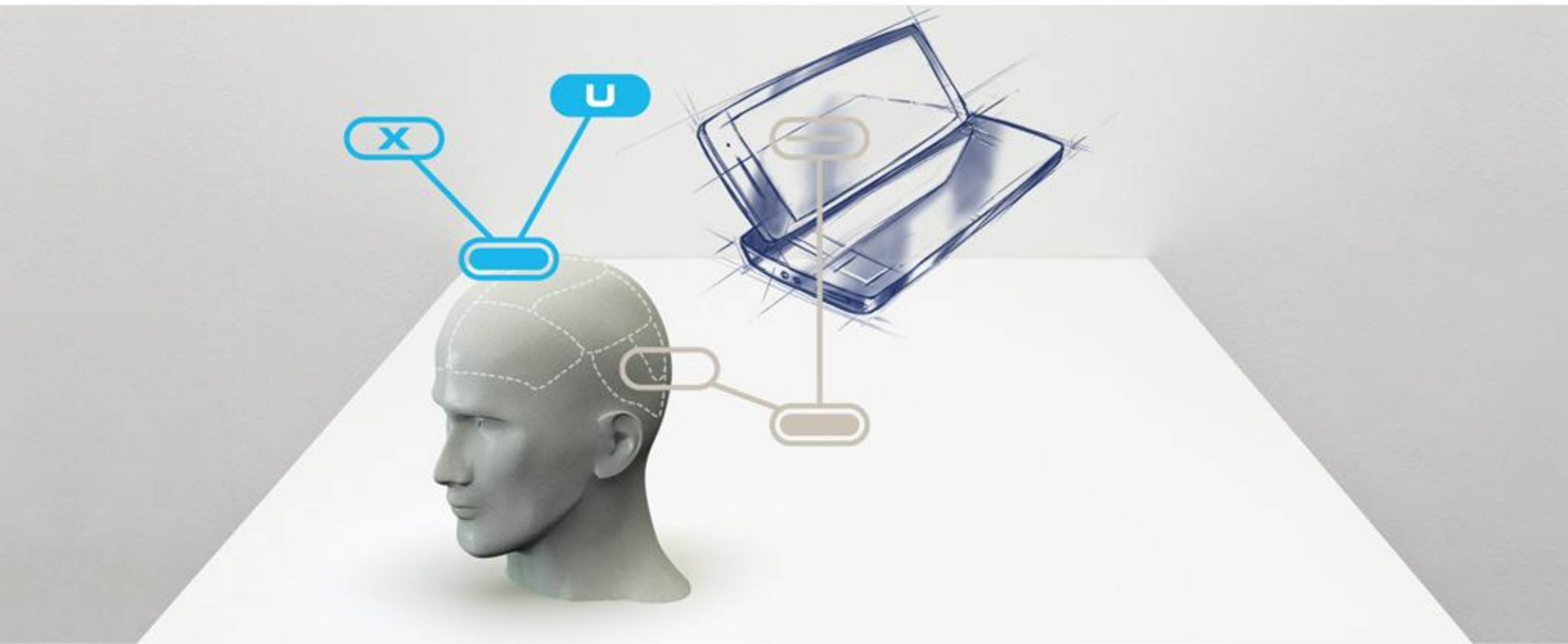
Consultants in Quantitative Methods

System Reliability, mastering of large systems

Marc Schuld, 8 June 2016



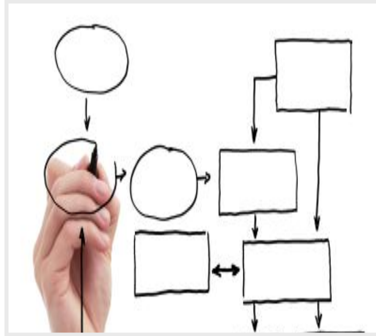
Topics

- Intro
- Challenge
- Framework: reliability embedded within development
- What knowledge, capabilities, and processes are needed, and how to mobilise your resources to face this challenge?
- What are the untapped opportunities for boosting your business?

Intro: Consultants in Quantitative Methods (CQM)

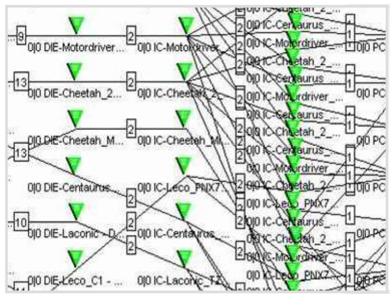
Specialists in **fact-based** development and improvement of industrial, R&D, logistic and planning processes.

