

# Risk Based Inspection Planning for Jacket Structures

Where did we start, what did we do and where to go?

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## Overview of Presentation

- **Who is ETH Zürich and Matrisk?**
- **Main interactions with IMP/Pemex**
- **RBI for platforms**
  - where did we start?
  - where are we now?
  - where to go?
- **An outlook and some observations**

## Who is ETH Zürich and Matrisk?

- **My ETH Research Group**

**15 researchers working in the areas of:**

- Inspection and maintenance planning for offshore facilities, structures and pressure vessels
- Probabilistic modeling of NDE methods
- Methods of systems reliability analysis
- Natural hazards risk management, earthquake, hurricanes, rockfall, avalanches, floods
- Decision making for sustainable developments
- Fire risk modelling and assessment
- Risk criteria and safety management

## Who is ETH Zürich and Matrisk?

- **Matrisk GmbH – Specialist Consulting Firm**

### Offshore and marine engineering

- Risk Based Inspection planning for fixed steel structures
- Risk Based Inspection planning for FPSO and FSO's
- Probabilistic Design Basis for FPSO's in the GoM
- Decision and risk assessment for decommissioning
- Development of RAC for design and operation
- Probabilistic modeling of loads
- Probabilistic modeling of deterioration

## Who is ETH Zürich and Matrisk?

- **Matrisk GmbH – Specialist Consulting Firm**

### Civil engineering

- Hurricane modeling and loss estimation
- Probabilistic design basis for structures
- Risk and safety project management
- Decision analysis for planning of deep thermal energy exploitation
- Risk assessment for roadway and tunnel systems
- Development of RAC for third persons
- Risk analysis of infrastructure systems

## Who is ETH Zürich and Matrisk?

- **Matrisk GmbH – Specialist Consulting Firm**

### **Client portfolio**

- Det Norske Veritas, Denmark
- Bureau Veritas, France, Thailand, Brazil
- ABS, Houston, USA
- Aon Re, Japan
- Mærsk Oil and Gas, Denmark
- Instituto Mexicano del Petroleo, Mexico
- Pemex, Ciudad del Carmen, Mexico
- Zentech, Houston, USA
- Norwegian and Swiss Roadway Authorities
- COWI, Denmark
- Andermatt Tourist Resort, Switzerland

## Who is ETH Zürich and Matrisk?

- **My own background**

### **Positions**

- PhD (1989) from Aalborg University of Denmark
- Post-doc at Technical University of Munich, with Rackwitz.
- Private company, RCP, software STRUREL and consulting for the aeronautical and the offshore industry
- COWI, group leader risk and reliability, infrastructure and offshore
- Det Norske Veritas, lead engineer for the RBI of Jotun and Balder fields including FPSO's, subsea and flexible systems
- ETH Zürich, (2000), chair of Risk and Safety,
- Leader of MAS on Natural Hazards Risk Management
- **DTU (2011, Jan 1), Professor in Risk and Safety and Dean of Civil Engineering DTU, Denmark**

## Main Interactions with IMP / Pemex

- **RISC project - 1994**

- Joint Industry Project with IMP (Dr. Oscar Valle) and University College London and Technical Software Consultants (Prof. Bill Dover)

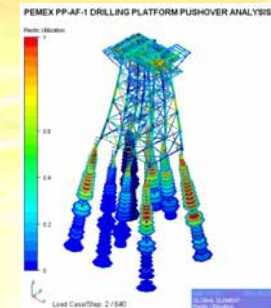
Together with UCL/TSC and IMP a software was developed for RBI for steel offshore platforms and we tested this on Nohoch B



## Main Interactions with IMP / Pemex

- **The period 2001 - 2010**

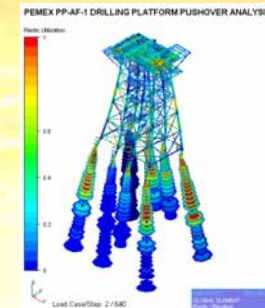
- For Pemex - in collaboration with Zentech and UNACAR we have conducted RBI planning for welded joints of 67 platforms in the bay of Campeche
- For Pemex we have conducted several courses on RBI for fixed steel jacket structures
- In collaboration with COMIMSA we have generalized our technique and also applied it for static process equipment on the AKAL-C facilities



## Main Interactions with IMP / Pemex

- **The period 2001 - 2010**

- In collaboration with IMP we have established a methodology for prioritization of repair works (SIPRIAM)
- In collaboration with IMP we have developed a risk based design basis for FPSO concepts in the Gulf of Mexico
- With IMP I/ETH have an MoU concerning development and knowledge transfer in the area of risk and reliability assessments



## Main Interactions with IMP / Pemex

- **IMP/Pemex Risk Symposium  
December 2001**

- A very successful event with good discussions (Bob Bea/Bernie Stahl)
- I presented my ideas on how we might use generic approaches to make RBI practically applicable
- Ing. Juan de Dios Dela O Ramirez contacted me and asked if I felt we were ready to do this for real....



## RBI for Platforms

- Where did we start?

