2014 ARS, North America, Indianapolis

Red Room, Session 2

Begins at 10:30 AM, Tuesday, June 3rd

Determining the Optimal Soft Life for a Key Component

Tom Ryan
Rolls-Royce

PRESENTATION SLIDES

The following presentation was delivered at the:

International Applied Reliability Symposium, North America
June 3 - 5, 2014: Indianapolis, Indiana
http://www.arsymposium.org/2014/

The International Applied Reliability Symposium (ARS) is intended to be a forum for reliability and maintainability practitioners within industry and government to discuss their success stories and lessons learned regarding the application of reliability techniques to meet real world challenges. Each year, the ARS issues an open "Call for Presentations" at http://www.arsymposium.org/present.htm and the presentations delivered at the Symposium are selected on the basis of the presentation proposals received.

Although the ARS may edit the presentation materials as needed to make them ready to print, the content of the presentation is solely the responsibility of the author. Publication of these presentation materials in the *ARS Proceedings* does not imply that the information and methods described in the presentation have been verified or endorsed by the ARS and/or its organizers.

Introduction

- Tom Ryan
  - Senior Systems Engineer
  - Rolls-Royce Corporation
- Safety critical parts are often life limited and have published not to exceed hard lives.
- These hard lives are determined by engineering analysis and testing.
- Soft lives are established for economic reasons.
- The purpose of a soft life is to reduce the total cost of maintenance for key tracked components that exhibit a wearout mode.
- A case study in determining the soft life of a bearing will be presented.

Agenda

• Introduction	5 min
• Types of Maintenance	5 min
• Types of Lives	10 min
• Reliability Centered Maintenance	5 min
• Case Study	20 min
• Summary	5 min
• Questions	10 min

Types of Maintenance

- Corrective
- Preventative
- Scheduled
- Unscheduled
- Condition-monitored
- On-condition
- Opportunistic

Types of Lives

- Hard Lives
- Soft Lives
- Stub Lives

Hard Life

- Safety critical components
- Age based preventative maintenance
- Predetermined age limit
- Mandatory replacement
- Cannot exceed FAA Chapter 5 Life Limited Parts (LLP)

Hard Life

The purpose of hard lives are to prevent failures like this:

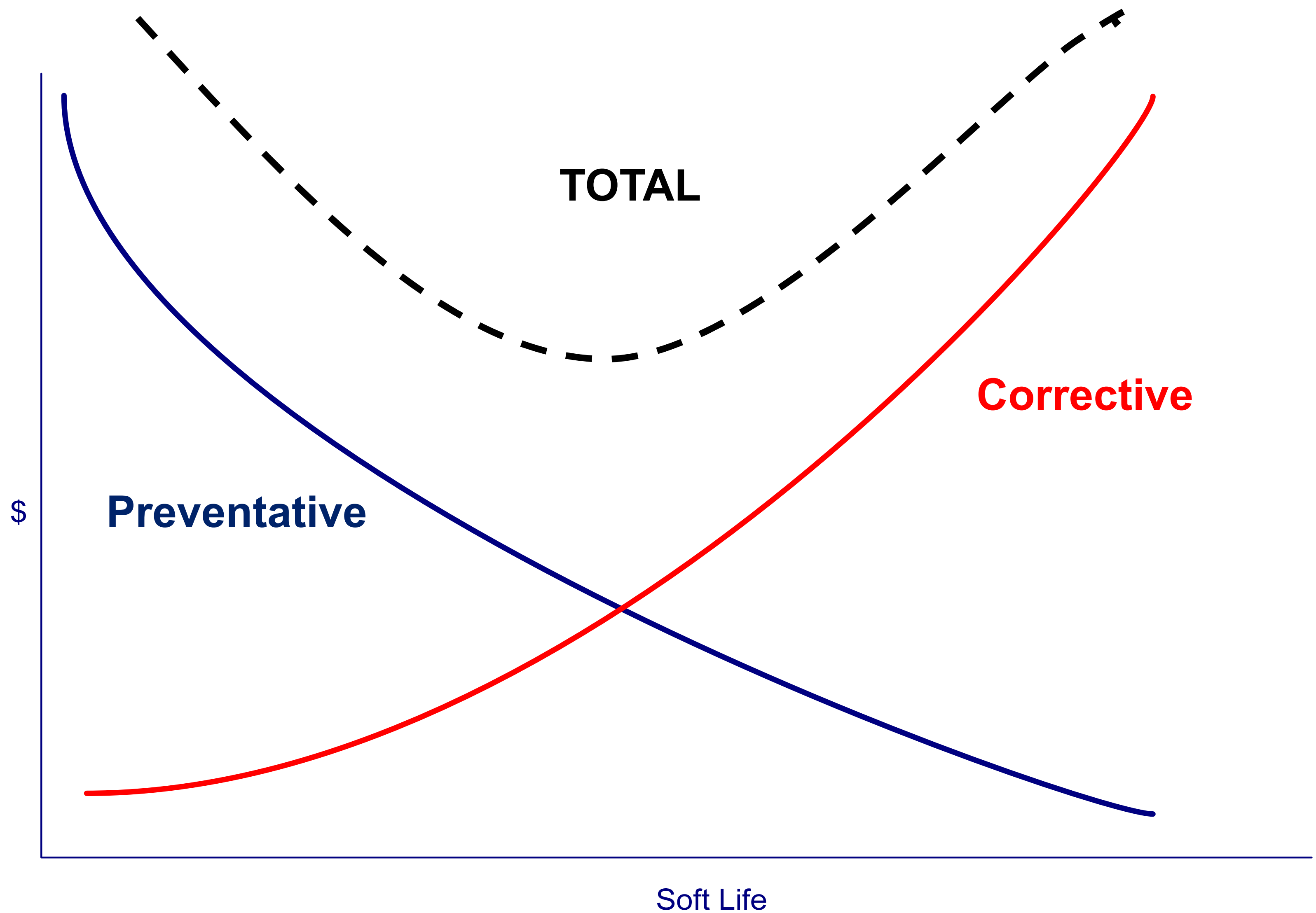
Source: http://www.iasa.com.au/folders/Safety_Issues/FAA_Inaction/severityUnderstated.html

Soft Life

- Tracked components
- Demonstrated wearout mode
- Age based opportunistic replacement
- Recommended replacement
- Established for economic reasons