Focus



- **R&D**
- Supply chain analytics
- Transport planning & Rail
- Energy
- Data science

Our basis



- Mathematics
- Statistics
- Optimization
- Six sigma

Our company

- 35 consultants
- For over 35 years of experience
- Based in Eindhoven

Focus CQM w.r.t. reliability

We focus on supporting our customers by means of:

- development of accelerated test plans
- development of system reliability models and software
- analysis of FCR data and prediction of returns.
- providing evidence at the release of products @ milestones
- reliability auditing

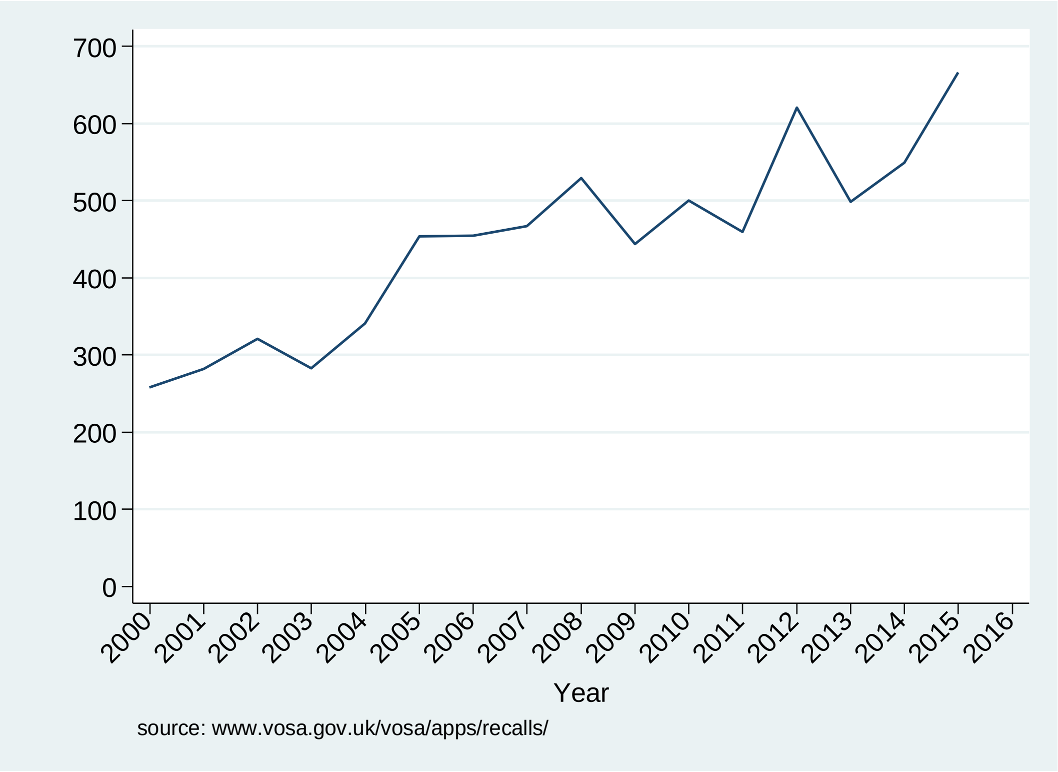
Importance of product /system reliability

Increasing importance of reliability studies

- Increasing speed of innovation
- More complicated products with more components & features
- Higher customer expectations for reliability
- Competition
- Has large implications for the business - warranty costs, customer satisfaction, sales, revenue, profits (sword of Damocles)
- For customers -maintenance cost, consequences of failures

Some interesting sites

www.recalls.gov
www.fda.gov/Safety/Recalls/default.htm
http://www.vosa.gov.uk/vosa/apps/recalls/



