A Successfully Implemented Coordinated Subsystem Reliability Growth Planning Approach

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Topics

AMSAA
Excellence in Analysis

- *Reliability Growth Planning Model SSPLAN*
  - Overview
  - Principal Benefits and Features
  - Model Inputs and Outputs
  - Procedure used to Generate Model Outputs
- *Bombardier Applications*
  - Bombardier Overview
  - Problem Statement / Opportunity
  - Reliability Maturation Model
  - New Reliability Growth (NRG II) Model Objectives
  - Railway example of implementation process
  - Interactions between basic elements of reliability process
  - Summary of NRG II Benefits

SSPLAN Overview

- Reliability Growth Planning Model based on system level reliability objective (mean test duration between failure, MTBF) and coordinated subsystem growth program inputs.

- Applies to systems composed of a series of subsystems that independently generate failures.

- Can accommodate a mixture of growth and non-growth subsystems.

- Measure of test duration, t , is continuous (e.g., time, distance).

- Assumes for each growth subsystem i, the number of failures that occur in test interval [0,t], $N_i(t)$, is governed by a nonhomogeneous Poisson process (NHPP) with a power law mean value function $\lambda_i t^{\beta_i}$ assumed at system level in U.S. MIL-HDBK-189.

- Developed by AMSAA and documented in AMSAA Reliability Growth Guide (Technical Report No. TR-652, Sept. 2000)

Principal Benefits and Features

- **Helps construct a set of subsystem planning curves with associated subsystem test durations and target MTBFs**
  - **that are consistent with system reliability objective and growth subsystem reliability allocations**
  - **whose achievability can be gauged by past experience**

- **Subsystem planning curves and test durations have property that if realized during developmental test program, with a *specified probability*, subsystem test data would provide a *specified level of assurance* that system reliability objective is met.**

- **Subsystem planning curves support decision process with respect to allocation of test resources**
  - **prior to test program**
  - **during testing with regard to reallocation to address subsystem reliability deficiencies**
    - ✓ **can provide objective basis for prioritizing subsystem corrective action efforts**

- **System and associated subsystem planning curves serve as benchmarks against which reliability improvement can be measured**
  - **highlights to program management and customers assessed reliability versus reliability goals at program milestones**
    - ✓ **at system and subsystem levels**

Model Inputs & Outputs

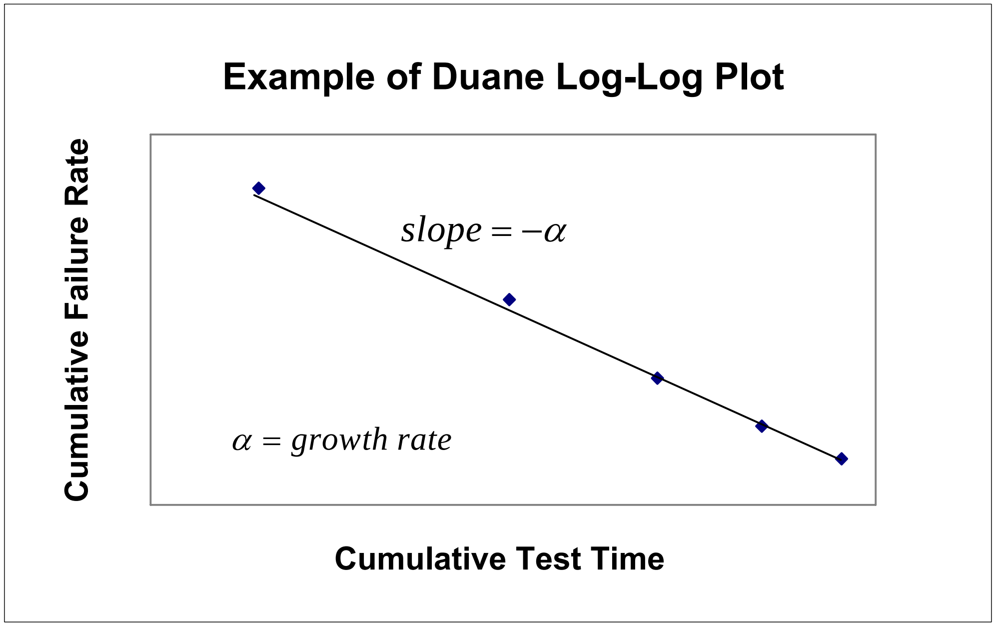
- ***System Level Inputs***
  - System MTBF objective, $M_{obj,Sys}$
  - Statistical confidence level γ for lower confidence bound LCB_γ on achieved system MTBF
  - Specified probability p_0 that subsystem test data would yield a value of LCB_γ that meets or exceeds $M_{obj,Sys}$ if subsystems grow in accordance to planning curves for planned test durations
    - ✓ γ is the *specified level of assurance*
    - ✓ p_0 is the *specified probability* that assurance level would be realized under growth assumption
- ***System Level Output***
  - System MTBF target , $M_{targ,Sys}$
    - ✓ Reciprocal of sum of subsystem target failure intensities
    - ✓ $M_{targ,Sys} > M_{obj,Sys}$ for practical values of γ and p_0

