CONFERENCE
OMAINTEC
2018
EXHIBITION

INTERNATIONAL OPERATIONS & MAINTENANCE CONFERENCE
IN THE ARAB COUNTRIES

UNDER THE THEME
"MANAGING MAINTENANCE WITHIN INDUSTRY 4.0"
CONICIDE WITH THE 16TH ARAB MAINTENANCE EXHIBITION

AN ANAYTIC TOOLBOX FOR EVIDENCE BASED ASSET MANAGEMENT

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ANALYTICS

Today, we frequently see the term "analytics," nicely defined by Davenport and Harris in their 2007 book *Competing on Analytics: The New Science of Winning* as:

"the extensive use of data , statistical and quantitative analysis, explanatory and predictive models, and fact based management to drive decisions and actions."

CONSIDER THE MAINTENANCE TACTIC: CONDITION BASED MAINTENANCE

With the 4th industrial revolution, Industry 4.0, data come from everywhere, and everything is linked to everything else.

ISO 55001 stresses in Section 8.2.3:

"The organization should have the capability to make evidence –based decisions on proposed changes and the ability to consider scenarios systematically across the entire organization"

Key issue: **WHICH DATA ARE THE MOST RELEVANT?**

ELEMENTS OF THE ANALYTIC TOOLBOX

1.DATA FROM SENSORS

2. DATA FROM WORK ORDERS

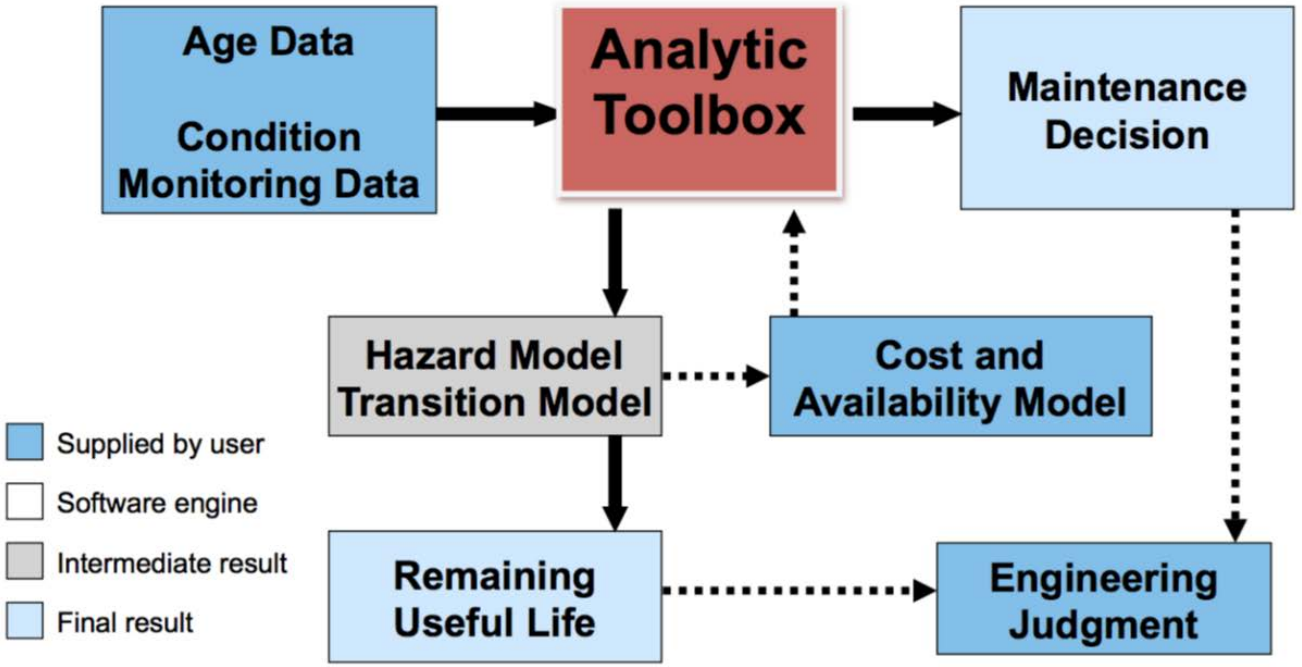
3. A PROPORTIONAL HAZARDS MODEL

4. A TRANSITION PROBABILITY MATRIX

5. A COST OPTIMIZATION MODEL

6. AN AVAILABILITY MAXIMIZATION MODEL

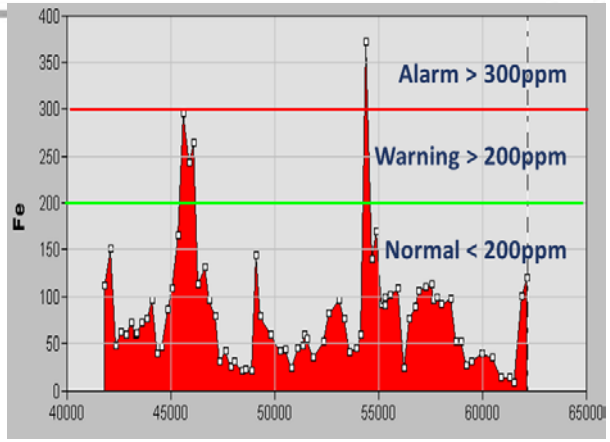
ANALYTIC TOOLBOX FOR CBM OPTIMIZATION



NOTE: All tools in the Analytic Toolbox (software engine) are in the public domain