The number of failure modes evolve with complexity

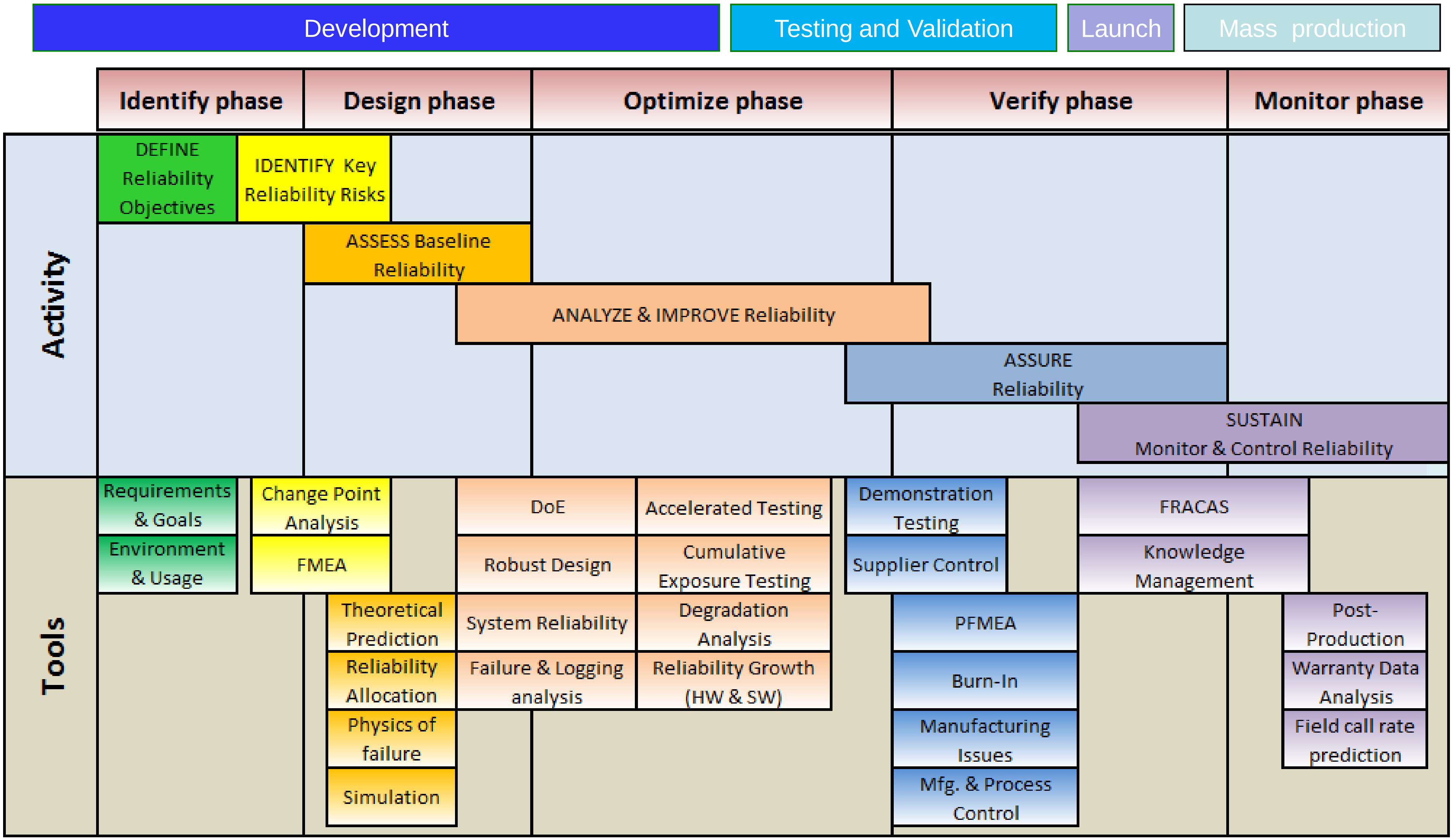
Challenge

- The challenge is to master the reliability at all levels, that is at component level (hard + software), and (sub) system level for different user profiles (temperature, humidity, shock, vibration, corrosion, industrial gases, etc). Even further, the system needs to be controlled and maintained.
- Sharing of knowledge (sensitive info)

Framework: reliability embedded within development

- With increasing expectations and requirements a solid Design for Reliability (DfR) program becomes especially important. Reliability practices must be well integrated into the product development cycle.
- Often systems are developed through a tightly controlled design and development process, where the quality of product is evaluated at each milestone and activities to realize deliverables (and guidelines on how to perform such activities) are clearly defined.

Reliability activities throughout the product's life cycle



Set Reliability objectives / requirements

- Depending on the industry/product requirements may be based on:
  - CoNQ
  - Safety
  - Regulatory considerations
  - Marketing / customer / consumer (VoC)
  - OEM
  - Competitive benchmarking (what do competitors claim?)

