SAFEX XVIIth Congress

The Evolution of Risk Management In Orica Mining Services A Case Study

Istanbul, May 2011

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Expert Teams: Background

- Formed after the Lorena accident
- The initial remit was to ensure ‘control’ of our products and processes
  - Make the rules, establish the standards
  - Publish the rules and standards (BoS, Engineering Stds)
  - Audit against the rules/standards
  - Close any compliance gap
- The explosives business area was considered the most ‘at risk’, the responsibility of the EET (Explosives Expert Team)
  - Determined to be data driven in the process
  - Have driven the internal and Joint CERL Hazards Projects

The EET: Status

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- All the key standards established
- Developing second generation of BoS documents
- On third round of packaged plant audits
- Introduced a new structure
  - Core team plus regional technical and operations/SHE representatives
- Have filled many of the key knowledge gaps
  - Many more identified and R&D started
- Are increasingly looking at risk driven decisions
  - The AN EP had been operating on a risk driven approach
    - QRAs for AN Plants, large storage sites

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Stockholm Project

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Stockholm Project: Background

- Large contract for the extension of the subway systems
  - This is a very important business in the Nordics area
  - There are ramifications for Orica elsewhere (e.g. Hong Kong)
- Initial volume at roughly 4 te/week
  - Serviced by 3 x 1.4 te plastic bin on-site ANE storage
- Expansion to 20 te/week
  - Customer required larger on-site storage
  - Small storage/frequent ‘refill runs’ not economically competitive
  - Competitors offering up to 30 te u/g or surface ANE storage

Stockholm Project: Background

- EET requested to sign off on 30 te ANE storage under Stockholm Central RR Station
  - EET ‘declined the opportunity’
  - This was viewed as a ‘bet the company’ decision
- Proposal was compliant with regulations
- Question rephrased:
  - What can we do?
  - What do we need to do to get that permission?
- EET decided to evaluate the proposal and try to answer the rephrased question

Stockholm Project: Evaluation

- There was no clear path forward as OMS had never evaluated this type of proposal before
- The project could only be approved if a full QRA demonstrated that it met regulatory and OMS requirements
- A QRA requires reliable frequency and consequence data to evaluate the risk

Stockholm Project: Evaluation

- What we had
  - The Transport HIRAC/Fault Tree methodology had proven to be an extremely powerful tool in developing that BoS
    - Some of the data would be directly applicable
    - The methodology could be extended to this proposal
  - Nordics had provided excellent and detailed data on what they were doing and what they wanted to do
  - Good historical data on pump safety, interlock reliability
  - Output from the CERL Hazards Program (projectile sensitivity, thermal stability, Minimum Burning Pressure)

Stockholm Project: Evaluation

- What we didn't have:
  - Baseline frequencies for some events
  - Critically, a method to estimate the surface effects of an u/g blast
  - A Risk Matrix that a) extended to relevant consequence levels:
    - Tens or hundreds of fatalities
    - Billions of dollars of liability
    - Irreversible damage to corporate reputation
  - Or b) frequency levels on which such consequences could be acceptable

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Stockholm: Project Team

- Leigh Hart: EET Owner
- Dallas Wilkinson: Business Owner
- Bill Evans: Project Leader, EET Core Group
- Johan Hakansson, Nordics Business
- David Reid, EET EMEA
- Rob Kitching, SHE EMEA
- Graham Haire, EET Core Group
- Ian Dennison, EET Core Group
- Travis Hillaby, EET, Watkins
- Ayman Tawadrous, Watkins Technology
- Dale Preece, Watkins Technology

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Stockholm Project: Evaluation

- What we did to fill the gaps
  - Risk Matrix
    - Development of the draft EET Extended Risk Matrix
  - Consequences
    - Ayman Tawadrous/Dale Preece used existing model to predict ‘gross’ surface effects
    - Developed a methodology to convert this to a Richter Scale value
  - Baseline frequencies
    - Transportation: Transport HIRAC (UK data)
    - Storage: IME data (NA)
    - Transfer: OMS HERC analyses