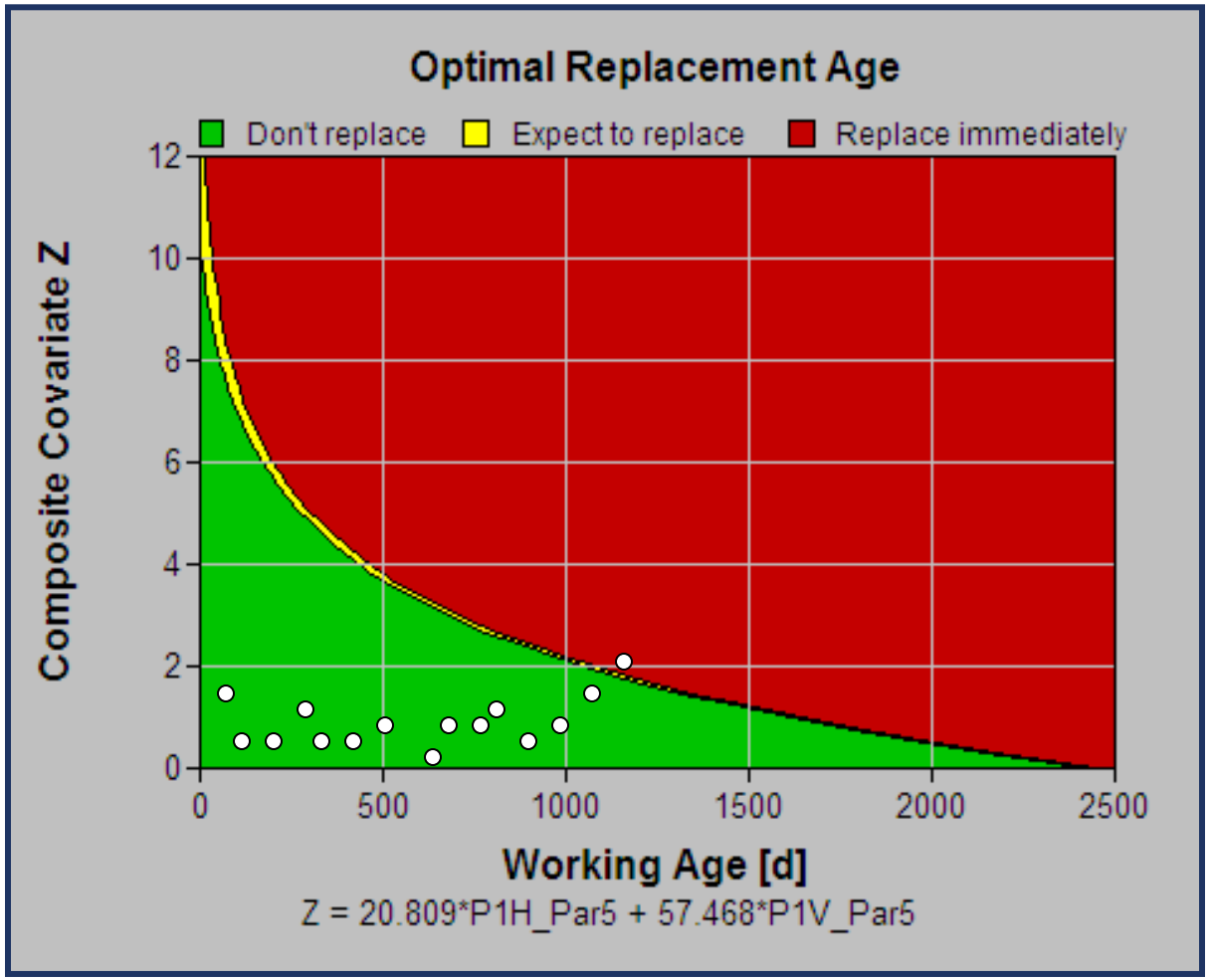
CONDITION MONITORING VIA WARNING LIMITS

- **Simple to understand**
- **Limitations:**
  - **Which measurements?**
  - **Optimal limits?**
  - **Effect of Age?**
  - **Predictions?**
  - **Consequence of failure**
- **CBM optimization extends and enhances the Control Chart technique.**



OPTIMAL DECISION – OUTPUT FROM TOOLBOX: A NEW "CONTROL CHART"