Soft Life

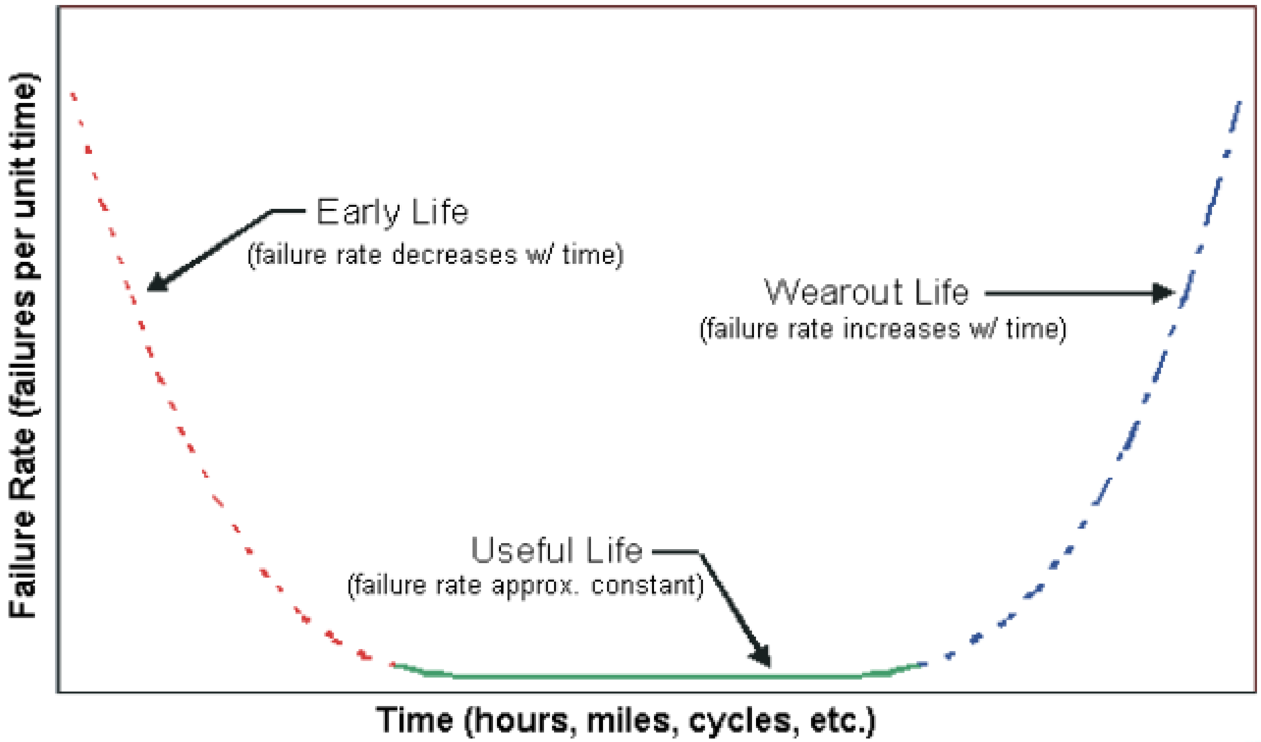
The purpose of a soft life is to minimize the total maintenance cost.



Stub Life

- Similar to a soft life.
  - Soft life is the age of the part.
  - Stub life is the time remaining to the hard life.
- Established for economic reasons.
- Minimum issue life (MISL)
- Minimizes the total number of shop visits.
- Ensures that the remaining life of the part closely matches the expected time on wing of the engine when it returns to service.

Reliability Centered Maintenance



Source: http://www.weibull.com/hotwire/issue14/relbasics14.htm

Ideally, the best time to replace a part is after its useful life is exceeded and before it fails. There is an optimal point somewhere on the wearout part of the curve to perform maintenance. However, this point is not always known and may not be practical.

Case Study

Source: http://rr/c_ra/CS_ME/Active_Pages/AE3007.htm

 # 4 Ball Bearing

Support and locates the rotor

Transfer bearing loads to structure

Failure Mode and Effects

- **Failure Mode**
  - Spalling

- **Effects:**
  - Reduced capability to properly position the rotor shaft.
    - Increased axial and radial movement.
    - Possible compressor and turbine blade rub.
      - Possible secondary rub damage to the rotor.
  - Possible metal debris in oil.
  - Possible loss of oil from sump.
  - Possible increased oil temp.
  - Possible in-flight shutdown (IFSD).