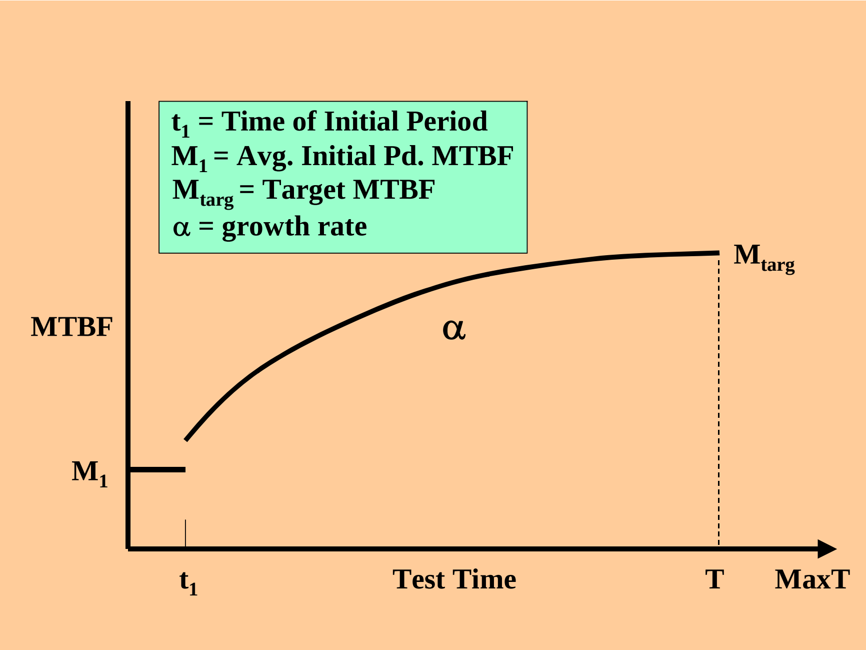
Model Inputs & Outputs

- ***Growth Subsystem Inputs***
  - Growth rate α_i
    - ✓ Negative of slope on log-log plot of expected cumulative failure intensity versus cumulative test duration
  - Initial test period $t_{1,i}$
    - ✓ Growth is planned to commence by the end of initial test period
  - Average MTBF expected over initial test period, $M_{1,i}$
  - Allocation fraction, a_i , of growth subsystem portion of target system failure intensity to growth subsystem i
    - ✓ If all subsystems have growth programs, target failure intensity for subsystem satisfies $\lambda_{targ,i} = a_i \cdot \lambda_{targ,Sys}$
  - Maximum subsystem test duration

- ***Growth Subsystem Outputs***
  - Test duration for subsystem i, T_i
  - Target MTBF for subsystem i, $M_{targ,i}$
  - Expected number of subsystem failures in test, $E(N_i) = T_i / \{(1-\alpha_i) \cdot M_{targ,i}\}$

Duane Plot and Subsystem Idealized Reliability Growth Curve





__Duane Postulate__: If changes to improve reliability are incorporated into the design of a system under development, then on a log-log plot, the graph of cumulative failure rate versus cumulative test time tends to exhibit a linear relationship (Duane, 1964).

Outline of Procedure to Obtain Subsystem Test Durations (case where all subsystems are growth subsystems)

- **$N_i(t)$ is a NHPP with rate of occurrence function $\rho_i(t)$**
  - **$\rho_i(t) = \lambda_i \beta_i t^{\beta_i - 1}$ where $\beta_i = 1-\alpha_i$ and $\lambda_i = t_{1,i}^{\alpha_i} / M_{1,i}$ for growth subsystem i**
- **Steps**
  - **Use trial value $M_{targ,Sys}$ to calculate $\lambda_{targ,i} = a_i \cdot \lambda_{targ,Sys}$**
  - **Obtain trial value T_i by inverting eq. $\lambda_{targ,i} = \rho_i(T_i)$**
  - **For each growth subsystem i simulate NHPP from 0 to T_i**
  - **Calculate pseudo demo. test no. of failures $n_{D,i} = n_i / 2$ & time $T_{D,i} = T_i / (2\beta_{est,i})$**
    - ✓ **$\beta_{est,i}$ is max. likelihood estimate of β_i from simulated growth test data.**
    - ✓ **Equate point estimate and LCB on $M_{targ,i}$ from pseudo demo. data to estimates from growth data to obtain pseudo demo. test data.**
  - **Combine subsystem pseudo demo. data to obtain approximate LCB_γ on $M_{targ,Sys}$**
    - ✓ **Applied Lindström – Madden method adapted for continuous test duration.**
    - ✓ **Could use other methods for combining pseudo demonstration test data.**
  - **Repeat last 3 steps prescribed no. of times to estimate Prob ($LCB_\gamma \geq M_{obj,Sys}$)**
  - **If estimated probability is close to p_0 stop - the current trial T_i are chosen as the subsystem test durations ; otherwise adjust $M_{targ,Sys}$ and repeat above steps.**

AEROSPACE & RAILWAY INDUSTRIES APPLICATION

A Successfully Implemented Coordinated Subsystem Reliability Growth Planning Approach

Bombardier's Implementation/Customization of the SSPLAN –

New Reliability Growth (NRG II)

Company Overview

- Corporate office based in Montréal, Canada
- Workforce of some 55,800 people worldwide as at January 31, 2006
- Revenues of $14.7 billion for fiscal year ended January 31, 2006
- More than 94% of revenues coming from foreign markets
- Listed on the Toronto Stock Exchange (BBD)