TOOLBOX CALLED EXAKT DEVELOPED AT THE UNIVERSITY OF TORONTO: ALL ELEMENTS OF THE TOOLBOX ARE IN THE PUBLIC DOMAIN

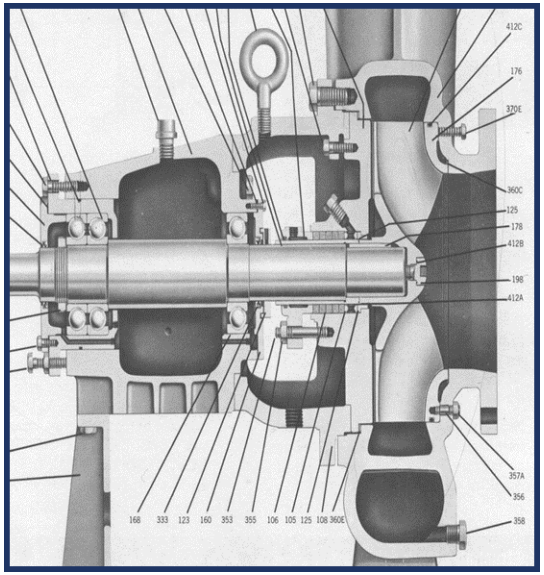


APPLICATION OF TOOLBOX AT IRVING PULP & PAPER

Analysis of Goulds 3175L Pumps
Bearing Vibration Data
56 vibration measurements provided by accelerometer

Using <EXAKT>:
2 measurements significant

A Check:
Had <EXAKT> model been applied to previous histories
Savings obtained = 33%