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The OMS Risk Matrix

Table 1: Risk Assessment Using Orica Residual Risk Matrix
(Refer also to Response Requirements in Table 2 below)

Likelihood of Occurrence (per annum)	Potential Consequences					
	Notable Event Cat 1	Significant Event Cat 2	Highly Significant Cat 3.1	Serious Event Cat 3.2	Extremely Serious Cat 4.1	Catas -trophic Cat 4.2
(A) Almost Certain > 1.0/yr	Level II 2M	Level II 1M	Level I 1M	Level I 1W	Level I 1D	Level I 1D
(B) Very Likely <1.0 & $>10^{-1}$/yr	Level III 9M	Level II 6M	Level II 3M	Level I 1M	Level I 1W	Level I 1W
(C) Likely $<10^{-1}$ & $>10^{-2}$/yr	Level III 2Y	Level III 1Y	Level II 9M	Level II 1M	Level I 1W	Level I 1W
(D) Unlikely $<10^{-2}$ & $>10^{-4}$/yr	Level IV	Level IV	Level III 5Y	Level III 5Y	Level II 1Y	Level I 1M
(E) Very Unlikely $<10^{-4}$ & $>10^{-6}$/yr	Level IV	Level IV	Level IV	Level IV	Level III 5Y	Level II 1Y
(F) Extremely Unlikely $<<10^{-6}$/yr	Level IV	Level IV	Level IV	Level IV	Level IV	Level III 5Y

* Matrix can be used for acute or chronic hazards
* 1D (1 day), 1M (1 month), 1Y (1 year), 5Y (5 years) – response time for risk reduction/action

EET works here

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Standard Matrix Consequences

- Catastrophic in a regional sense
- What about BP? Bhopal? Or?

Table 2: Summary of Potential Consequences
For Use with Qualitative Risk Analysis Matrix

CORPORATE ISSUE	Notable Event Cat 1	Significant Event Cat 2	Highly Significant Cat 3.1	Serious Event Cat 3.2	Extremely Serious Cat 4.1	Catastrophic Cat 4.2
SAFETY & HEALTH	1 Minor Injury, First Aid	Single MTC	Single LWC or Multiple MTC	Permanent Disability, Multiple LWC	Single Fatality	Multiple Fatalities
ENVIRONMENT "Click" Button to reveal more details	Very Minor Pollution	Minor Local Pollution	Evident Pollution	Significant Pollution	Major Pollution	Extreme Pollution
CORPORATE REPUTATION & IMAGE	Minor issue 1 complaint	Local issue 10 complaints	Local media 100 complaints	Regional or state media	National media coverage	Headlines corporate damage
CUSTOMER SERVICE/BUS. DISRUPTION	Minor stock out or product defect	Minor temporary loss of production	Short-term supply loss of major customer	Medium term supply loss for major customer	Long term loss of production and/or major customers	Permanent loss of production and/or major customers
BUSINESS LIABILITY IMPACT	< $5,000	> $5,000	> $50,000	> $200,000	>$1million	>$50million
SECURITY BREACH / VULNERABILITY IMPACT	Site problem or offsite < 1000 people alerted	Minor injuries plus offsite impact with < 10000 affected	Site non-fatal injuries 1 month offline or < 100000 people affected at ERPG2 or equivalent level		Site fatality(ies) & injuries plus offsite fatality(ies) > 100000 people affected at ERPG2 or equivalent level severe disruption	

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Standard Matrix Likelihoods

- An apparent gap between 10^{-6} and 10^{-7}

Event Likelihood Descriptors		
Likelihood Descriptor	Qualitative Description	Typical Range (pa)
Almost Certain	☐ Will occur at least once a year	> 1
Very Likely	☐ Very likely to occur at least once during a 10 year period of operation of the facility/business	1 to 10^{-1}
Likely (Possible)	☐ Has occurred at least once during the operating life of the facility/business	10^{-1} to 10^{-2}
Unlikely	☐ Known to have happened within the industry: periodically in small industries and more often in large industries	10^{-2} to 10^{-4}
Very Unlikely	☐ Has occurred somewhere in the world in all related industries	10^{-4} to 10^{-6}
Extremely Unlikely	☐ Could theoretically occur but not aware of any instances	<< 10^{-6} ie (around 10^{-7})