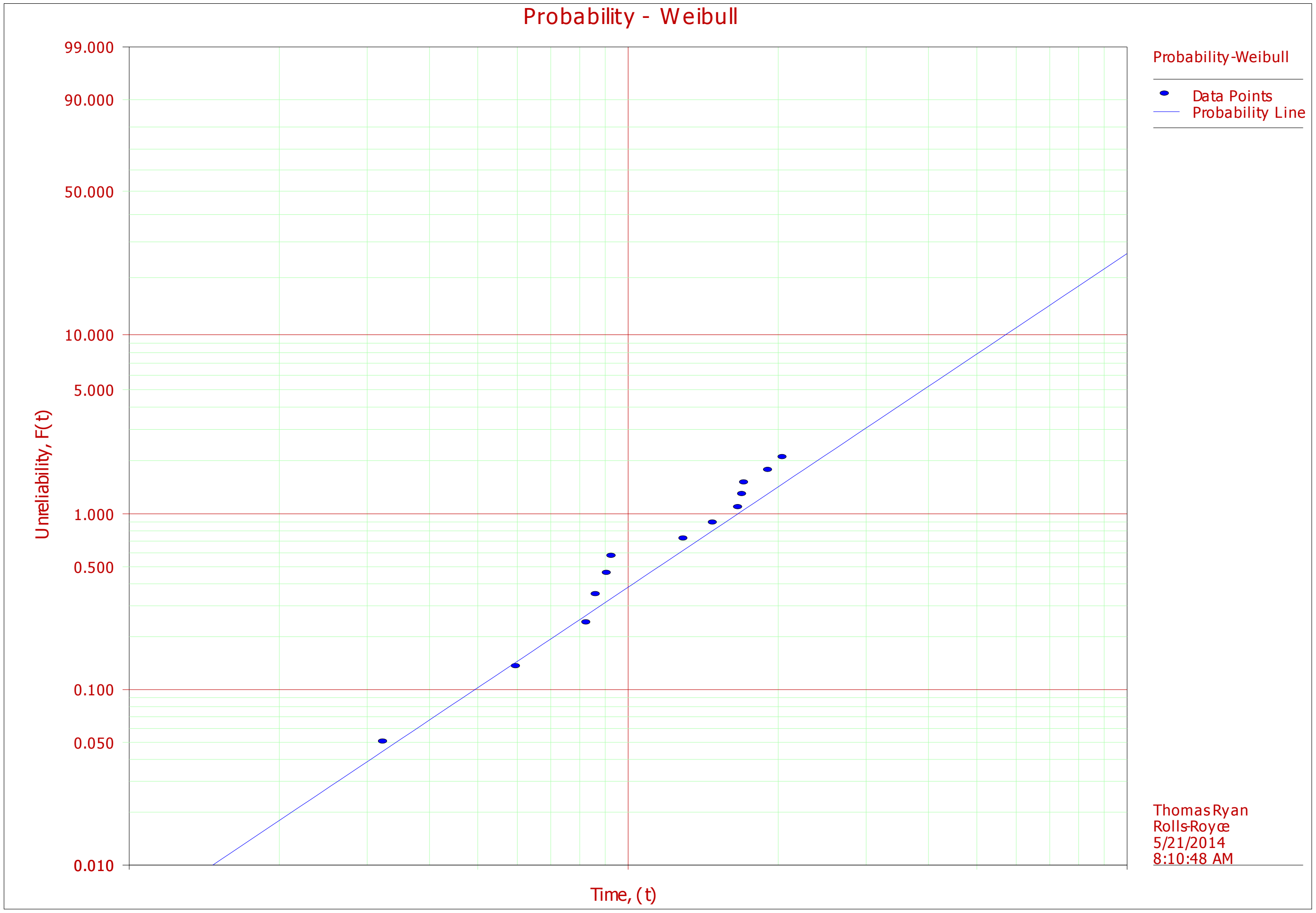
Failure Mode and Effects

- **Detection methods**
  - Metal on mag plug
  - Oil temperature monitoring
  - Oil quantity monitoring
  - Oil pressure monitoring
  - Vibration trending
  - Vibration exceedance
  - IFSD