The focus of Bombardier Inc. is based on two pillars

Transportation

45% of total Revenues

Annual Revenues in (2005/2006):
US$6.6bn

Aerospace

55% of total Revenues

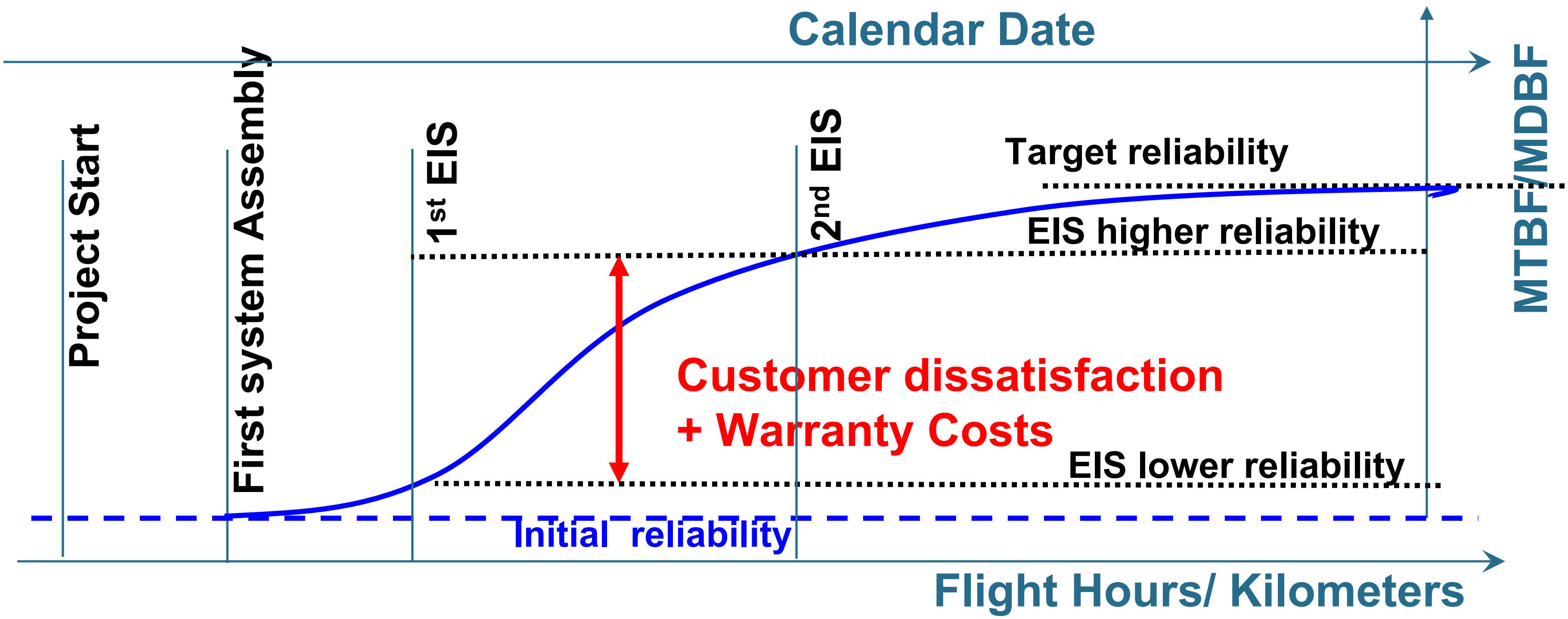
Annual Revenues in (2005/2006):
US$8.1bn

*Figures for the year ending January 31, 2006

Problem Statement / Opportunity

- **Problem Statement**
  - Warranty costs and customer dissatisfaction
  - Weakness in the process to predict, optimize and govern the product reliability in order to meet Entry into Service and in-service performance.
- **Opportunity to raise reliability performance**
  - Insure reliability performance meet commitments as per schedule
  - Reduce Warranty cost
  - Model Life Cycle Cost
  - Improve Maintenance Program
  - Highlight to senior management reliability progress of all subsystems
  - Prioritization of corrective actions

Reliability Maturation Model



- **Potential shortfalls in managing reliability**
  - System Reliability measurements start too Late.
  - No Prediction of reliability at Entry Into Service(EIS).
  - No Proactive action to ensure that EIS reliability will be met.

- **Need reliability growth program plan to conduct trade-off analysis between EIS calendar date and EIS expected reliability.**
- **Need to measure against program plan.**

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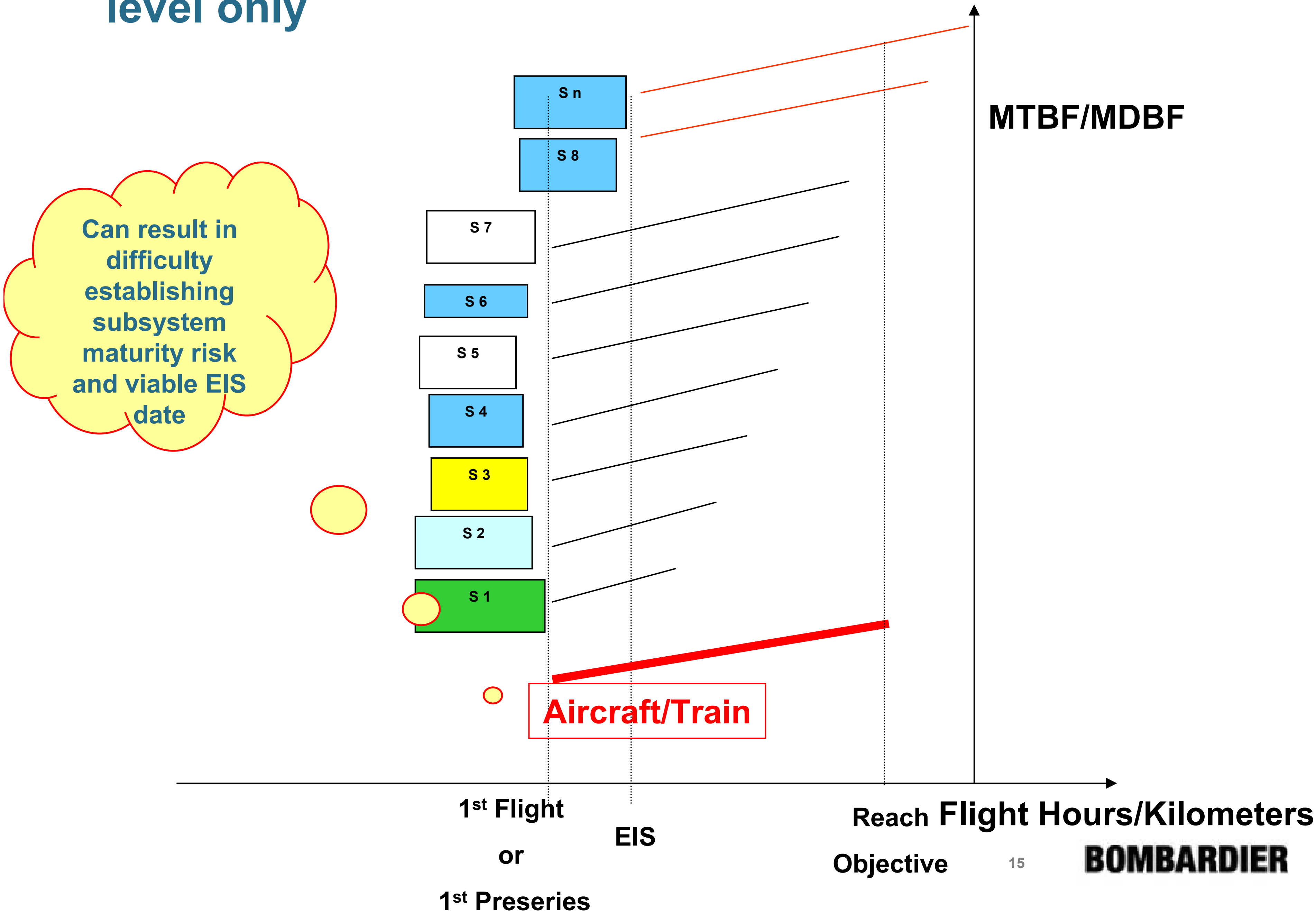
New Reliability Growth (NRG II) Model Objectives