But also: understand and define the usage conditions:

- What is the usage environment?
- What stresses will the product experience?

Define the reliability requirements

- Make sure that realistic and measurable requirement are defined.
  - All involved understand the impact of the metric to the customer
  - Understand the metrics financial impact

B50

B1

MTBF

B10

R(t)

MTTF

λ(t)

€

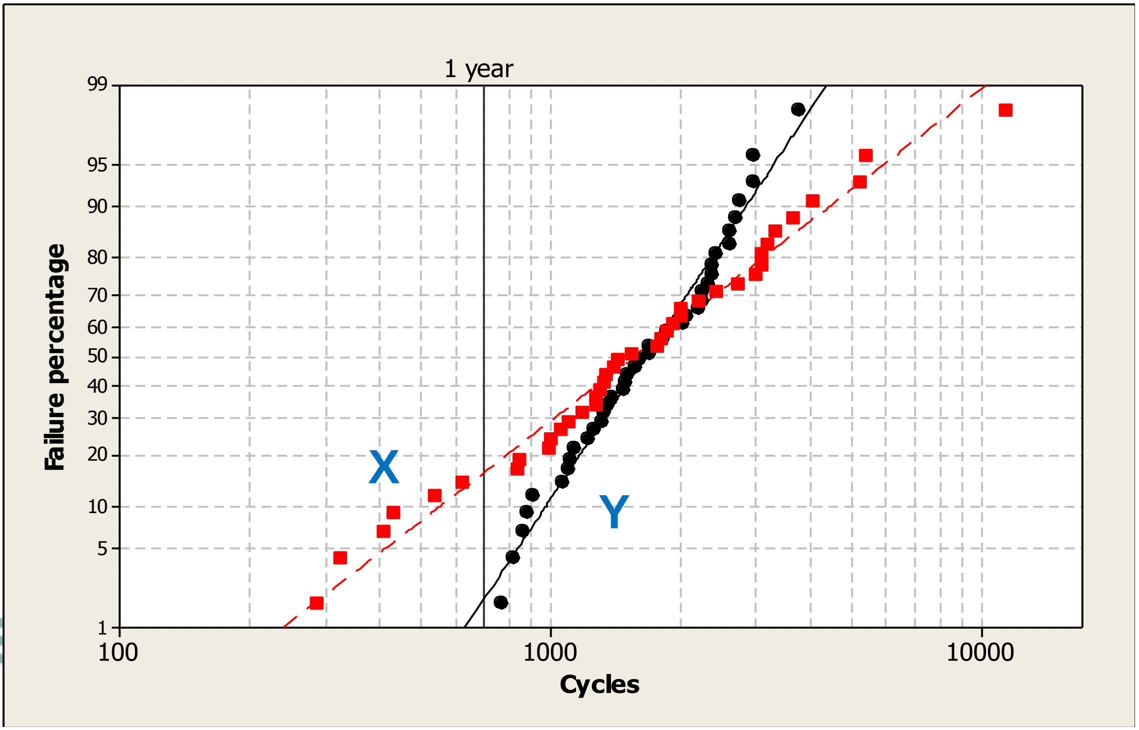
Understand the metric: financial consequences

- Consider the following case:

  You are the manufacturer of coffee machines X and Y. Both have a MTTF of 2000 cycles. You also provide an one year warranty.

  - Assumptions: usage of 2 cycles per day, sales of 200.000 machines, warranty cost of € 50,- per failure.

- Do both types X and Y have the same CoNQ?



Same MTTF, different distributions, different amount of early failures!