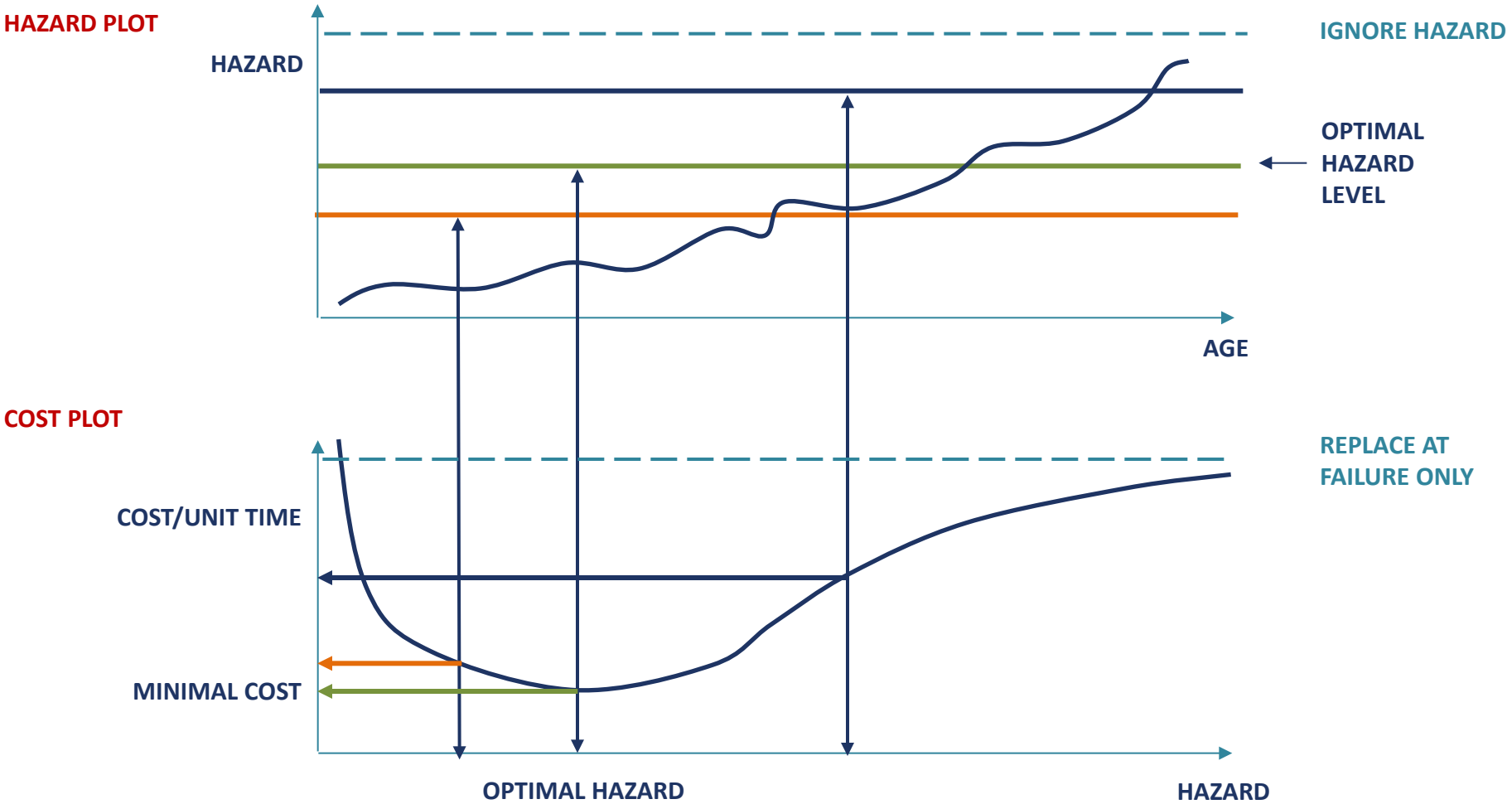
HOW IS TOOLBOX DEVELOPED?
STEP 1: HAZARD MODEL

$$\underbrace{\text{Hazard}(t, Z(t))}_{\text{Instantaneous rate of failure}} = \underbrace{\frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}}_{\text{Contribution of age to hazard}} \underbrace{e^{\gamma_1 z_1(t)+\ldots+\gamma_n z_n(t)}}_{\text{Contribution of condition information to hazard}}$$