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Use of Expanded Risk Matrix

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- The Key Question:
  - If one is in the bottom right hand corner of the standard matrix, which OMS deems to be acceptable, and the consequences get worse:
    - Is this still an acceptable risk?
  - The EET answer is no
  - Nor does the risk matrix allow one to reduce the frequency from that corner. One can only reduce the consequences, which is not always possible
- The EET belief was that the use of the standard risk matrix would significantly underestimate the risk in this case

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The Expanded Risk Matrix

OMS Risk Matrix Groupings

	Cat 1	Cat 2	Cat 3.1	Cat 3.2	Cat 4.1	Cat 4.2	Cat 4.3	Cat 5.1	Cat 5.2
Almost Certain > 1.0 / yr	Level II 2M	Level II 1M	Level I 1W	Level I 1W	Level I 1D	Level I 1D	Level I	Level I	Level I
Very Likely E-1 ↔ 1	Level III 9M	Level II 6M	Level II 3M	Level I 1M	Level I 1W	Level I 1W	Level I	Level I	Level I
Likely E-2 ↔ E-1	Level III 2Y	Level III 1Y	Level II 9M	Level II 1M	Level I 1W	Level I 1W	Level I	Level I	Level I
Unlikely E-3 ↔ E-2	Level IV	Level IV	Level III 5Y	Level III 5Y	Level II 1Y	Level I 3M	Level I	Level I	Level I
Unlikely E-4 ↔ E-3	Level IV	Level IV	Level III 5Y	Level III 5Y	Level II 1Y	Level I 3M	Level I	Level I	Level I
Very Unlikely (FAR) E-5 ↔ E-4	Level IV	Level IV	Level IV	Level IV	Level III 5Y	Level II 1Y	Level II	Level I	Level I
Very Unlikely (FAR) E-6 ↔ E-5	Level IV	Level IV	Level IV	Level IV	Level III 5Y	Level II 1Y	Level II	Level I	Level I
Extremely Unlikely E-7 ↔ E-6	Level IV	Level IV	Level IV	Level IV	Level IV	Level III 5Y	Level II	Level II	Level I
E-8 ↔ E-7	Level IV	Level IV	Level IV	Level IV	Level IV	Level III 5Y	Level III	Level II	Level II
E-9 ↔ E-8	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level III	Level III	Level II
E-10 ↔ E-9	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level III	Level III
< E-10 / yr	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level III

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Proposed Changes

- Likelihoods
  - Discriminate from 1E-06 to 1E-10
- Consequences (Draft)
  - Introduce Categories beyond 4.2

	Cat 4.3	**Cat 5.1**	**Cat 5.2**
Public	6 to 9 Fatalities	10 to 20 Fatalities	20 or more Fatalities
OMS Employees	3 to 5 Fatalities	6 to 9 Fatalities	10 or more
Business Liability ($)	250M to 1B	1B to 2B	2B+
Corporate Reputation	International Coverage Significant Damage to Corporate Reputation	International Headlines Severe Damage to Corporate Reputation (e.g. BP @ Gulf oil spill)	International Headlines; Potential Irreversible Damage to Corporate Reputation

Stockholm Project

- Estimation of Consequences
  - Used a 2D numerical modeling methodology
    - Detonation parameters of explosives
    - Generates shock and stress wave propagation through rock
    - Estimates ‘cavity expansion’

Stockholm Project

- Estimation of Consequences
  - Difficult to apply raw output to surface consequences
  - Developed a methodology to convert output to a Richter Scale equivalence
    - At ‘ground zero’
    - Distances out to 100 m
      - Greater distances not required due to relatively quick decay of vibrations