Coffee machine X
F(1 year) = 16%
Cost = 200,000 x 0.16 x € 50,- = 1.6 M€

Coffee machine Y
F(1 year) = 2%
Cost = 200,000 x 0.02 x € 50,- = 0.2 M€

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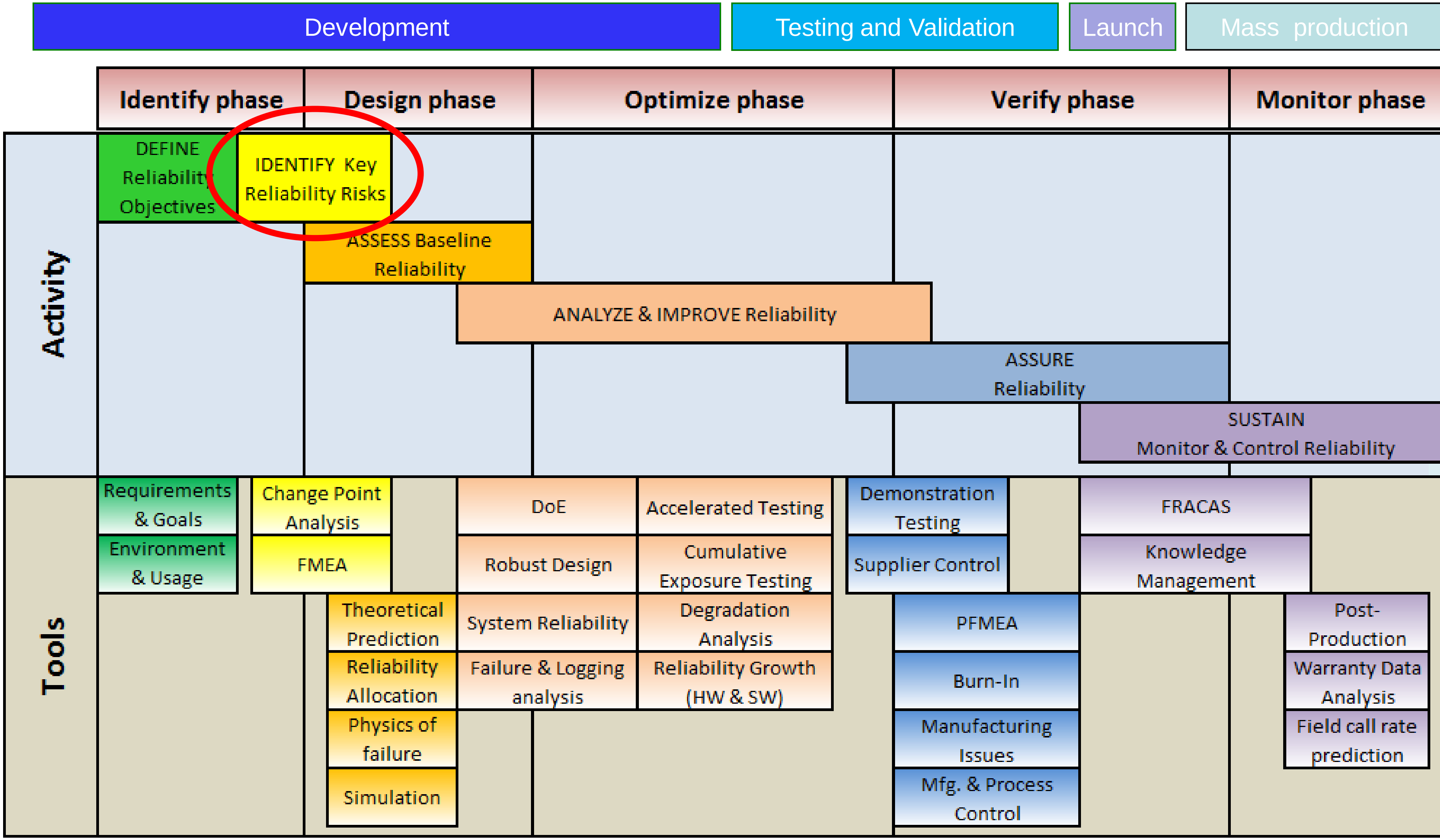
Identify reliability risks



