Application of Risk and Reliability Methods for Developing Equipment Maintenance Strategy

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Outline of presentation

- Why adopt Risk Based Strategies?
- Challenges facing maintenance
- Risk Based Maintenance (RBM) working process
  - Screening analysis
  - Detailed analysis:
    - Risk Based Inspection (RBI)
    - Safety Integrity Level Assessment (SIL)
    - Reliability Centered Maintenance (RCM)
- Data management systems and links to CMMS/ERP
- Technical hierarchy and failure modes, failure and root cause analysis (RCFA)
- Benefits of RBM – Case studies: Refinery, Petrochemical, Chemical and complex offshore topside process facility
- Conclusions
Why Adopt Risk Based Strategies?

Piper Alpha, North Sea 06.07.1988, 167 killed, compression unit drilling platform, property loss 1.86 billion US $, production loss 8.85 billion US$. 
1970 to 2003 large property damage losses world-wide

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Plant Type</th>
<th>Event Type</th>
<th>PD Loss US Milion</th>
<th>Including Production loss US $ Milion</th>
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<tbody>
<tr>
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<td>VCE</td>
<td>839</td>
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<td>Hurricane</td>
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<td>Louisina</td>
<td>Refinery</td>
<td>VCE</td>
<td>368</td>
<td></td>
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<td>Nevada</td>
<td>Chemical</td>
<td>Explosion</td>
<td>383</td>
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<td>Petrochemical</td>
<td>VCE</td>
<td>285</td>
<td>396</td>
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<tr>
<td>23/07/1984</td>
<td>Illinois</td>
<td>Refinery</td>
<td>VCE</td>
<td>268</td>
<td></td>
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<td>04/03/1977</td>
<td>Qatar</td>
<td>Gas Plant</td>
<td>VCE</td>
<td>174</td>
<td></td>
</tr>
<tr>
<td>01/06/1974</td>
<td>England</td>
<td>Petrochemical</td>
<td>VCE</td>
<td>164</td>
<td></td>
</tr>
</tbody>
</table>
CASE:

TYPE OF INDUSTRY : Gas plant
COMPONENT TYPE : Re-boiler
PROBLEM : Explosion and fire,
two people killed, eight injured
gas supply crippled for two weeks,
leading to claims of more than 1 billion A$ from customers.
Longford gas plant accident

Root Cause:
Brittle fracture
CASE:

**TYPE OF INDUSTRY**: LNG plant

**COMPONENT TYPE**: Waste heat recovery unit

**PROBLEM**: Explosion

Shut down of production!
Initial loss 40 mill US $ / week
Explosion in Waste Heat Recovery Unit at LNG plant

Root cause:
Thermal fatigue and material embrittlement caused by poor weld quality
TYPE OF INDUSTRY: Fertilizer (Ammonium Nitrite) plant
COMPONENT TYPE: Storage and handling systems
PROBLEM: Explosion
29 persons killed
2442 persons injured
Material damage: 2.3 billion Euros
(2.9 billion US $)
Ammonium Nitrate Explosion

A huge explosion ripped through AZF (Azote de France) fertilizer factory in an industrial zone on the outskirts of Toulouse, southwest of France, at 10:15 am, Friday 21 September 2001. The explosion occurred in a warehouse in which stored granular ammonium nitrate. The amount is said to be between 200 to 300 tonnes of ammonium nitrate, used to make fertilisers. The explosion had been caused by an accident following an "incident in the handling of products". The exact cause remains unknown.

Reference Kersten and Mak
International Symposium in the Manufacture, Storage, Use and Transportation and Disposal of Hazardous Materials
Tokyo, 10-12 March 2004
Causes for leaks in refineries and HC plants

About half of the containment losses in a refinery, petrochemical or chemical process plant can be influenced by maintenance and inspection.