We had:

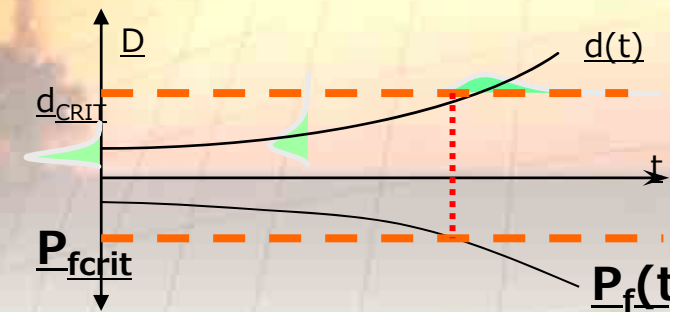
The general theoretical principles for RBI

- decision theory
- reliability theory
- structural analysis (FLS/ULS)
- fracture mechanics
- inspection modeling

The RBI planning was limited to experts in probabilistic engineering methods

Computation and data handling was involving

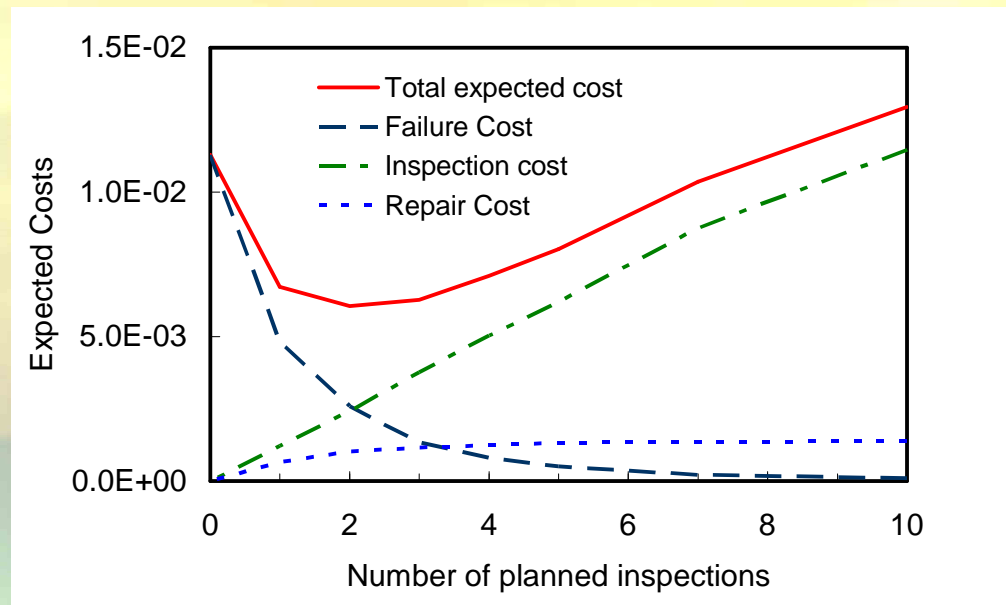
We were missing practical tools



## RBI for Platforms

- Where did we start?

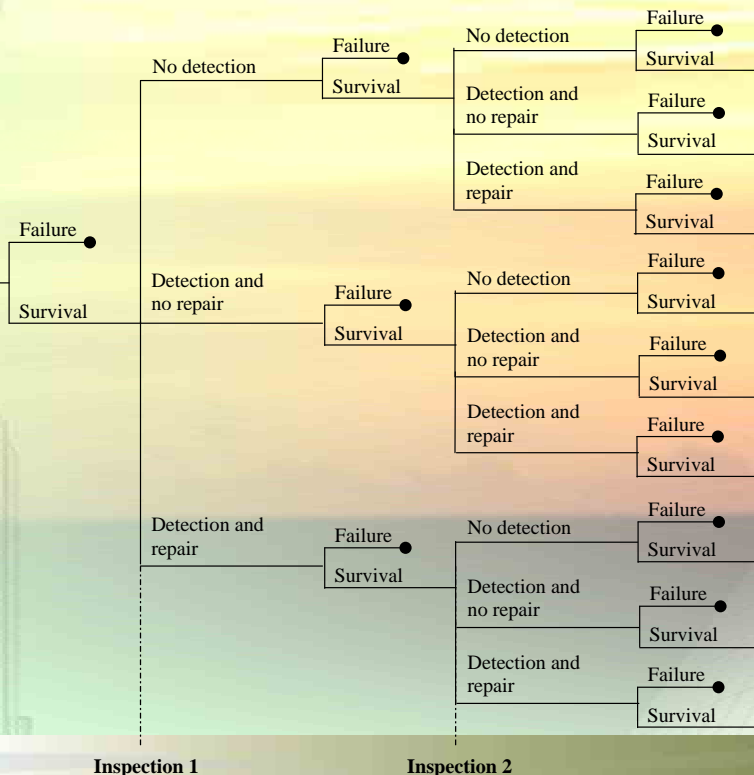
Risk Based Inspection planning as an optimization problem



## RBI for Platforms

- Where did we start?