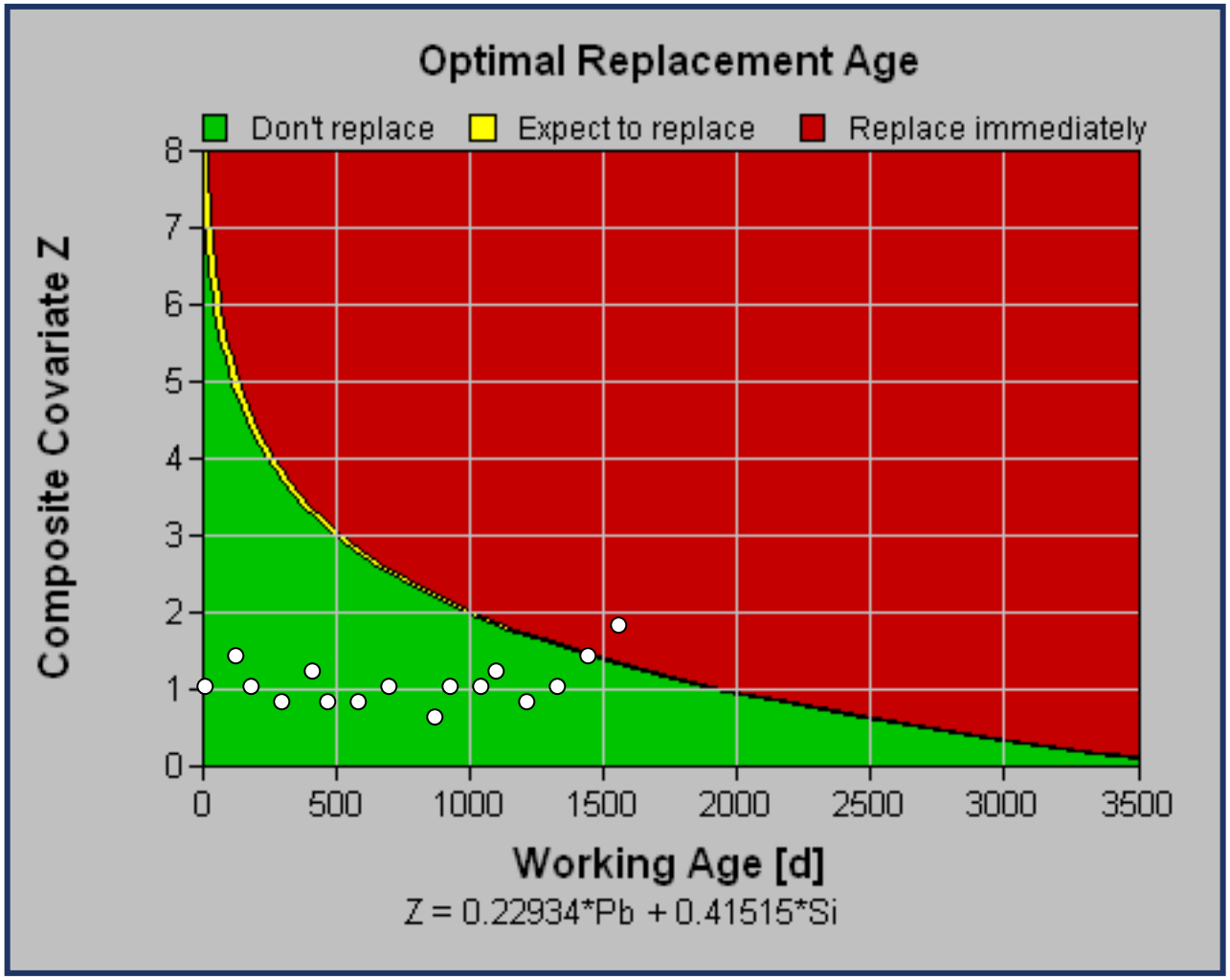
$$\frac{2.523}{3402}\left(\frac{t}{3402}\right)^{1.523} \exp\{0.2293 \cdot Pb + 0.4151 \cdot Si\}$$

CONSTANTS ESTIMATED FROM DATA

STEP 3: OPTIMAL HAZARD LEVEL FOR PREVENTIVE REPLACEMENT: INCLUDING ECONOMIC CONSEQUENCES



TOOLBOX OUTPUT: OPTIMAL DECISION CHART (OIL SAMPLING)