- **Predict Reliability Maturation**
  - Based on past performance by system and supplier
  - Include reliability growth from the start of testing
  - Supports spares contingency requirements
- **Optimize lifecycle costs linked to reliability**
  - Perform trade studies between increasing testing and fixing issues in the field
  - Allow analysis between EIS calendar date and EIS expected reliability
  - Optimize maintenance program
- **Govern Reliability Growth and issues from day one**
  - Set up a framework to compare actual reliability to planned reliability
  - Comparison provides basis for efficient proactive management with regard to failure mode mitigation
- **Utilize coordinated subsystem reliability growth strategy**

Classic growth – Planning and monitoring at system level only



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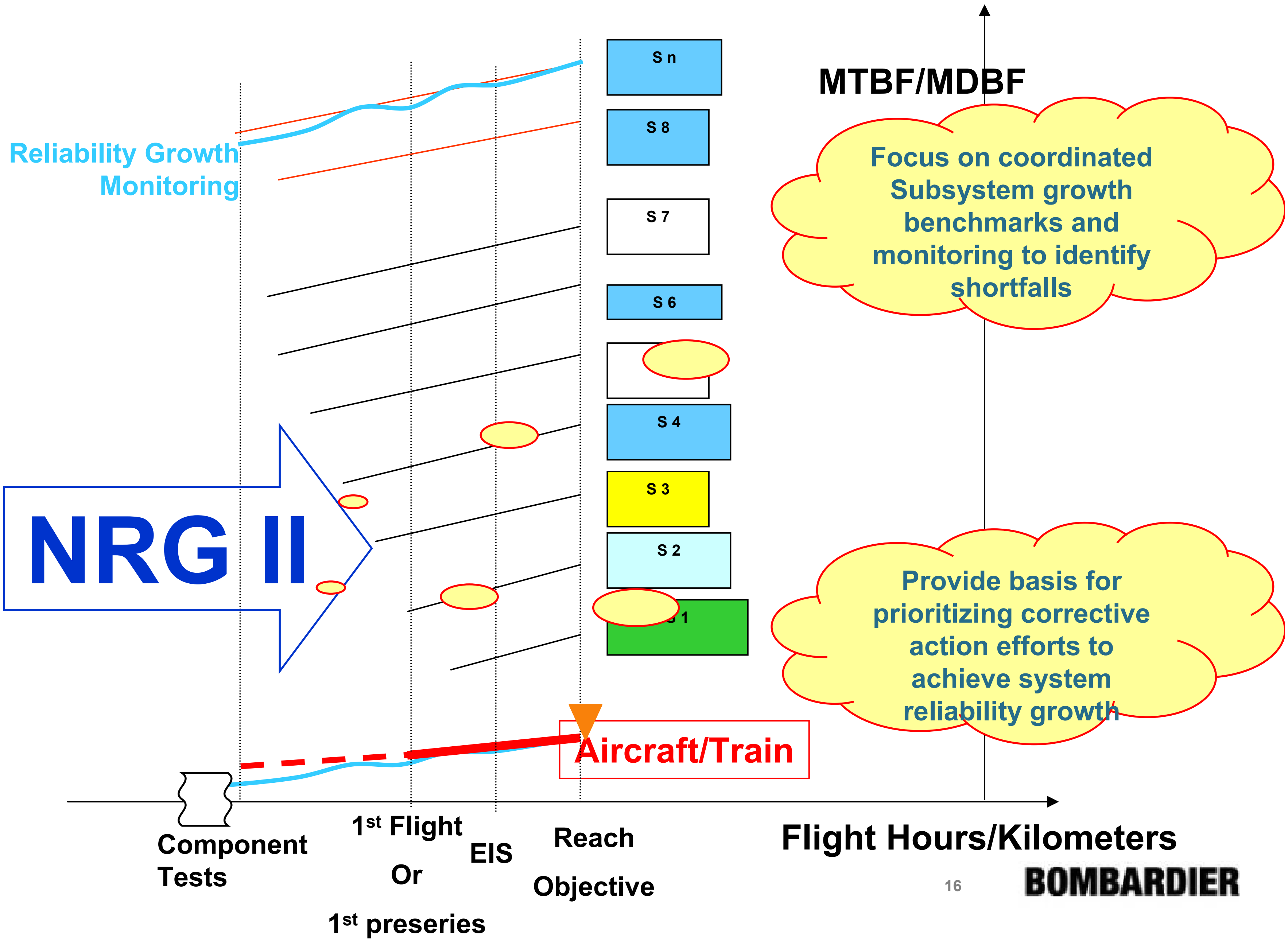
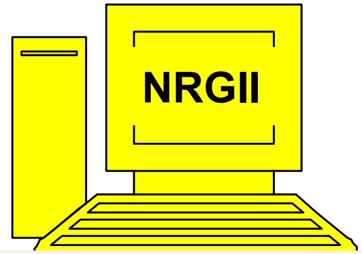
NRG II Approach

