14.00</td>
<td>1,344,451,01</td>
</tr>
<tr>
<td>2024</td>
<td>0.00</td>
<td>12.00</td>
<td>1,152,386,58</td>
</tr>
</tbody>
</table>

2014 | $0.00  |
2015 | $0.00  |
2016 | $0.00  |
2017 | $0.00  |
2018 | $10,000|
2019 | $20,000|
2020 | $30,000|
2021 | $40,000|
2022 | $50,000|
2023 | $60,000|
2024 | $70,000|
2025 | $80,000|
2026 | $90,000|
2027 | $0.00  |
2028 | $0.00  |
2029 | $0.00  |
2030 | $0.00  |
## Escalation and Total Construction Cost

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Escalation Rate</strong></td>
<td>2.3%</td>
<td>2.5%</td>
<td>3.1%</td>
<td>3.1%</td>
<td>3.1%</td>
<td>3.1%</td>
<td>3.1%</td>
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</tr>
<tr>
<td><strong>Compounded Escalation Rate</strong></td>
<td>2.3%</td>
<td>4.9%</td>
<td>8.1%</td>
<td>11.5%</td>
<td>14.9%</td>
<td>18.5%</td>
<td>22.2%</td>
<td>25.9%</td>
<td>29.9%</td>
<td>33.9%</td>
<td>38.0%</td>
<td>42.3%</td>
<td>46.7%</td>
<td>51.3%</td>
<td>55.9%</td>
<td>60.8%</td>
</tr>
</tbody>
</table>

Based on ENR's Construction Cost Index (CCI). 2015 historic data, 2016 ENR predicted, 2017-2029 estimated same as previous 20 year average.

**Color Key:**
- Escalation – Purple
- Risk Cost – Red
- Base cost – Blue
## Construction Cost Confidence Levels

<table>
<thead>
<tr>
<th>Confidence Interval (CI)</th>
<th>Base Cost</th>
<th>Post Mitigation Base + Risk</th>
<th>Pre-Mitigation Base + Risk</th>
<th>Base+Risk+Escalation Post Mitigation Total Cost (B+R+E)</th>
<th>Base+Risk+Escalation Pre Mitigation Total Cost (B+R+E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>$10,563,540,000</td>
<td>$12,645,310,000</td>
<td>$16,127,570,000</td>
<td>$15,738,210,000</td>
<td>$19,287,930,000</td>
</tr>
<tr>
<td>90%</td>
<td>$9,971,832,000</td>
<td>$10,968,610,000</td>
<td>$12,216,770,000</td>
<td>$13,942,860,000</td>
<td>$15,458,130,000</td>
</tr>
<tr>
<td>85%</td>
<td>$9,903,197,000</td>
<td>$10,837,560,000</td>
<td>$11,986,210,000</td>
<td>$13,811,750,000</td>
<td>$15,223,430,000</td>
</tr>
<tr>
<td>80%</td>
<td>$9,847,694,000</td>
<td>$10,739,660,000</td>
<td>$11,808,180,000</td>
<td>$13,710,060,000</td>
<td>$15,041,460,000</td>
</tr>
<tr>
<td>75%</td>
<td>$9,799,598,000</td>
<td>$10,659,320,000</td>
<td>$11,662,260,000</td>
<td>$13,626,340,000</td>
<td>$14,890,270,000</td>
</tr>
<tr>
<td>50%</td>
<td>$9,603,222,000</td>
<td>$10,358,770,000</td>
<td>$11,106,520,000</td>
<td>$13,311,570,000</td>
<td>$14,332,500,000</td>
</tr>
<tr>
<td>0%</td>
<td>$8,642,896,000</td>
<td>$8,954,646,000</td>
<td>$9,151,647,000</td>
<td>$11,698,650,000</td>
<td>$12,286,460,000</td>
</tr>
</tbody>
</table>
CONSTRUCTION TIME DELAY PROBABILITY DISTRIBUTIONS

Pre-Mitigation

Post-Mitigation
CRITICAL PATH DELAY DISTRIBUTION PROFILE

Mega-Project Critical Path Delay Distribution Profile (Date)

Confidence Interval (%)

Delay (Date from 01/01/29)

<table>
<thead>
<tr>
<th>Confidence Interval (CI)</th>
<th>Months Post Mitigation Base + Risk</th>
<th>Months Pre-Mitigation Base + Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>46.5</td>
<td>78.3</td>
</tr>
<tr>
<td>90%</td>
<td>14.0</td>
<td>22.1</td>
</tr>
<tr>
<td>85%</td>
<td>12.2</td>
<td>19.0</td>
</tr>
<tr>
<td>80%</td>
<td>11.0</td>
<td>16.6</td>
</tr>
<tr>
<td>75%</td>
<td>9.9</td>
<td>14.8</td>
</tr>
<tr>
<td>50%</td>
<td>6.2</td>
<td>9.0</td>
</tr>
<tr>
<td>0%</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
QUANTITATIVE ANALYSIS

- **BE CAREFUL WITH STATISTICS**
- Critical factors in this process include:
  - Experience in obtaining correct input
  - Strict mathematical discipline with analysis and model
  - Clarity rather than over-simplification in output
- There is a right answer – but you must be ready to defend your method

- Useful analysis at milestone points of design and construction
  - Assessing prudent budget contingency required during design
  - Assessing when to release that contingency during construction
- Not as effective in *managing* day-to-day project risk as qualitative methods
CONCLUSIONS

- Risk register should be a contract document
- Risk register supported by a Risk Allocation Report
- Design risk register should be scrubbed thoroughly before being used during procurement
- Risk register should have contractor-identified risks added in a workshop held before NTP
- All contractual parties must respond positively for full project risk management benefits to be recognized
- Use qualitative methods for day-to-day management of project risk
- Quantitative methods can be used effectively at project milestones to check and potentially release contingency
ACKNOWLEDGE THE POTENTIAL HAZARDS AROUND YOU
BE JUDICIOUS ABOUT YOUR RISK ASSESSMENT
AVOID THE BAD GUYS
DON’T GO INTO RISK MANAGEMENT HALF WAY!
QUESTIONS?

- **The Documents**
  - Codes of Practice – BTS (2003) and ITIG (2012)

- **The Tools**
  - The Contract!
  - Risk register
  - Risk Allocation Report
  - Qualitative and quantitative management of risk