Decision analysis and risk assessments as framework for optimization



$$C_{IN}(\mathbf{e}, d) = \sum_{i=1}^N C_{IN,i}(\mathbf{q})(1 - P_F(T_i)) \frac{1}{(1+r)^{T_i}}$$

$$C_{REP}(\mathbf{e}, d) = \sum_{i=1}^{T_L} C_{R,i} P_{R_i} \frac{1}{(1+r)^{T_i}}$$

$$C_F(\mathbf{e}, d) = \sum_{t=1}^{T_L} C_F(t) \Delta P_{F,t} P_{COL|FAT_j}(RSR) \frac{1}{(1+r)^t}$$

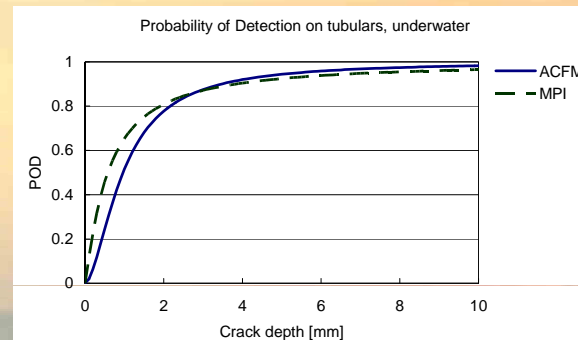
$$\Delta P_{F_i} = P\left(\bigcup_k \{B_k(t-1) \cap S(t-1) \cap B_k(t) \cap \bar{S}^U(t)\}\right)$$

$$P_R(t) = P\left(\bigcup_k \{S(t-1) \cap B_k(t-1) \cap R(t)\}\right)$$

## RBI for Platforms

- Where did we start?

Considering predictable fatigue crack growth and accounting for the quality of inspections



## RBI for Platforms

- Where did we start?

Basis is taken in the fatigue design – the SN curves

But SN curves cannot relate performance to observable characteristics

Therefore fracture mechanic formulations are calibrated to SN approach

$$N = N_I + N_p$$

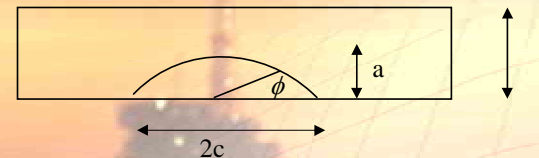
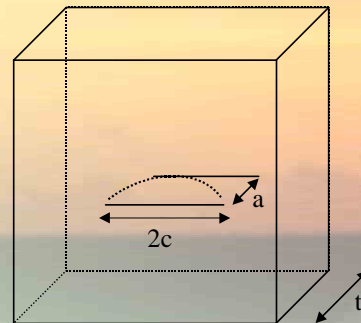
$$\frac{dc}{da} = \frac{C_c}{C_A} \left( \frac{\Delta K_C}{\Delta K_A} \right)^m$$

$$\frac{dN}{da} = \frac{1}{C_A (\Delta K_A)^m}$$

$$C_A = 1.1^m C_C$$

$$c(a_0) = c_0$$

$$N(a_0) = N_I$$

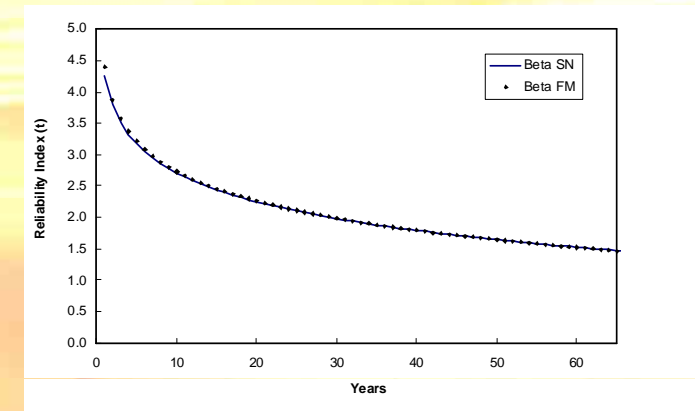


## RBI for Platforms

- Where did we start?

The calibration is performed for different design conditions/assumptions , i.e. for different

- stress model uncertainties
- Weibull long term stress distribution shape parameter
- material thickness
- design fatigue life
- design SN-curve