Large property losses in the HC-chemical ind., a 30 year review, 14th edition, M&M Protection Consultants, 1992
Fewtrell & Hirst and DNV have identified a number of root causes related to safety and safety critical equipment and process control systems:

- Defective or wrongly designed isolation valves
- Insufficient firewater
- Deficiencies in the inspection and maintenance procedures for critical equipment
- Unreliable or inadequate process control equipment
- Wrong material selection and inadequately inspected welds in safety critical systems
Challenges facing inspection and maintenance

**Maximising**
- Plant efficiency / reliability levels
- Product generation/throughput

**whilst**

**Minimising**
- Manning costs
- Materials costs
- Maintenance work load
- Transportation and support
- Downtime affecting revenue/operating costs

**Maintaining**
- Contractual nominations
- HSE requirements
Risk Based Maintenance Management

By assessing past performance, identifying the risk among individual equipment and identifying opportunity areas for improvement, plants are moving towards a risk based management philosophy incorporating the latest thinking in:

- Reliability Centered Maintenance (RCM) and Root Cause Failure Analysis (RCFA)
- Risk Based Inspection (RBI)
- Safety Integrity Analysis (SIL)
- Task bundling and resource load-leveling
- Work Order Automation
RIMAP – Risk based Inspection and Maintenance Procedures for European industry
RIMAP - Large industry participation

Chemical
- DOW
- Hydro Agri
- Solvay

Petrochemical
- ExxonMobil

Steel
- Corus

Chemical
- EnBW
- ESB
- Siemens,
RIMAP - Large industry participation

**Consultants**
- Bureau Veritas
- Det Norske Veritas
- Mitsui-Babcock Technology Centre
- TÜV Süddeutschland

**Research institutes**
- Joint Research Centre
- MPA
- Technical Research Centre of Finland (VTT)
- TNO
What was done in the RIMAP project?

- Developed a generic procedure for risk based inspection and maintenance (RBM). The procedure
  - defines the principles behind making risk based decisions
  - defines the scope and limitations of an RBM analysis
  - set requirements to an RBM analysis
  - describes the management processes needed to support the use of risk based techniques
  - provides the steps in developing a RBM plan
- Developed and documented methods for risk assessment to be used within RBM
- Prepared industry specific workbooks for the petrochemical, power, steel, and chemical industries.
### RIMAP vs API 580 – main differences

<table>
<thead>
<tr>
<th>Issues/-Features</th>
<th>RIMAP</th>
<th>API</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance management</td>
<td>Described and set specific requirement to maintenance management process</td>
<td>Focused on inspection management only</td>
</tr>
<tr>
<td>Equipment covered</td>
<td>All; Static, safety systems and active components</td>
<td>Static systems</td>
</tr>
<tr>
<td>Hazid</td>
<td>Scenario description (Bow-tie). All failure modes. Leak size per damage type.</td>
<td>Leak failures only. Standard leak sizes.</td>
</tr>
<tr>
<td>CoF</td>
<td>All chemicals. (DNV uses the DIPPR database &amp; Phast). Screening models available.</td>
<td>Limited chemicals. Consequence sum (S, E, C)</td>
</tr>
<tr>
<td>PoF</td>
<td>Screening to detailed assessment. Facilitated group work. Flexible method.</td>
<td>Pre-determined calculation models.</td>
</tr>
<tr>
<td>Risk decision</td>
<td>Risk matrix tailored to actual company/-plant. SIL-requirement for safety systems</td>
<td>Generic risk matrix.</td>
</tr>
<tr>
<td>Mitigation</td>
<td>Inspection, maintenance, process constraint, redesign/construction</td>
<td>Mostly inspection</td>
</tr>
</tbody>
</table>
DNV RBM Methodology

① Screening
   Qualitative analysis

② Detailed Analysis
   Quantitative analysis
Risk Based Maintenance (RBM) Strategy Development

**Output:**
- Inspection plans
- Equipment function testing
- Preventative maintenance
- Operator surveillance rounds
- First line maintenance tasks
- Condition monitoring
- On-line maintenance
- Off-line maintenance
- Turn around tasks