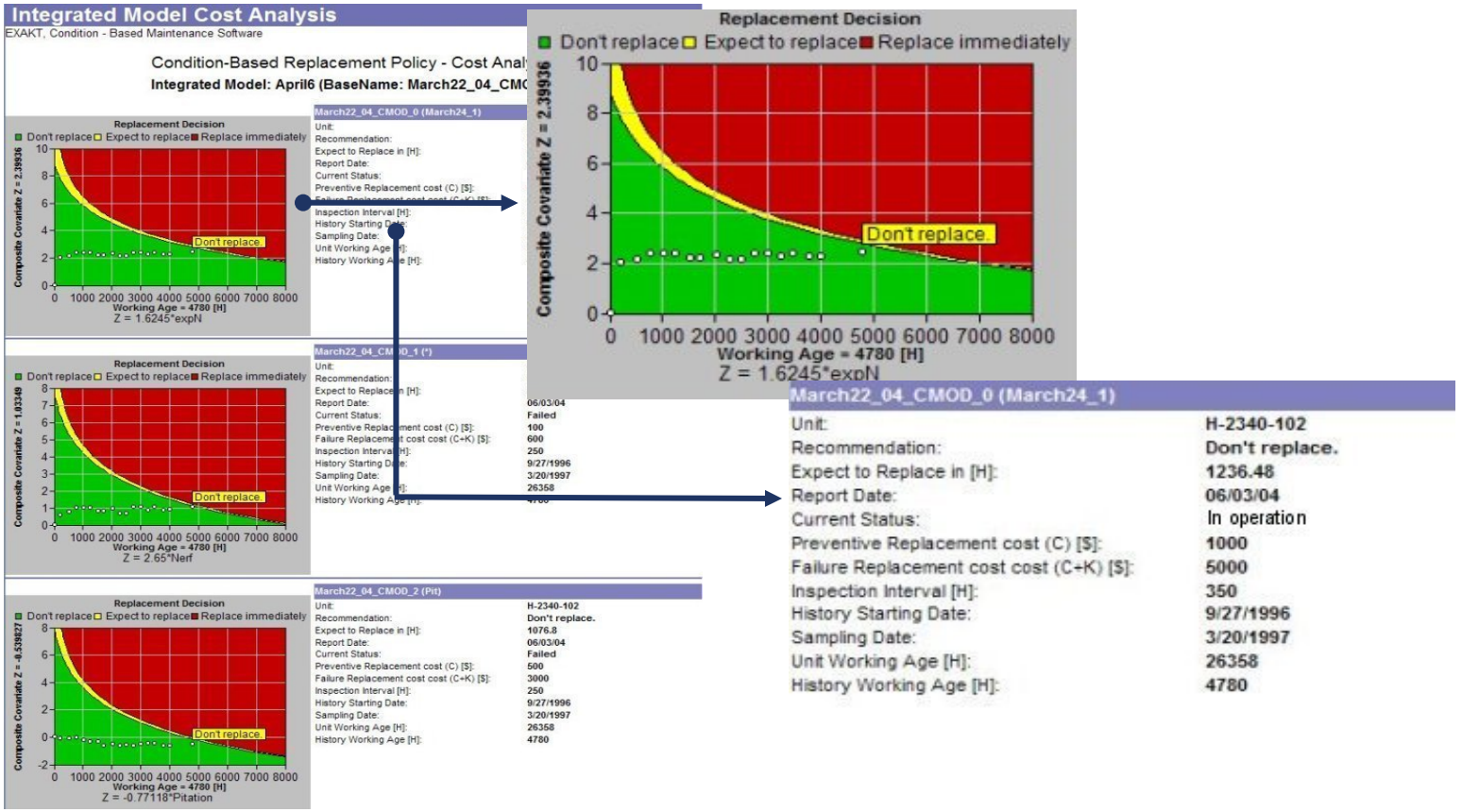
APPLICATION OF TOOLBOX FOR REPAIRABLE SYSTEMS