Failure Mode and Effects

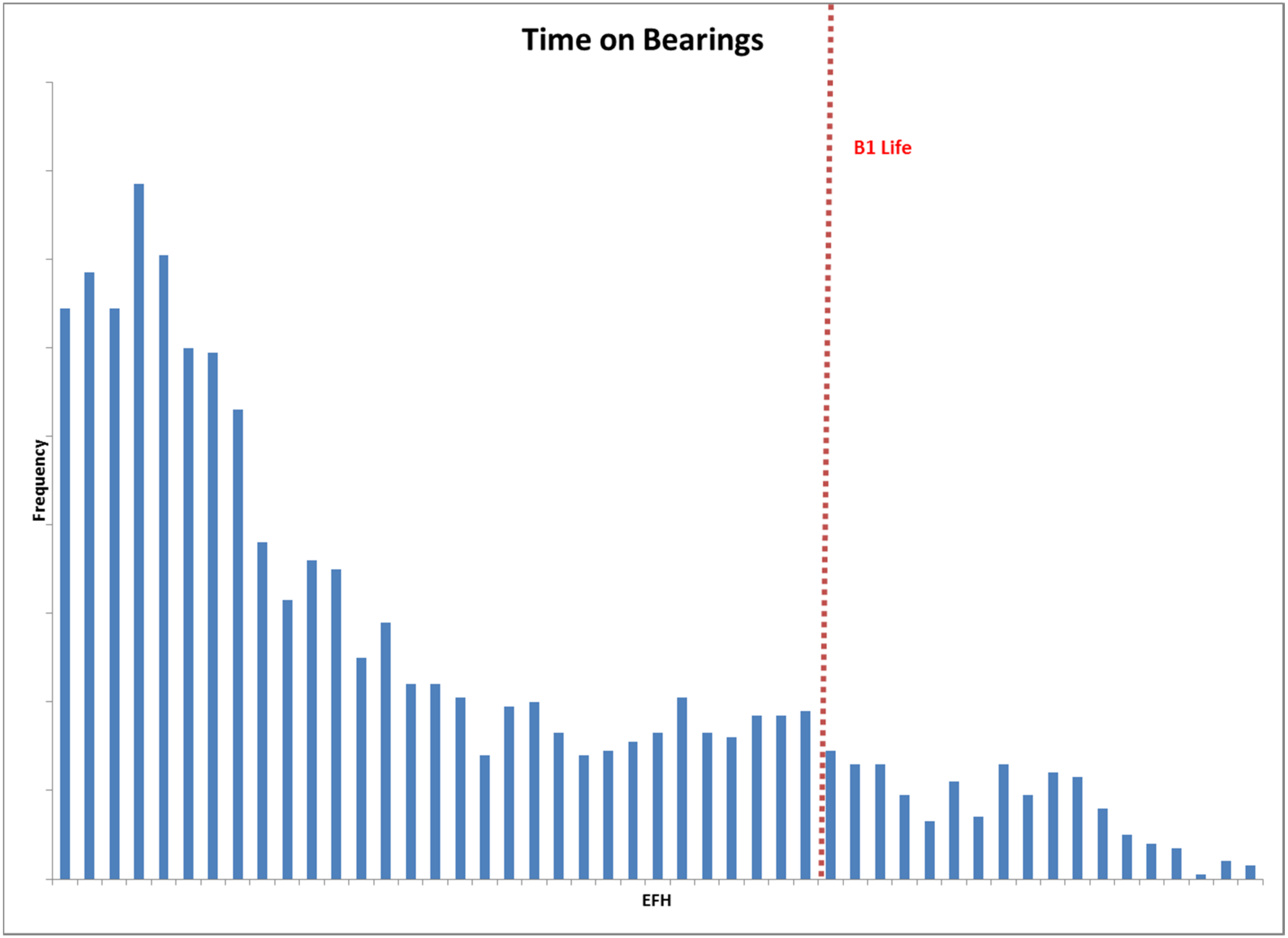
- **Once detected, then:**
  - Engine removal
  - Unscheduled shop visit
    - $$$$
- **Disruption to customer operations**
  - Possible flight diversion
  - Possible flight cancellation
  - Maintenance burden
  - $$$$

Weibull Results



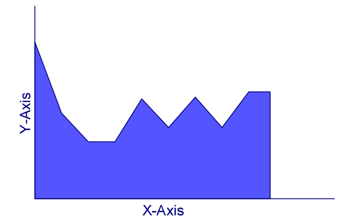
The Weibull slope Beta = 1.9, higher then the expected value for bearings. The characteristic life is greater than 100,000 EFH.