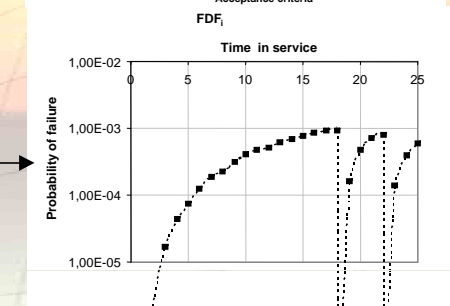
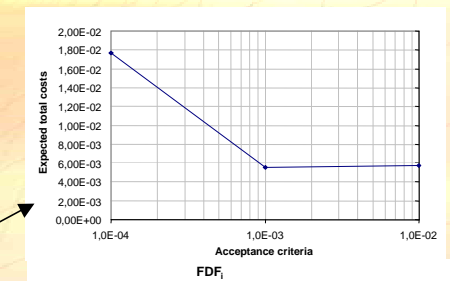
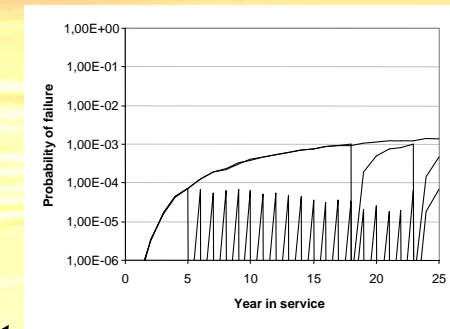
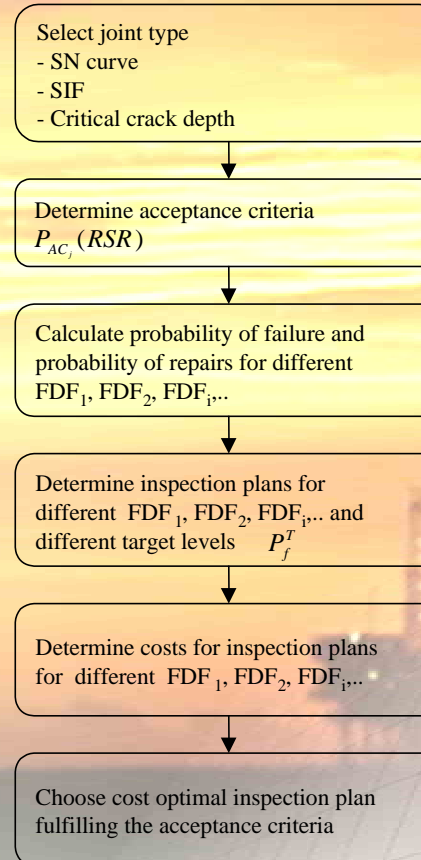
## RBI for Platforms

### Where are we now?

Generic approach to RBI

This formed the basic building stone for efficient and practical RBI at larger scale

- using indicators for the joint performance
- constant threshold of annual failure probability
- prefabrication of optimal inspection plans

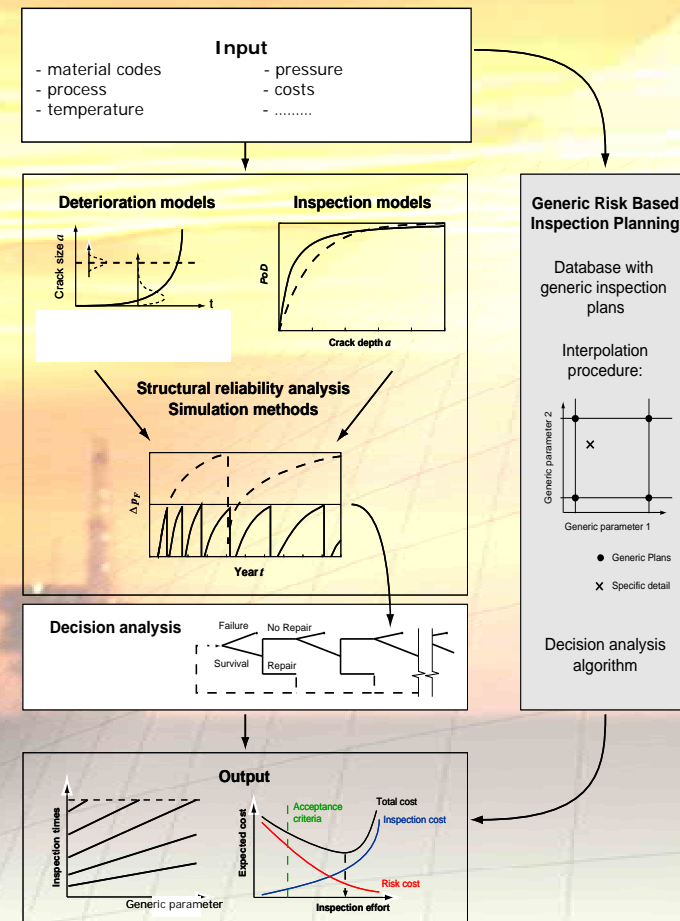


## RBI for Platforms

### Where are we now?

Inspection plans are performed as function of Indicators of future joint performance such as

- Design fatigue life
- Thickness of the elements
- Inspection methods
- Design SN curves
- Thresholds of annual probability of failure
- Stress model uncertainty
- Long term stress characteristics



## RBI for Platforms

- Where are we now?

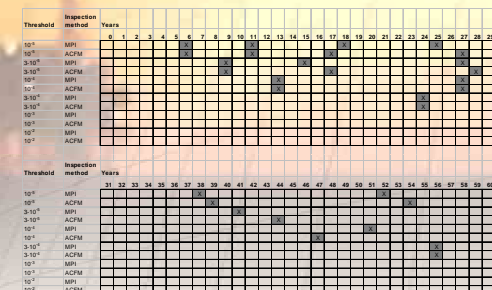
Development of the tool iPlan (MS Excel based)