MODELING OF DIESEL ENGINES EMPLOYED ON T23 FRIGATES

DIESEL ENGINES: FAILURE MODES

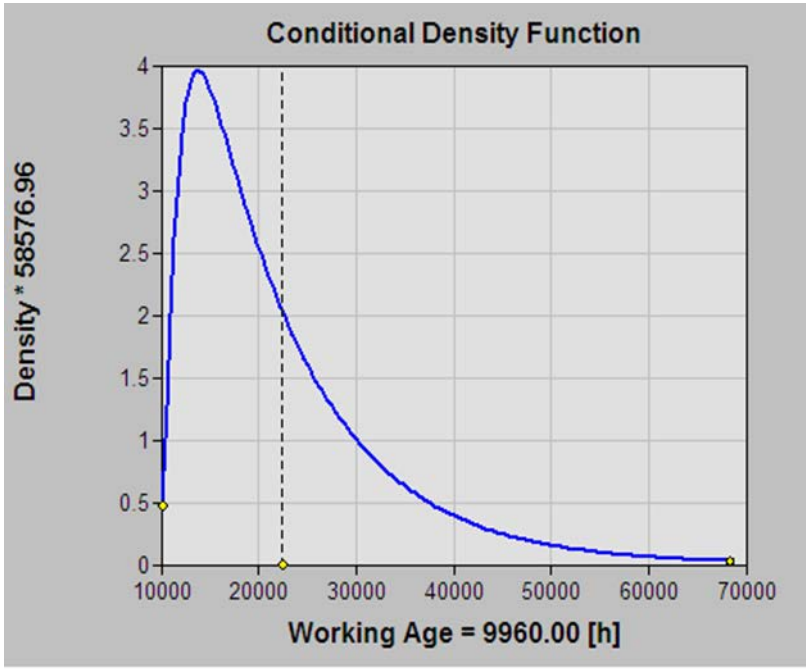
	TYPE OF FAILURE	COUNT	
0	Not Known	3	NOT OIL
1	Cooling System	13	
2	Fuel System	6	
3	Generator	9	
4	Accessories	9	
5	Cylinder Liners and Rings	24	OIL
6	Valves and Running Gear	20	
7	Pistons, Articulations and Bearings	15	
8	Cylinder Heads	14	
9	Misc, including cylinder block failures	12	

SIMULTANEOUS DECISIONS FOR EACH FAILURE MODE OF A REPAIRABLE SYSTEM



CONDITIONAL DENSITY FUNCTION & REMAINING USEFUL LIFE

- Shows the shape of the distribution of the time to failure given current conditions
- Expected time to failure (Remaining Useful Life, or RUL)
- Standard deviation



Probability Intervals

RUL=12425.554043, StdDev=10724.113435

ANALYTIC TOOL BOX APPLICATIONS: REFERENCES

1. Vlok, PJ et al, *Optimal component replacement decisions using vibration monitoring and the proportional-hazards model*, Journal of the Operational Research Society 53(2) · February 2002. This is an excellent paper that provides the theory behind the application of the analytics associated with CBM optimization. In addition it includes an application of the use of the theory to a CBM vibration monitoring decision problem with Sasol in South Africa

2. Sundin, P et al, *Pulp Mill On-Site Implementation of CBM decision support software*, ICOMS Asset Management Conference, Melbourne 2007

3. Thompson, E. *Improving Physical Asset Management Decisions*, IMPACT magazine, published Fall 2016 by OR Society, UK. The article explains the benefits of using analytics to assist with making optimal Condition Based Maintenance (CBM) decisions, in the context of work done at the Centre for Maintenance Optimization and Reliability Engineering (C-MORE), University of Toronto. Cases described come from collaborations with: UK Ministry of Defence, Hong Kong Mass Transit, Irving Pulp and Paper (Canada), Cardinal River Coals (Canada), Sasol (South Africa), Campbell Soup Company and EDF (France)

4. Jardine, A K S., An Analytic Toolbox, Assets magazine, Published by the Institute of Asset Management, August 2018

5. The mathematical foundation for the presentation can be found in *Maintenance, Replacement and Reliability: Theory and Applications*, *2nd Edition,* A K S Jardine and A H C Tsang, CRC Press, 2013: Chapter 3, Section 3.5 titled Optimizing CBM Decisions.

THANK YOU

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My web page:
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