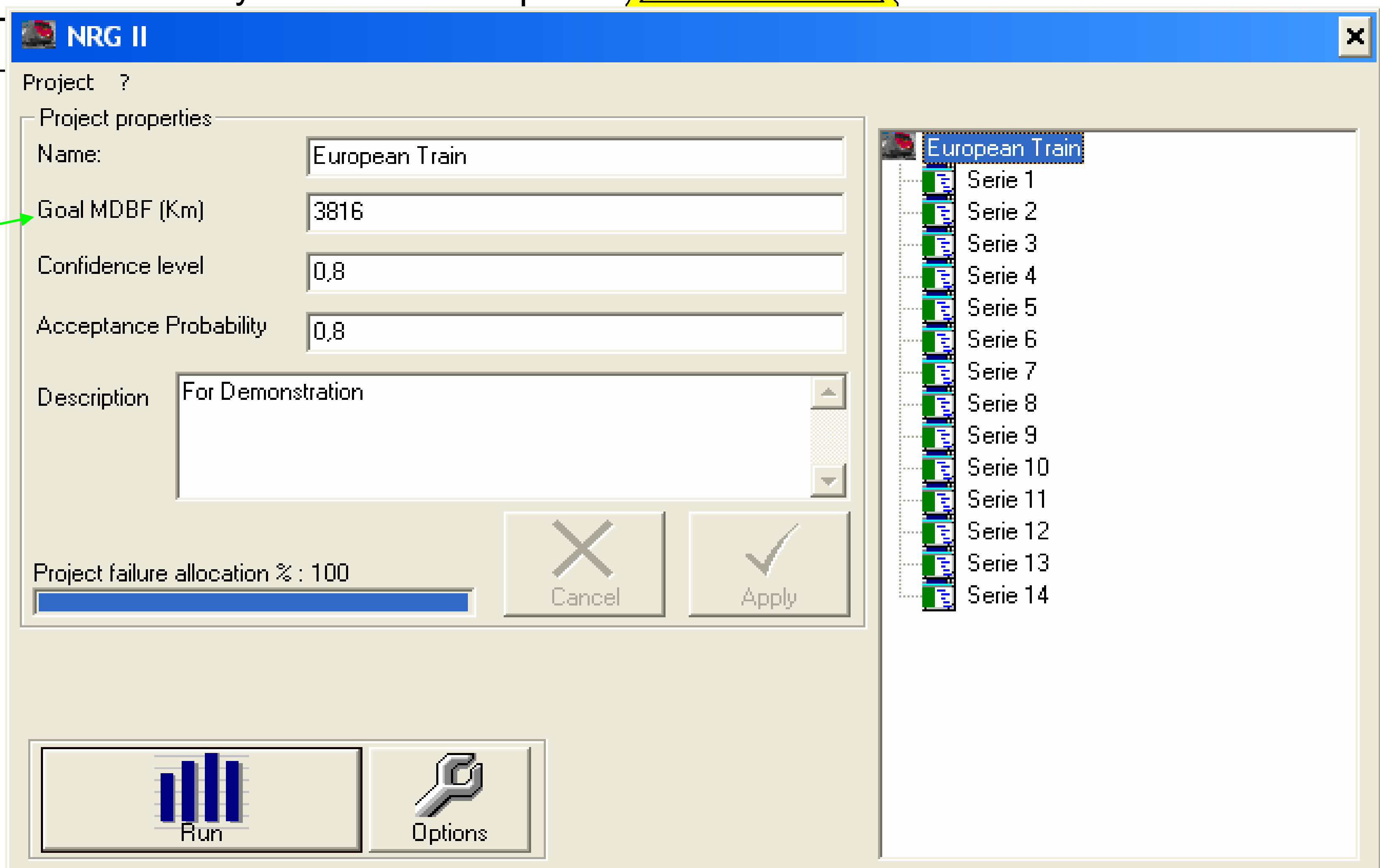


Reliability Growth : method NRG II

- Name of the Product
- MDBF or MTBF Objective (Contractual)
- Confidence Level
- Acceptance Probability
- List of all Main Subsystems