Input

Fatigue Life  
Thickness  
COV  
Environment  
Model uncertainties

iPlan

Output

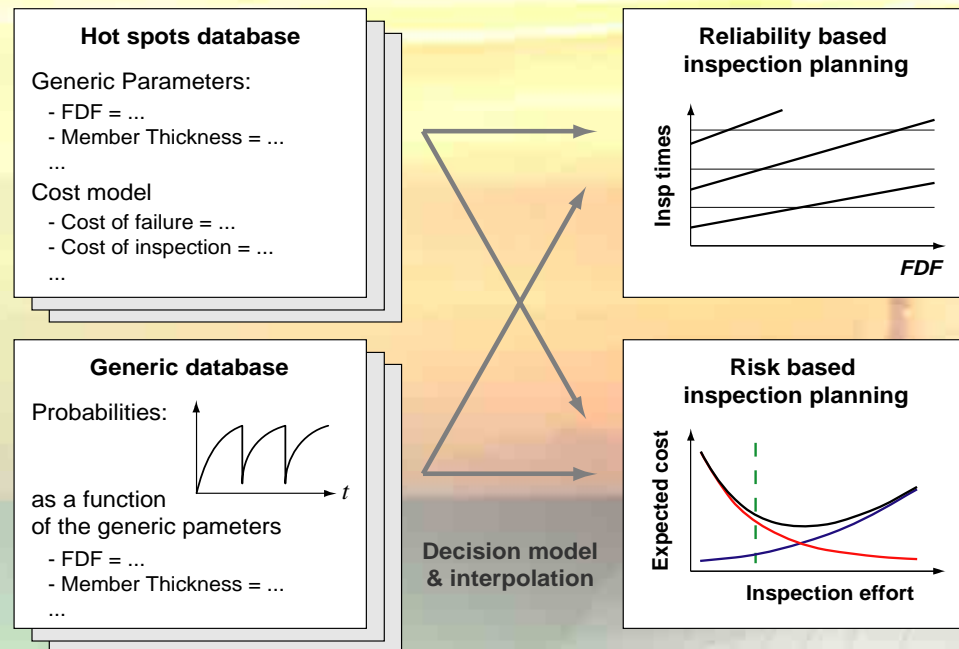


The image shows two grid charts representing inspection schedules. Each grid has 'Threshold' and 'Inspection method' on the y-axis and 'Years' on the x-axis. The top grid covers years 0 to 30, and the bottom grid covers years 31 to 60. Shaded cells in the grids indicate inspection points for various combinations of thresholds and methods.

## RBI for Platforms

- Where are we now?

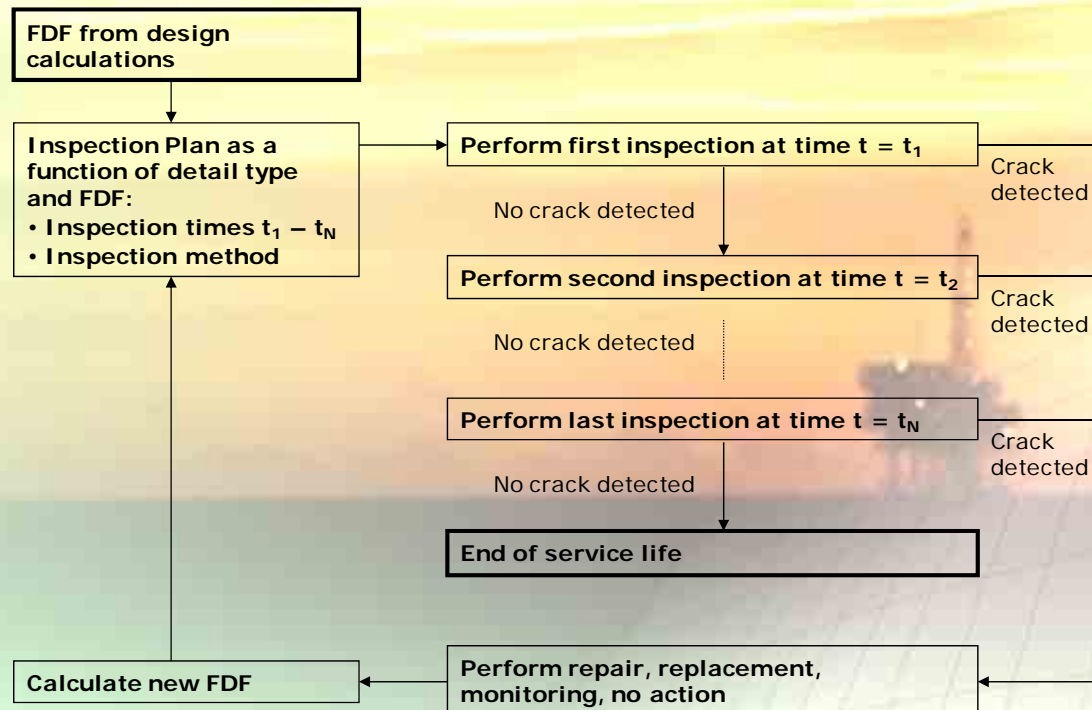
### Development of the tool iPlan (MS Excel based)



## RBI for Platforms

- Where are we now?


The procedure for generic RBI



## RBI for Platforms

- Where are we now?