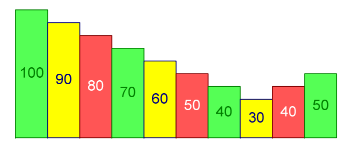
Monte Carlo Inputs

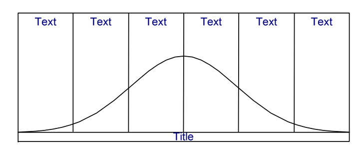


Monte Carlo Inputs

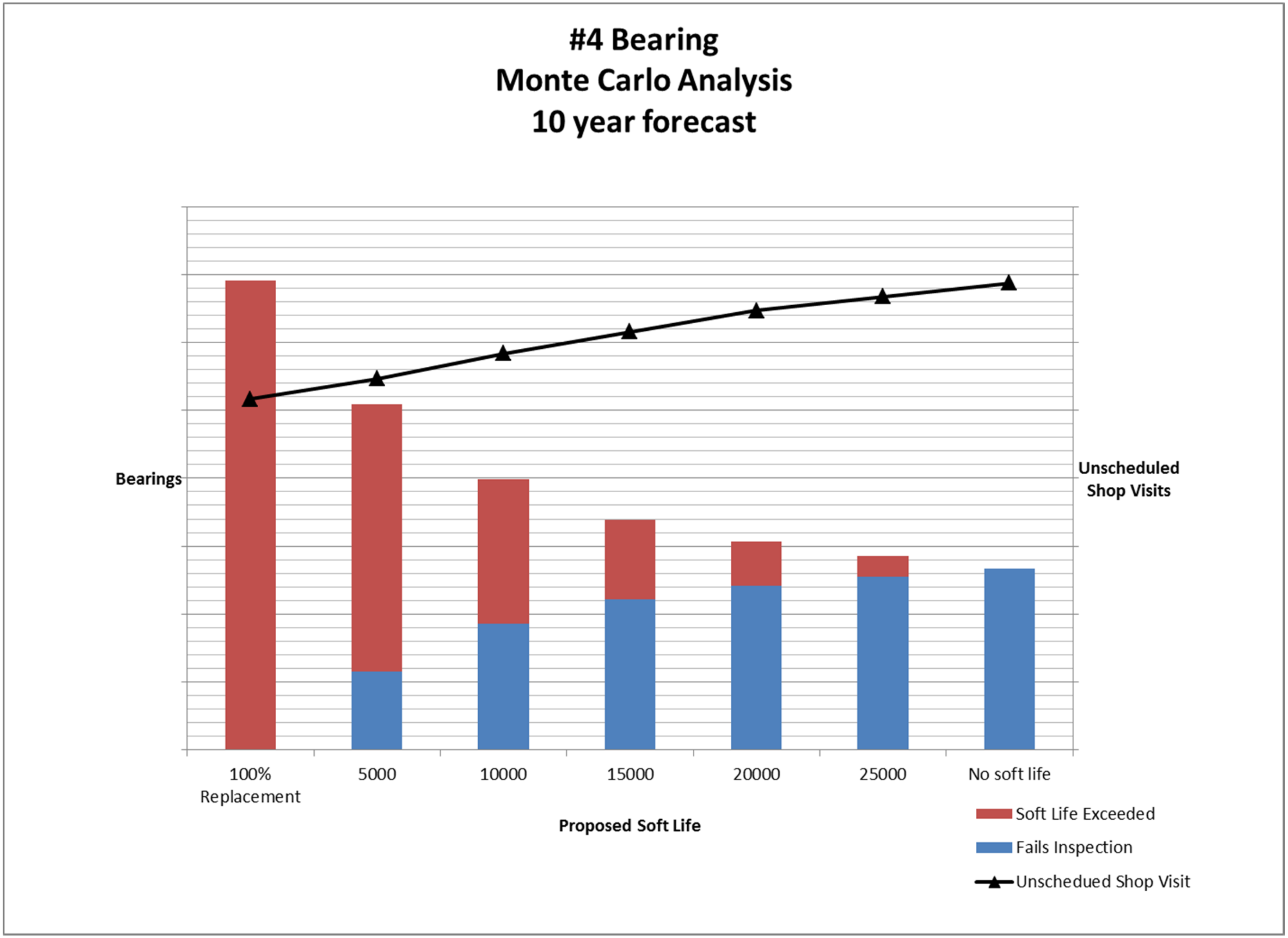
- Proposed Soft Lives
- Weibull Parameters
- Annual Usage Distribution
- Shop Visit Rate
- Shop Visit Cost Distribution
- Inspection Reject Percentage
- Customer Disruption Cost Distribution
- Current and Expected Bearing Cost