Stockholm Project

- Consequence Modeling Output
  - Original proposal (30 te storage)
    - Explosion would breach basements of nearby buildings
    - Buildings would be expected to collapse
    - Major damage to structures out to 50+ meters
  - Completely unacceptable to Orica at any explosion frequency

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Stockholm Project

- Consequences cont'd
  - Ran model for various quantities
    - Determined consequences for different quantities
    - Accepted Richter Scale = 4 as the maximum for 'permanent risks', e.g. storage
      - This corresponds to max 5.6 te storage (specific to product, depth, rock type)
    - Accepted Richter Scale = 4.5 as the maximum for transitory risks, e.g. transfer operations

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Consequence Analysis – Input & Base Output

- Density of Rock = 2700 kg/m^3
- Depth of Charge = 37.5 m
- Mean Frequency = 500 Hz

Horizontal Distance	Peak Particle Velocity	
(m)	1 Ton	2.5 Ton
0	1.65	2.00
10	0.60	0.93
20	0.50	0.94
30	0.40	1.10

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Consequence Analysis – Input/Output

Inputs

	One Ton				2.5 Tons			
Density of Rock (kg/m3)	2700	2700	2700	2700	2700	2700	2700	2700
Horizontal Distance to Point of Interest (m)	0	10	20	30	0	10	20	30
Depth of Explosive Charge (m)	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
PPV at Point of Interest (m/s)	1.65	0.6	0.5	0.4	2	0.93	0.94	1.1
Mean Frequency at Point of Interest (Hz)	500	500	500	500	500	500	500	500

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Consequence Analysis - Output

Outputs

	1 te				2.5 te			
Calculated Seismic Energy (J)	2.2E+10	2.9E+09	2.0E+09	1.3E+09	3.2E+10	6.9E+09	7.0E+09	9.6E+09
Calculated Seismic Energy (GJ)	21.65	2.86	1.99	1.27	31.81	6.88	7.03	9.62
Richter Scale	3.7	3.1	3.0	2.9	3.8	3.4	3.4	3.5

Stockholm Project - QRA

- The modeling work had provided a method of estimating the surface consequences of an u/g blast
- The original Orica Risk Matrix is too limited on both axes (Frequency and Consequences) to evaluate this type of project
- The Expanded Risk Matrix allows one to extend the QRA approach to very high conseauence/very low frequency events

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Stockholm Project: QRA

- Methodology
  - Carry out a HIRAC on a generic process to determine the key hazards as well as preventative and mitigative factors
  - Develop seven scenarios covering the options to service the account
  - Identify the key transportation (rural, suburban and urban segments), storage, transfer and use steps for each scenario
  - Develop a comparative fault tree for each scenario which includes all relevant steps

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Scenarios

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- **Scenario 1:** Packaged products, EMS to ETS to JS, No local surface or u/g storage at JS
- **Scenario 2:** ANE, EMS to JS, surface storage (7 te, plastic IBCs) and transfer to mini-SSEs
- **Scenario 3:** As Scenario 2, 2 x 8 te storage in aluminium tanks
- **Scenario 4:** ANE, EMS to JS, u/g storage (3 x 5 te separated stores in aluminium) and transfer to mini-SSEs
- **Scenario 5:** As Scenario 4, storage in plastic bins
- **Scenario 6:** As Scenario 5, u/g transportation and storage in plastic
- **Scenario 7:** Original scenario (30 te storage in single aluminium tank u/g)

EMS – Manufacturing Site; ETS – Transit Storage

JS – Job Site (surface area)

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Stockholm Project: Evaluation

- Each step was evaluated
  - Frequency per annum
  - Probability of an incident
  - Any relevant modifiers
  - Worst possible event
  - Consequences, modified by
    - Surface / u/g (use Richter Scale)
    - Relevant population density
    - Degree of evacuation possible

Stockholm Project: Evaluation

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- The Risk Analysis Process
  - Modified frequencies
    - Transportation
      - OMS improvements (see BoS)
      - Transport in aluminium (or plastic)
    - Storage
      - Use of aluminium or plastic
    - Transfer
      - By pump type and safety/interlock level