The RBI tool iPlan – Input Sheet



iPlan PhD  
Input sheet

Project name: Test Jacket

Platform installation year:

Service life [Yrs]:

Bi Yearly Inspections  
 Odd Years  Even Years

Date: 2004-01-24  
Prepared by: DS  
Checked by:  
Approved by:

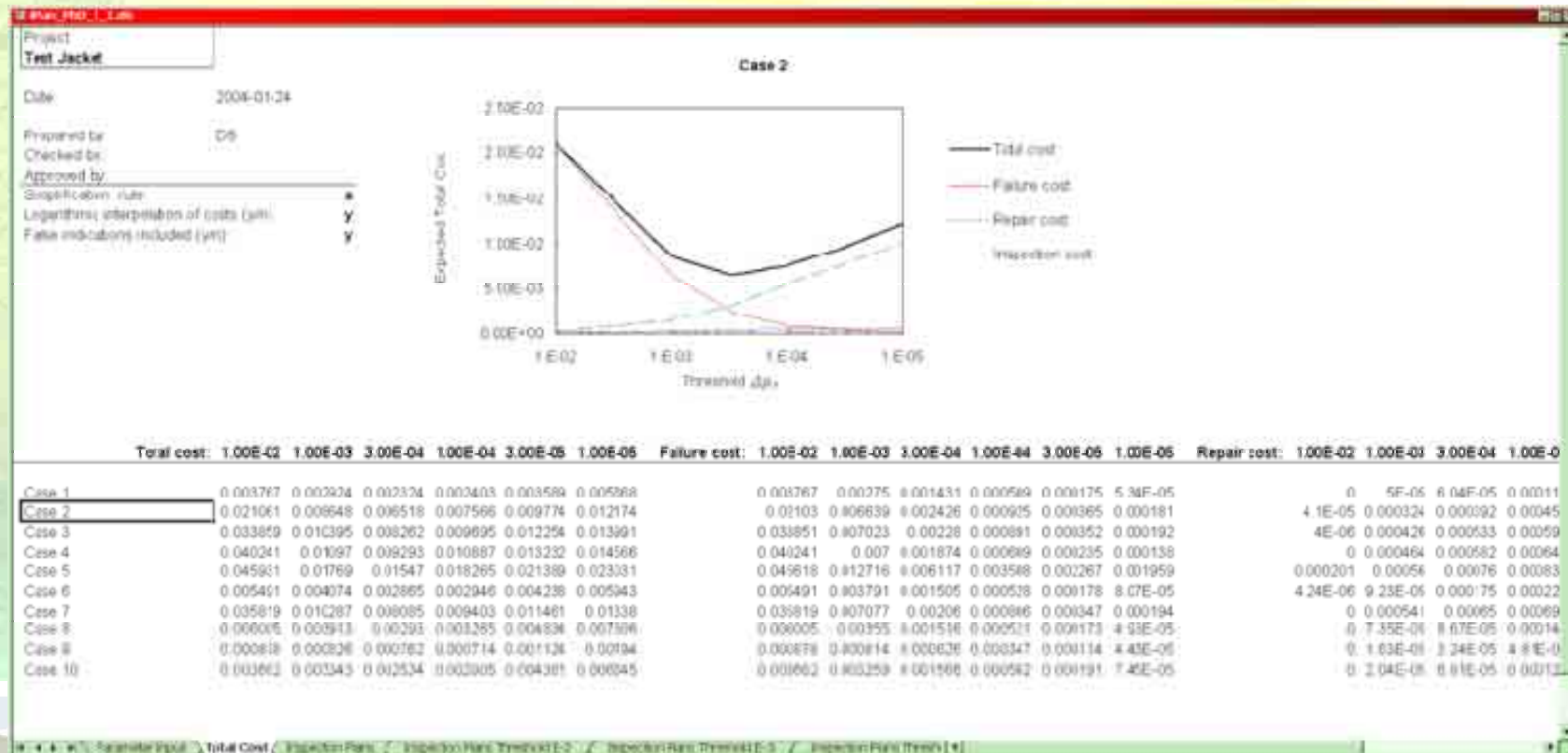
| Index   | SN Curve | Median |        |      | v [yr <sup>-1</sup> ] | Thickness [m] | DoBI     | Initiation Model | Fatigue Life [Yrs] | Inspection model | Threshold |      | Comments | Cost Model |        |         |          |
|---------|----------|--------|--------|------|-----------------------|---------------|----------|------------------|--------------------|------------------|-----------|------|----------|------------|--------|---------|----------|
|         |          | BS     | COV BS | λ AS |                       |               |          |                  |                    |                  | [pf/yr]   | RIF  |          | Inspection | Repair | Failure | Interest |
| Case 1  | DoE_D    | 1.00   | 0.30   | 0.70 | 3.00E+06              | 1.00E-02      | 2.00E-01 | Lassens_Model    | 200                | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |
| Case 2  | DoE_D    | 1.00   | 0.35   | 0.90 | 3.00E+06              | 4.00E-02      | 3.00E-01 | Lassens_Model    | 135                | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |
| Case 3  | DoE_D    | 1.00   | 0.33   | 1.10 | 3.00E+06              | 2.00E-02      | 4.00E-01 | Lassens_Model    | 83                 | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |
| Case 4  | DoE_D    | 1.00   | 0.30   | 1.30 | 3.00E+06              | 1.30E-02      | 5.00E-01 | Lassens_Model    | 64                 | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |
| Case 5  | DoE_D    | 1.00   | 0.40   | 1.50 | 3.00E+06              | 5.00E-02      | 6.00E-01 | Lassens_Model    | 175                | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |
| Case 6  | DoE_D    | 1.00   | 0.35   | 1.00 | 3.00E+06              | 3.00E-02      | 7.00E-01 | Lassens_Model    | 302                | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |
| Case 7  | DoE_D    | 1.00   | 0.35   | 1.00 | 3.00E+06              | 8.00E-03      | 8.00E-01 | Lassens_Model    | 79                 | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |
| Case 8  | DoE_D    | 1.00   | 0.30   | 0.60 | 3.00E+06              | 1.20E-02      | 8.00E+00 | Lassens_Model    | 160                | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |
| Case 9  | DoE_D    | 1.00   | 0.30   | 0.80 | 3.00E+06              | 4.50E-02      | 4.00E-01 | Lassens_Model    | 400                | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |
| Case 10 | DoE_D    | 1.00   | 0.35   | 0.90 | 3.00E+06              | 1.00E-02      | 3.00E-01 | Lassens_Model    | 200                | MPI_Tubular_ICON | 1.0E-04   | 0.75 |          | 0.001      | 0.01   | 1       | 0.05     |