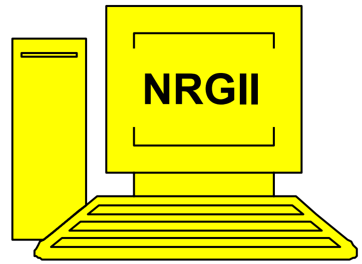


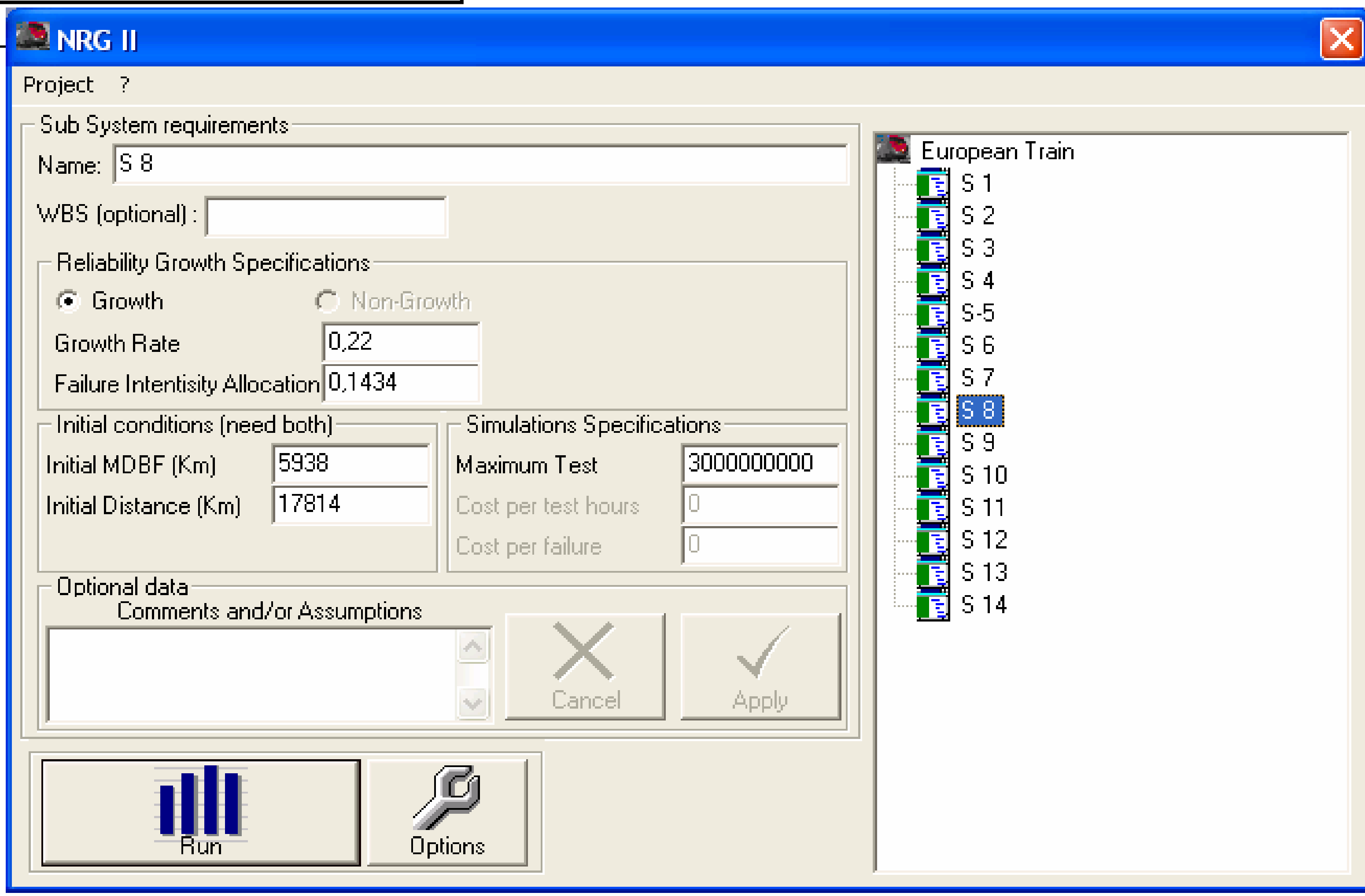
Objective



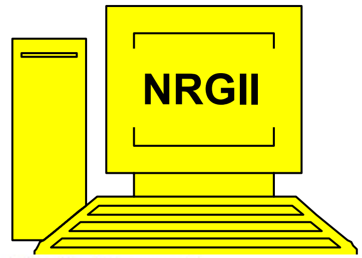
Reliability Growth : method NRG II

- Growth rate alpha
- Failure intensity allocation
- Initial MDBF
- Initial Test Distance
- Maximum Test





Reliability Growth : method NRG II



Per Subsystem:
- Number of Failures
- Total test Distance
- Final MDBF

For the Product:
- Computed Target MDBF

Project	File Name : 2007_02_13_European Train #3				
Name	Comments and/or Assumption	Objective MDBF (Km)	Confidence level	Probability of acceptance	Number of subsystems
European Train	For Demonstration	3816	0.8	0.8	14

Sub-systems

Name	G/N	Alpha	Initial MDBF (Km)	Initial Distance	Maximum Distance	MDBF (Km) at system objective	Failure Allocation	Expected failures	Total test Distance	Final MDBF (Km)
			Initial conditions							
S 1	Growth	0,39	311,509	934,528	3000000000	1,413,333	0.0027	**17.64**	**17,055,812**	**1,585,039**
S 2	Growth	0,19	21,000	65,000	3000000000	50,543	0.0755	**86.89**	**3,989,576**	**56,684**
S 3	Growth	0,2	22,035	66,105	3000000000	85,369	0.0447	**437.94**	**33,542,866**	**95,741**
S 4	Growth	0,22	6,113	18,338	3000000000	27,394	0.1393	**380.71**	**9,123,000**	**30,722**
S-5	Growth	0,19	25,435	76,500	3000000000	47,522	0.0803	**28.68**	**1,238,304**	**53,295**
S 6	Growth	0,21	33,677	101,030	3000000000	150,830	0.0253	**535.68**	**71,584,125**	**169,154**
S 7	Growth	0,2	33,456	111,457	3000000000	70,667	0.054	**42.97**	**2,724,189**	**79,252**
S 8	Growth	0,22	5,938	17,814	3000000000	26,611	0.1434	**380.78**	**8,863,814**	**29,844**
S 9	Growth	0,23	3,787	11,362	3000000000	16,975	0.2248	**278.63**	**4,084,317**	**19,037**
S 10	Growth	0,19	35,000	105,000	3000000000	63,920	0.0597	**25.96**	**1,507,564**	**71,685**
S 11	Growth	0,4	578,518	1,735,553	3000000000	2,544,000	0.0015	**15.27**	**26,139,970**	**2,853,071**
S 12	Growth	0,24	7,454	22,363	3000000000	33,415	0.1142	**209.24**	**5,959,427**	**37,475**
S 13	Growth	0,2	26,997	80,922	3000000000	120,759	0.0316	**777.53**	**84,240,787**	**135,431**
S 14	Growth	0,37	279,284	837,853	3000000000	1,272,000	0.003	**21.95**	**19,724,117**	**1,426,535**