**Risk Based Maintenance Strategies (RBM)**

**Input data for screening**
- Equipment database
- Inspection, Maintenance history, Failure records

**Screening**
- DNV, Operator Experience

**Risk Level**
- High Risk
- Low Risk

**Containment**
- Y
- N

**Protective Function**
- Y
- N

**Minimum maintenance evaluation/ Corrective Maintenance**

**RBI: Risk based Inspection**

**SIL: Safety Integrity Level**

**RCM: Reliability Centered Maintenance**

**ERP Interface**

**Upload to ERP**
Up-load to ERP

Output:
- Inspection plans
- Equipment function testing program
- Preventative maintenance routines
- Operator surveillance rounds
- First line maintenance tasks
- Condition monitoring
- On-line maintenance
- Off-line maintenance
- Turn around tasks
Integration of RBI and RCM

Need for a data management system (CMMS, INSP, DOC..) that can interface/interact with the ERP (SAP/etc.) system
DNV RBM Methodology – Asset Register

Detailed RBM analysis – Establish RBM Technical Hierarchy

Failure Mode, Failure Causes, Root causes

MANAGING RISK
Root Cause

Detailed RBM analysis – Establish RBM Technical Hierarchy

Ball- /Roller Bearing
- Poor design
- Manufacturing defects
- Poor alignment and balance
- Seal failure
- Electrical discharge (arching)

- Overload
- Inadequate lubrication
- Vibration
- Contamination
- Fretting
- Corrosion
**DNV RBM Methodology**

Detailed RBM analysis principles

- **Probability of Failure**: RBI- Containment
- **Consequence of Failure**: SIL- Safety System, E/E/PES
  
  **RCM – Rotating, electrical,…**

- **Standard Consequence Analysis techniques**
  - Fault trees
  - Leak and Dispersion modeling / Probabilities of ignition
  - DNV PHAST Software
  - Financial consequence models
  - Environmental impact models

\[ \text{Risk} = \text{Probability of Failure} \times \text{Consequence of Failure} \]
RBM - Risk Based Inspection (RBI)

- **Containment**
- Define limit state functions for

  **Corrosion local /general**
  - Stress corrosion cracking
  - Fatigue and corrosion fatigue
  - Creep and creep fatigue
  - HTHA
  - ......
Calculation of Risk in RBI as per API

PROBABILITY OF FAILURE

\[ P_{oF} \]

CONSEQUENCE

\[ C_{oF} \]

RISK

\[ = \]

Management Factor

\[ \times \]

Generic Failure Frequency

\[ GFF \]

\[ \times \]

Likelihood Factor

\[ DF \]

\[ \times \]

Injury ($)

Env. clean up ($)

Item repair ($)

Adjacent repairs ($)

Downtime ($)

TOTAL ($)

Number of inspections and probability of detection (POD) accounted for using Bayesian updating of failure probability
RBM - Safety Integrity Level Assessment (SIL)

- Safety systems, electric, electronic and programmable electronic systems
  - Failure rates $\lambda$,
  - System reliabilities ($koon$)
  - Probability of failure on demand (PFD)
  - Bayesian approach to updating of test intervals
  - Risk cost optimization
Requirements to availability or cost/benefit?

- **Availability requirements** - Absolute acceptance requirement for availability
  - IEC61508/IEC61511
  - OLF 070 guideline
  - Legislative requirements, company requirements, ...

- **Cost-benefit**
  - In some cases it is economically beneficial to test more frequently than the requirements says.
  - In some cases the consequence is reduced to an economic consequence only.
RBM-Reliability Centered Maintenance (RCM)

Other systems (rotating, electrical etc.)
- Stream lined RCM approach
- Failure mode and effect analysis (FMEA)
- Failure rates from CMMS, from databases or estimated or from literature
- Consequence analysis
- Risk matrices for Safety, Business, Environmental, Capital
- Risk cost optimization
- Maintenance/Inspection task bundling
- Maintenance resource load leveling
DNV RCM Methodology