Parameter Input / Total Cost / Inspection Plans / Inspection Plans Threshold E-2 / Inspection Plans Threshold E-3 / Inspection Plans Thresh

## RBI for Platforms

- Where are we now?

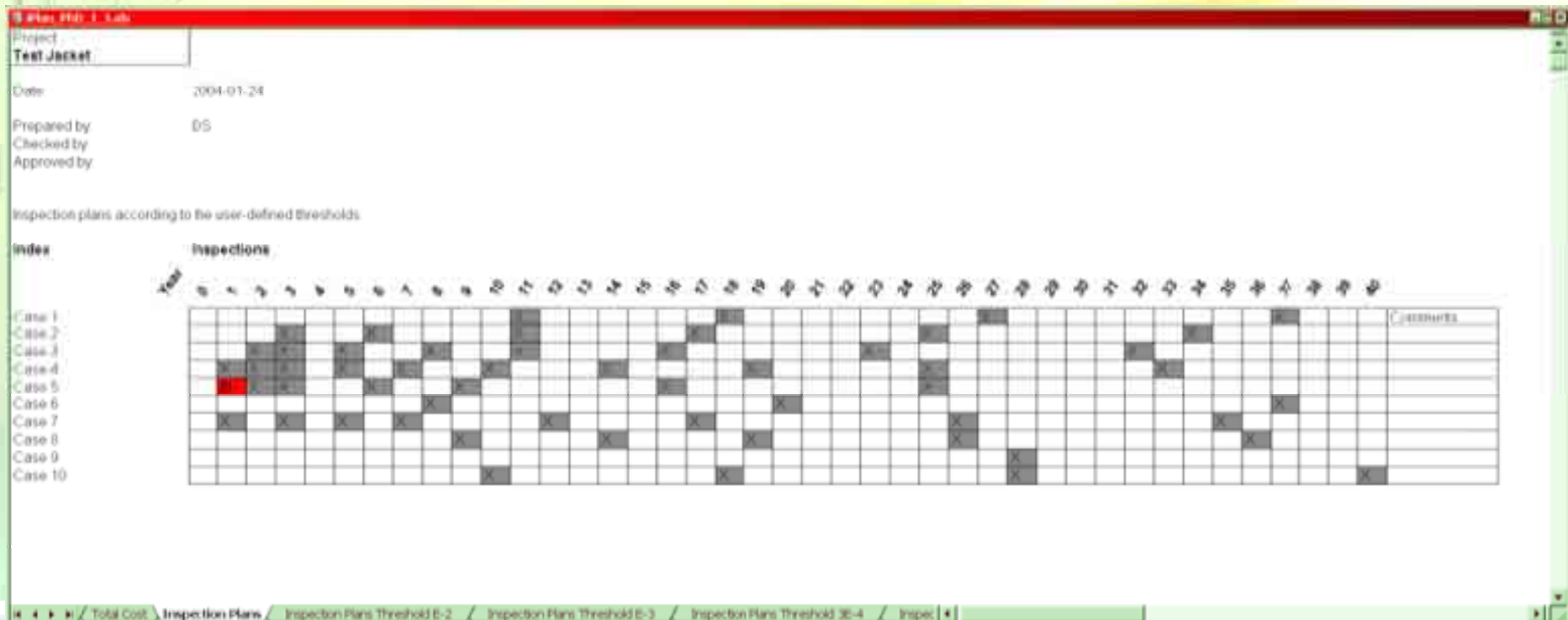
The RBI tool iPlan – Optimal Threshold Sheet



## RBI for Platforms

- Where are we now?