System

Epsilon	Number of iterations	Computed probability of acceptance	Computed target MDBF (Km)
	500	0.8	4280

Output

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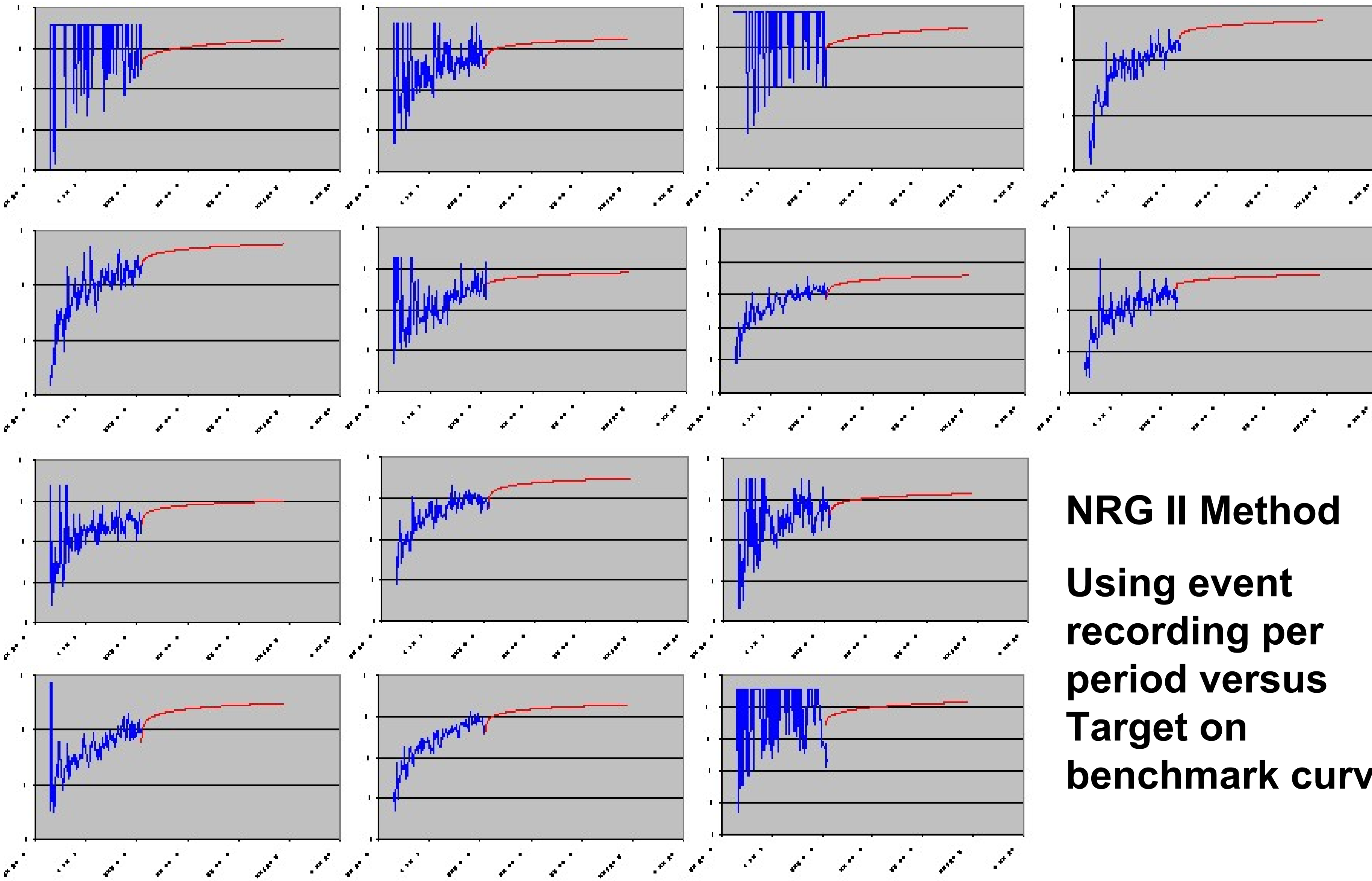
Example of Reliability Growth monitoring of initial subsystem MDBF's for a Product composed of 14 subsystems