Monte Carlo Results



Monte Carlo Results

Options

1. Keep current policy – NO SOFT LIFE.
2. Implement 100% replacement at every shop visit.
   - Cost of inspection goes to zero.
   - 30% fewer unscheduled shop visits.
   - 200% increase in spare bearings will be needed above what would be naturally attrited.
     - Additional demand on vendors.
     - Increase in inventory costs.
     - Low time, good bearings, will be needlessly replaced.
3. Implement a soft life policy.

Optimal Soft Life

The objective of a soft life is to minimize the total maintenance cost.

$$TC = EC_c + EC_p$$

- Where:
  - TC = total cost
  - EC_C = expected cost of corrective maintenance
  - EC_P = expected cost of preventative maintenance

Optimal Soft Life

Corrective maintenance costs can easily exceed a million dollars for a single incident.

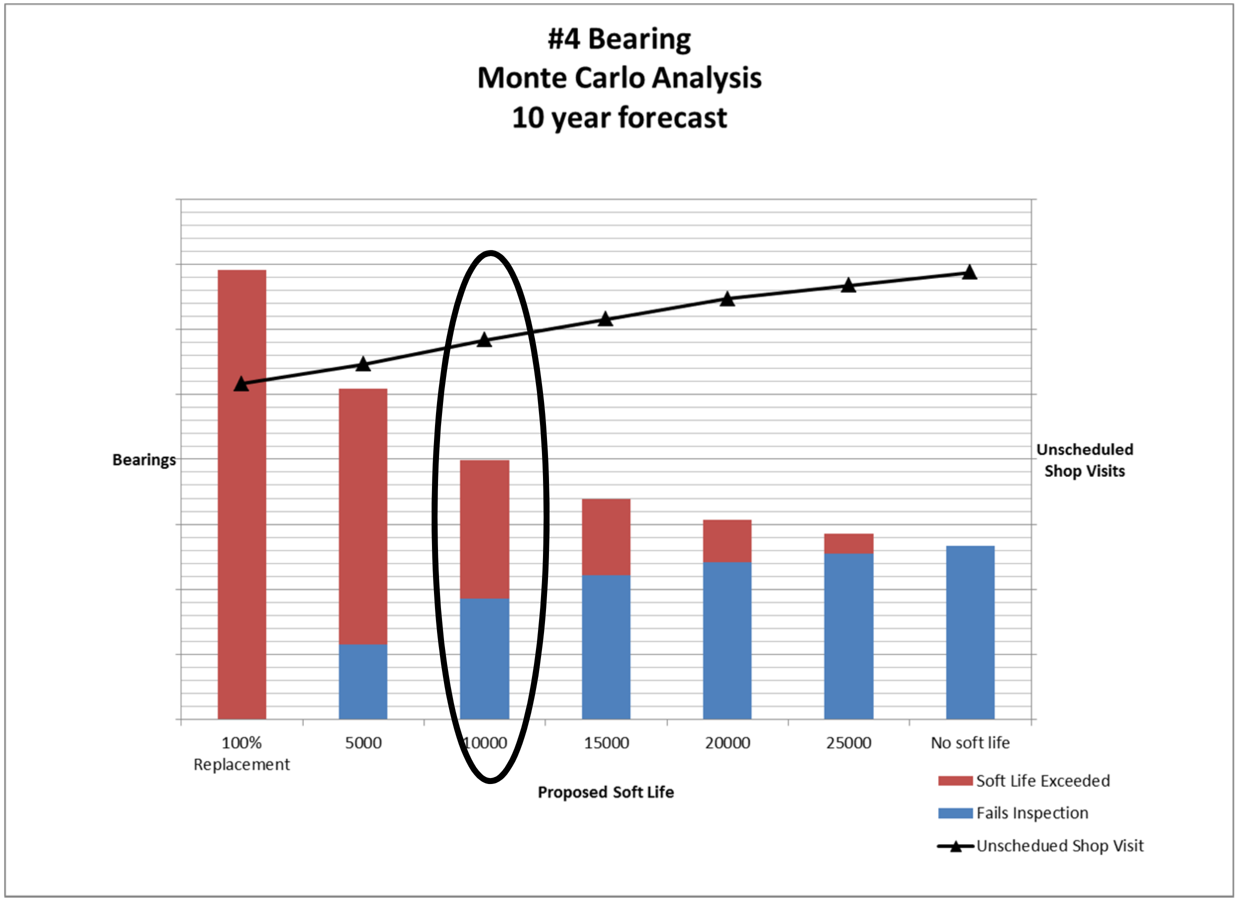
- Shop visit costs
  - Direct
  - Indirect
  - “Sunshine” parts
- Transportation costs
- Storage costs
- Warranty costs
- Failure investigation costs
- Payments to airlines for service disruptions