**Detailed RCM analysis principles**

- System / Equipment Boundary Definition
- System Functions
- Functional equipment and equipment types
- Assignment of failure modes FMEA
- Risk Analysis
- Failure and Root causes
- Maintenance Strategy Development

**DNV Best Practice Database:**
- Refinery
- Process Plants
- Offshore

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**DNV ORBIT RCM**

*Failure Mode and Cause database*

**DNV ORBIT RCM**

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MANAGING RISK
### DNV RBM Methodology

#### Four areas of Risk
- Risks to people (Safety Risk)
- Risks to the environment
- Risks to the business interruption (Business Risk)
- Risks to capital assets (Follow Costs)

#### Safety Risk Matrix

<table>
<thead>
<tr>
<th>PoF Cat</th>
<th>Failure per year / Frequency</th>
<th>Qualitative definition (Probability)</th>
<th>No Injury</th>
<th>Slight injury</th>
<th>Major injuries</th>
<th>Single fatality</th>
<th>Multip fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.1-1 (between 1 in 10 yrs and 1 per yr)</td>
<td>Expected (&gt; 0.8)</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>B</td>
<td>0.01-0.1 (between 1 in 100 yrs and 1 in 10 yrs)</td>
<td>Probable (0.3-0.1)</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>C</td>
<td>0.001-0.01 (between 1 in 1000 yrs and 1 in 100 yrs)</td>
<td>Possible (0.1-0.01)</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>D</td>
<td>0.0001-0.001 (between 1 in 10,000 yrs and 1 in 1000 yrs)</td>
<td>Unlikely (0.01-0.001)</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>E</td>
<td>0.00001-0.00001 (between 1 in 100,000 yrs and 1 in 10,000 yrs)</td>
<td>Totally unlikely (&lt; 0.001)</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
</tr>
</tbody>
</table>

#### Business Risk Matrix

<table>
<thead>
<tr>
<th>PoF Cat</th>
<th>Failure per year / Frequency</th>
<th>Qualitative definition (Probability)</th>
<th>Slight effect</th>
<th>Moderate effect</th>
<th>Localized effect</th>
<th>Major effect</th>
<th>Massive effect</th>
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<tbody>
<tr>
<td>A</td>
<td>0.1-1 (between 1 in 10 yrs and 1 per yr)</td>
<td>Happens several times per year per facility (&gt; 0.8)</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>B</td>
<td>0.01-0.1 (between 1 in 100 yrs and 1 in 10 yrs)</td>
<td>Happens several times per year pre operation (0.8-0.1)</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>C</td>
<td>0.001-0.01 (between 1 in 1000 yrs and 1 in 100 yrs)</td>
<td>Has been experienced by most operators (0.1-0.01)</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
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<tr>
<td>D</td>
<td>0.0001-0.001 (between 1 in 10000 yrs and 1 in 1000 yrs)</td>
<td>Has occurred in oil &amp; gas industry (0.01-0.001)</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>E</td>
<td>0.00001-0.00001 (between 1 in 100000 yrs and 1 in 10000 yrs)</td>
<td>Never heard of in oil &amp; gas industry (&lt; 0.001)</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
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</tbody>
</table>

MANAGING RISK
RBM Implementation

Results of a RBM study

The outcome of the RBM analysis is a recommended preventive maintenance plan comprising:

- What to do
- Skill and tools needed to do it
- How often to do it
- An estimate of the required man-hours
- Job packing to find when to do it
- Up-load to MMS/ERP (Asset number, activities, resources, department number, schedule, hours/cost and spares required)
RBM Implementation

Results of a RBM study RBM

- Spare parts  Awareness of safety and environmental issues on maintainers level
- Awareness of main contributors to production unavailability
- Documented preventive maintenance program
- More efficient maintenance program, fits the client organisation (competence and crew)
- Modifications
DNV Best Practice Database:

- Refinery
- Process Plants
- Offshore

...
Plant requirements and DNV-PRIMALUX solution
- Data integration requirements
Primalux Enterprise Asset Management System as a ‘value-added’ to the financial ERP