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Stockholm Project: Evaluation

- The analysis provides a frequency and consequence for each step
- The Expanded EET Risk Matrix was used to assess the risk level for each step
- For comparative reasons, the standard Risk Matrix was also used
- Level III and IV risks were considered to be acceptable

Stockholm Analysis Summary – Old Matrix

Activity	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Transport EMS - ETS							
Rural Only	Level III/IV				Level IV	Level IV	
Transport EMS - JS							
Rural Portion		Level IV	Level IV	Level IV			Level IV
Suburban Portion		Level III	Level III	Level III			Level III
Urban Portion		Level III	Level III	Level III			Level III
Transport ETS - JS							
Suburban Portion	Level II				Level III	Level III	
Urban Portion	Level III				Level III	Level III	
Transport JS - U/G							
U/G	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV
Richter Scale (0 Distance)	3.7	3.8	3.8	4.2	3.9	3.9	4.2
Transport U/G - Face	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV
Richter Scale (0 Distance)	3.7	3.8	3.8	3.8	3.8	3.8	3.8
Surface Storage		Level III	Level III				
U/G Storage				Level IV			Level III
Richter Scale (0 Distance)				3.9			5.0
Transfer to Surface Mag		Level III	Level III				
Transfer to U/G Mag				Level IV			Level III
Richter Scale (0 Distance)				4.3			5.0
Transfer to Mini-SSE		Level III	Level III	Level IV	Level IV	Level IV	Level III
Richter Scale (0 Distance)		N/A	N/A	3.9	3.9	3.9	5.0
Loading Operations		Level IV	Level IV	Level IV	Level IV	Level IV	Level IV
Richter Scale (0 Distance)		3.8	3.8	3.8	3.8	3.8	3.8

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Stockholm Analysis Summary – New Matrix

Activity	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Transport EMS -ETS							
Rural Only	Level III/IV				Level IV	Level IV	
Transport EMS - ETS							
Rural Portion		Level IV	Level IV	Level IV			Level IV
Suburban Portion		Level III	Level III	Level III			Level III
Urban Portion		Level III	Level III	Level III			Level III
Transport ETS - JS							
Suburban Portion	Level II				Level III	Level III	
Urban Portion	Level II				Level III	Level III	
Transport JS - U/G							
U/G	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV
Richter Scale (0 Distance)	3.7	3.8	3.8	4.2	3.9	3.9	4.2
Transport U/G - Face	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV	Level IV
Richter Scale (0 Distance)	3.7	3.8	3.8	3.8	3.8	3.8	3.8
Surface Storage		Level II	Level II				
U/G Storage				Level IV			Level II
Richter Scale (0 Distance)				3.9			5.0
Transfer to Surface Mag		Level II/III	Level II/III				
Transfer to U/G Mag				Level IV			Level III
Richter Scale (0 Distance)				4.3			5.0
Transfer to Mini-SSE		Level IV	Level IV	Level IV	Level IV	Level IV	Level IV
Richter Scale (0 Distance)		N/A	N/A	3.9	3.9	3.9	5.0
Loading Operations		Level IV	Level IV	Level IV	Level IV	Level IV	Level IV
Richter Scale (0 Distance)		3.8	3.8	3.8	3.8	3.8	3.8

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Stockholm Analysis - Conclusions

- Scenarios 4, 5 and 6 were all acceptable (only Level III and IV risks)
- Nordics business picked the most cost effective of those options
  - 17 te u/g storage (3 x 5.6 te separated stores)
  - Meets customer, business and EET requirements
- The analysis has been used to evaluate other similar projects
- Work is going on in further development of the Risk Matrix and in developing a ‘Richter Scale Matrix’ for max quantity (Richter 4) vs depth vs rock type
- This work will be used to develop a BoS for u/g storage

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Stockholm Analysis - Conclusions

- We believe that the application of the results of this work provides a basis to enhance industry safety and permit further development of the UG tunneling industry using explosives without compromising operational flexibility

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