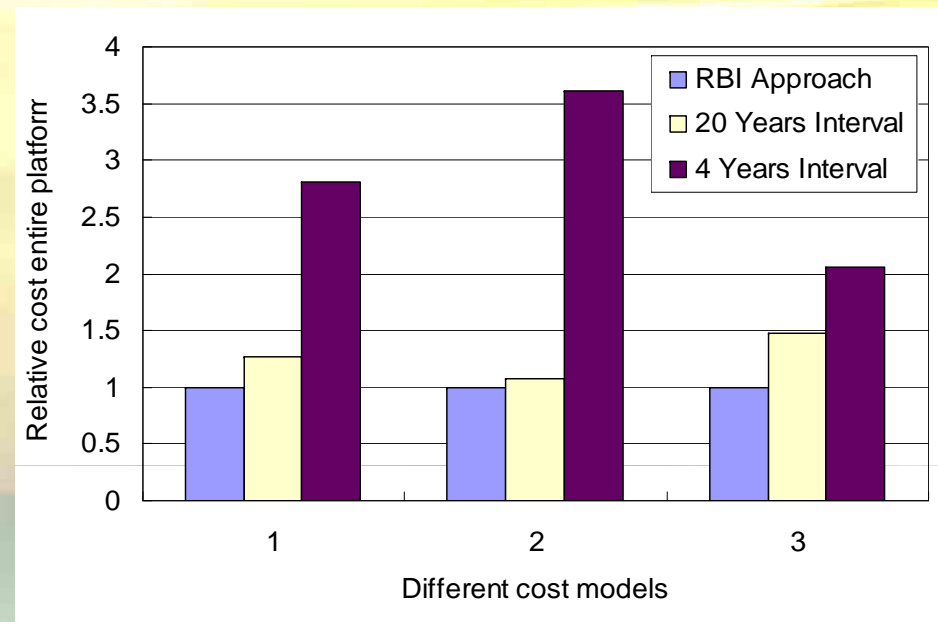
The RBI tool iPlan – Final Inspection Plans Sheet



## RBI for Platforms

- **Where to go?**

Benefit of RBI ?

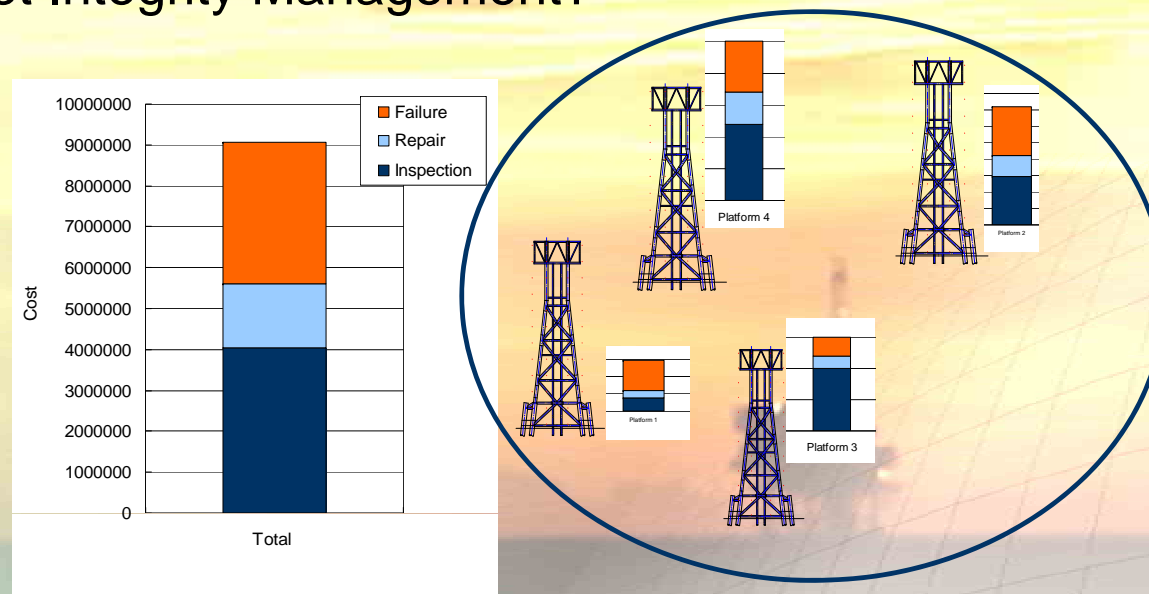


**YES !**

## RBI for Platforms

- Where to go?

Tool for Asset Integrity Management?



YES!

## An Outlook and Some Observations

- **Pemex and IMP are in the forefront !**

Significant investments have been directed into the development of methodologies and tools

But availability of tools is not enough !

- tools must be distributed
- tools must be integrated into operational and strategic routines
- tools must be learned
- tools must be updated and kept alive

## An Outlook and Some Observations

- **Which should be the next developments**

Tools are presently available for

- RBI for joints in steel jacket structures – iPlan (jacket)
- RBI for static process equipment – iPlan (Process)
- Inspection and repair prioritization - SIPRIAM

We now need tools facilitating the integration of these basic tools with the daily routines of the assets, some of the next logical steps would be to establish links with

- graphical databases
  - inspection and repair contracting
  - condition reporting for updating
- and to fix procedures on how to utilize the available tools in operational and strategic routines



## 1er. Simposio “Análisis, diseño, evaluación, inspección y mantenimiento de plataformas marinas. Aspectos relevantes”

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**Gracias por su atención**