NRG II Method

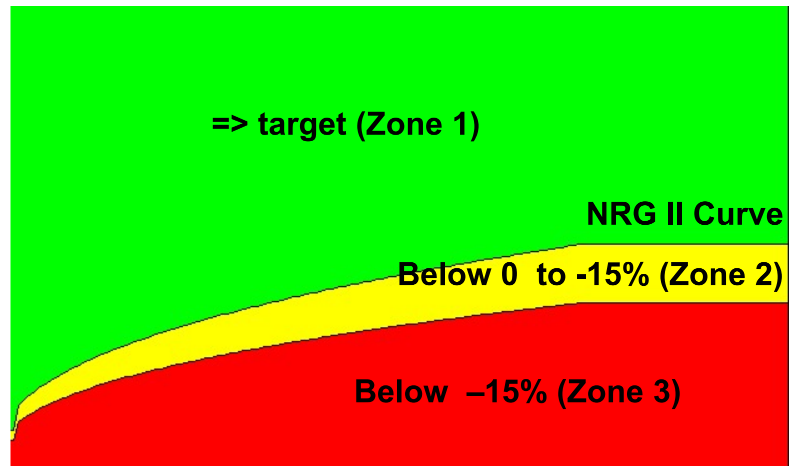
Using event recording per period versus Target on benchmark curve

Establishing priority of corrective actions

Life Cycle Cost

Zone	% measured LCC exceeds target LCC
1	Less 5%
2	5 to 15%
3	15% and up

Reliability performance



			Reliability performance		
			>= target	below 0 to -15%	below -15%
		Zone	1	2	3
LCC	Less 5%	1	1	2	3
	5 to 15%	2	2	4	6
	Above 15%	3	3	6	9

Priority weight

Safety failures have the highest priority

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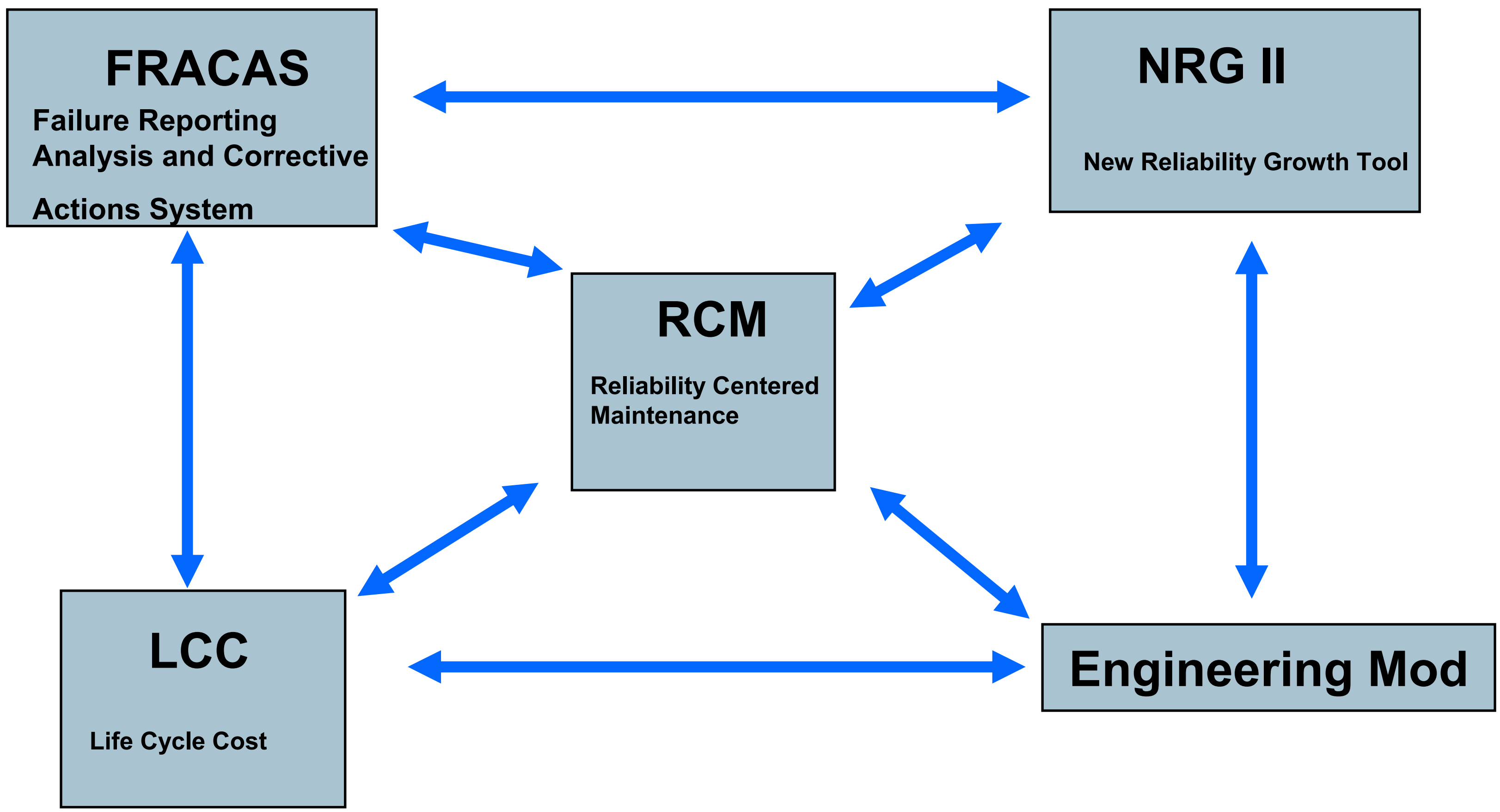
Interactions between basic elements of reliability process



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Summary of NRG II Benefits

- Promotes a proactive approach to maturing product reliability
- Establishes corrective action priority based on comparisons of measured LCC and reliability values to target values
- Highlights to senior management reliability progress of all subsystems
- Reduces cost of Product Introduction
- Assists in modeling LCC
- Assists in performing trade-off analysis between EIS calendar date and expected EIS reliability
- Helps in optimizing maintenance program
- Applies to new product development or in-service improvements

Fosters idea that reliability growth is a responsibility we all share to achieve customer satisfaction

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