Optimal Soft Life

A slight increase in preventative maintenance costs can significantly reduce total cost:

- Cost of part increase in shop visit costs.
    - Some additional labor.
- Incremental increase in inventory costs.
- Possible reduction in component unit cost with increased volume.

Optimal Soft Life



In this example, total cost was minimized with the selection of a 10,000 EFH soft life. Approximately one additional bearing a month for the next ten years will result in two fewer unscheduled shop visits.

Other benefits of soft lives

- Increase in the Average Time on Wing (ATOW)
- Increase in availability A_0 with an increase in MTBR
- Improved customer satisfaction
- Enhanced product reputation
- Heightened brand image
- **COMPETITIVE ADVANTAGE**

Summary

- Soft lives are opportunistic maintenance.
- The goal is to reduce the total cost of maintenance.
- Unlike hard lives which are usually tied to safety, soft lives are economic based.
- A small increase in preventative maintenance costs can be leveraged into large savings.

Where to Get More Information

- ATA MSG-3 *Operator/Manufacturer Scheduled Maintenance Development.*
- Kumar UD, Crocker J, “Age-related maintenance versus reliability centred maintenance: a case study on aero-engines.” *Reliability Engineering and System Safety* 67 (2000) 113–118.
- Kumar UD, Crocker J, Knezevic J., “Evolutionary maintenance for aircraft engines.” *Proceedings of the Annual Reliability and Maintainability Symposium*, 1999. p. 62–8.
- USACERL Technical Report 99/41 Reliability Centered Maintenance (RCM) Guide, US Army Corps of Engineers.

Tom Ryan

Tom Ryan is a Senior Systems Engineer for Rolls-Royce Corporation in Indianapolis, IN. He has held positions in project engineering, customer support, quality, reliability and life cycle engineering and is an ASQ CRE, CQE, CSSGB, and CMQ/OE. Before joining Rolls-Royce, he was an Aircraft Maintenance Duty Officer in the US Navy.

Tom has a BS in mathematics from the US Naval Academy, an MBA from Butler University, and a Certificate in Reliability Engineering from the University of Maryland.

- Tom Ryan
- Senior Systems Engineer
- Rolls-Royce Corporation
- Tom.Ryan@rolls-royce.com

Questions

Thank you for your attention.

Do you have any questions?