- External Systems
- AutoCad Integration
- ORBIT RBI
- Advanced Process System
- PDA
- Data Logger
- HMI
- EDMS

Data Exchange / Data Loading Utilities
Asset Register
Inspection
Conditioning Monitoring
Drawing/Document

DNV Primalux Asset Integrity System

Maintenance Management
Parts Management

DNV Primalux-CMMS or ERP System

ERP

Finance Management
Sales & Distribution
Human Resources
Other Modules
Management Reports
Procurement
Materials / Warehouse

MANAGING RISK
Benefits from RBI/RCM implementation at refinery

- increased intervals between turnarounds (4 yrs to 6 yrs)
- decrease in hidden failures, process trips (not quantified)
- improved process monitoring allowing for mitigation of failures
- fully documented, consistent and integrated maintenance and operating plan for over 40,000 pieces of equipment
- decrease in maintenance costs (est. 8% to 10%)
- platform for creating operator-round process monitoring procedures
- identification of many (>500) “other reliability issues” such as design changes, procedure changes, potential hidden failures, significant drawing errors
- identification of over 10,000 pieces of equipment that were deemed “non-critical, run to failure”, eliminating many unnecessary maintenance tasks
Benefits of RBM for Petrochemical plants

- **Infineum – Petrochemical industry**

- **Reduction in SHE risks** by implementing a improved system for maintaining and monitoring performance of safety critical equipment.

- **Economic Impact - Plant Level**
  - 5% increase in production
  - 10% reduction in maintenance cost

The economic benefits were achieved with no increase in SHE risk.
Benefits of RBM for Chemical plants

- **DOW, Solvay, yARA – Chemical industry**
  - Reduction in SHE risks
  - Increase in uptime (reduction in downtime and increase in prime production time)
    - 0.5% by extending turnaround intervals by 50%
    - 0.2% by reducing unplanned outages by 25%
    - 1% by improving operational prime production time
  - Economic potential for site: 5 m€/year
  - Economic potential for company: 100 m€/year
Benefits for Complex Offshore Topside Process Facility

Overall the client stated that they realized many benefits by linking the RBI/RCM through the RBM process:

- Same consistent methodology and approach
- Same risk matrices
- Consistent up-load to ERP
- No grey zones
- Saved a lot of headaches by having same contractor doing both and dealing only with one company saved a lot of time, and most importantly:
  - Nothing fell between two chairs – as the process identified items in the grey zone between RBI and RCM
  - Information was passed on between the two processes
  - The RBM process was efficient and most useful for maintenance and inspection scheduling and resource estimation

RCM database for FPSO topside:
11,000 tags, wrt FMEA 52,000 records
Conclusions

Experience from conducting RBI and RCM studies for refineries, petrochemical, chemical, and offshore topsides has demonstrated significant potential risk reductions and cost benefits of the predictive and proactive maintenance strategies developed.

- The benefits of the integrated RBM process will be exceeding the benefits achieved for the individual initiatives due to synergy effects such as: job packing, improvement to data management and workflow.
- Improved reliability of the equipment items and hence the system can be achieved.
- Maintenance intervals can be optimized based on the continuous feedback from the maintenance activities and the failure records and failure causes identified.
Conclusions

- RBM saves money due to direct maintenance cost reductions by identification of pieces of equipment that are deemed “non-critical, run to failure”, eliminating many unnecessary maintenance tasks.
- Systematic removal of root causes and repetitive problems lead to reduced production loss associated with un-planned shutdowns, increasing the bottom line result.
- Management of Safety Critical Equipment and protective functions by SIL assessment improves reliability and yields cost-benefits.
- To implement RBM by integrating RBI/SIL/RCM, it is required that the equipment information is available in a central data management system and that the Risk Based Inspection/Maintenance Strategies, scheduling and resource information can be up-loaded to the ERP system applied for the day to day plant operation.
- Thus methods need to be consistent and integrated and there must be a dynamic link to the enterprise resource planning (ERP) system’s work order and work flow.
Thank You!