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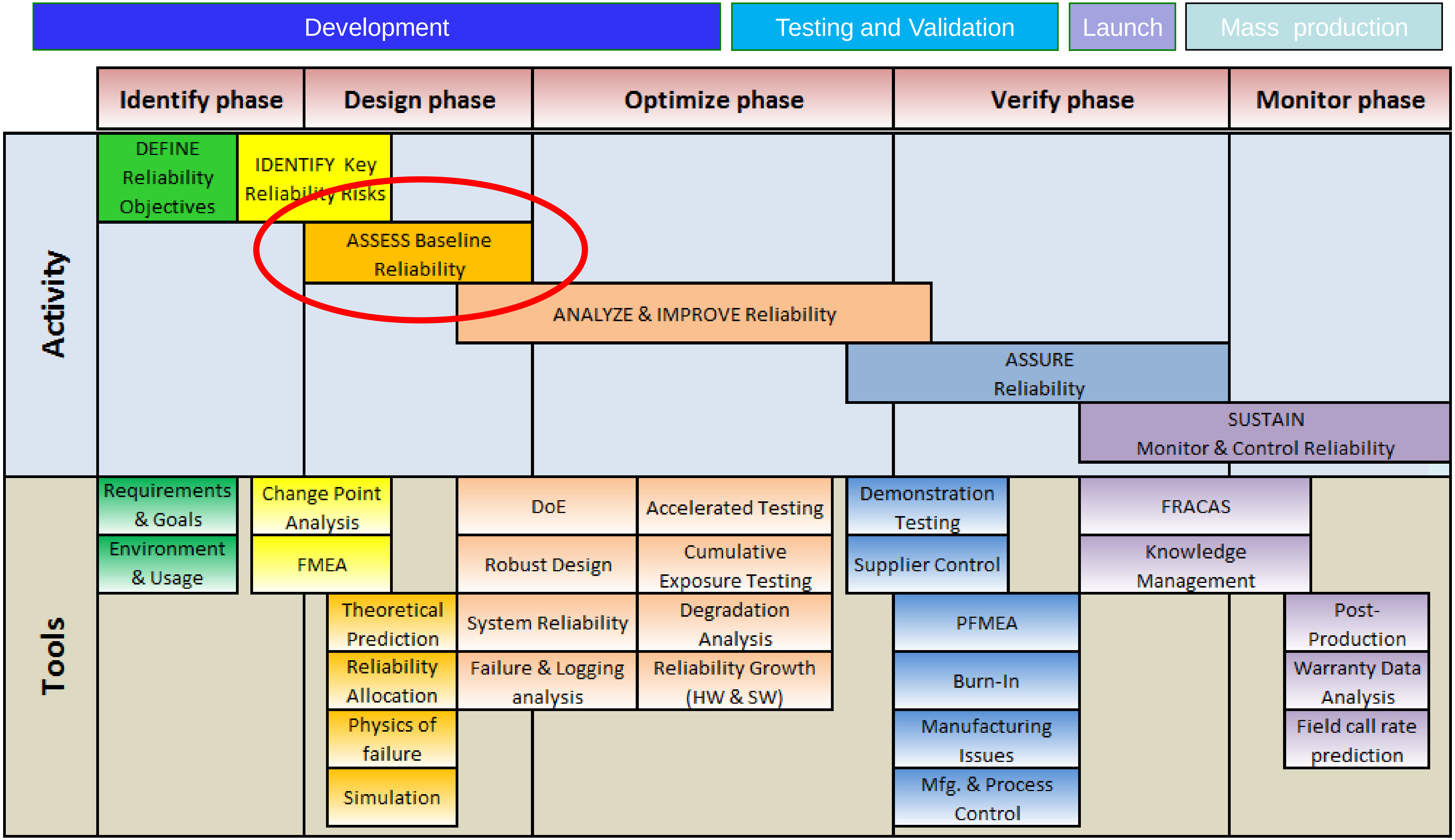
Identify key risks

- Assess / identify your current knowledge and blind spots of the new design from:
  1. Identify the failure modes of all functions. A failure mode is defined as the way a component, (sub)system could fail to meet the design intent and customer requirements. Failures can be adverse responses to bad data, failed hardware or failed interfaces.
  2. Prior designs (e.g. warranty data)
  3. How much (if at all) do we modify the existing components?
  4. Does the proposed application (stress) pose new risks to the existing components?

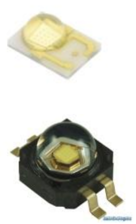
➔ (update) FMEA

Assess Baseline reliability



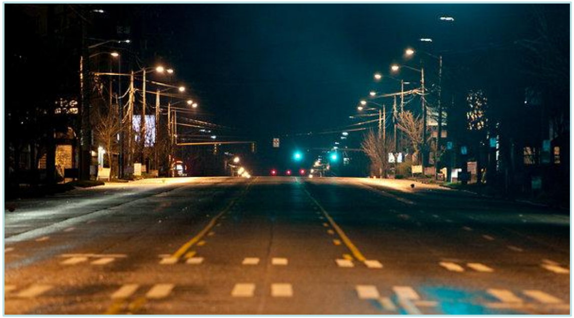
Assess Baseline reliability

1. **Budget the allowable system failures down to the component level**
2. **Compute the baseline reliability of components and subsystems**, based on:
   - Field data (failure & logging data)
   - Knowledge on physics of failure
   - Assumptions
3. **System reliability = f(component reliability + interactions)**



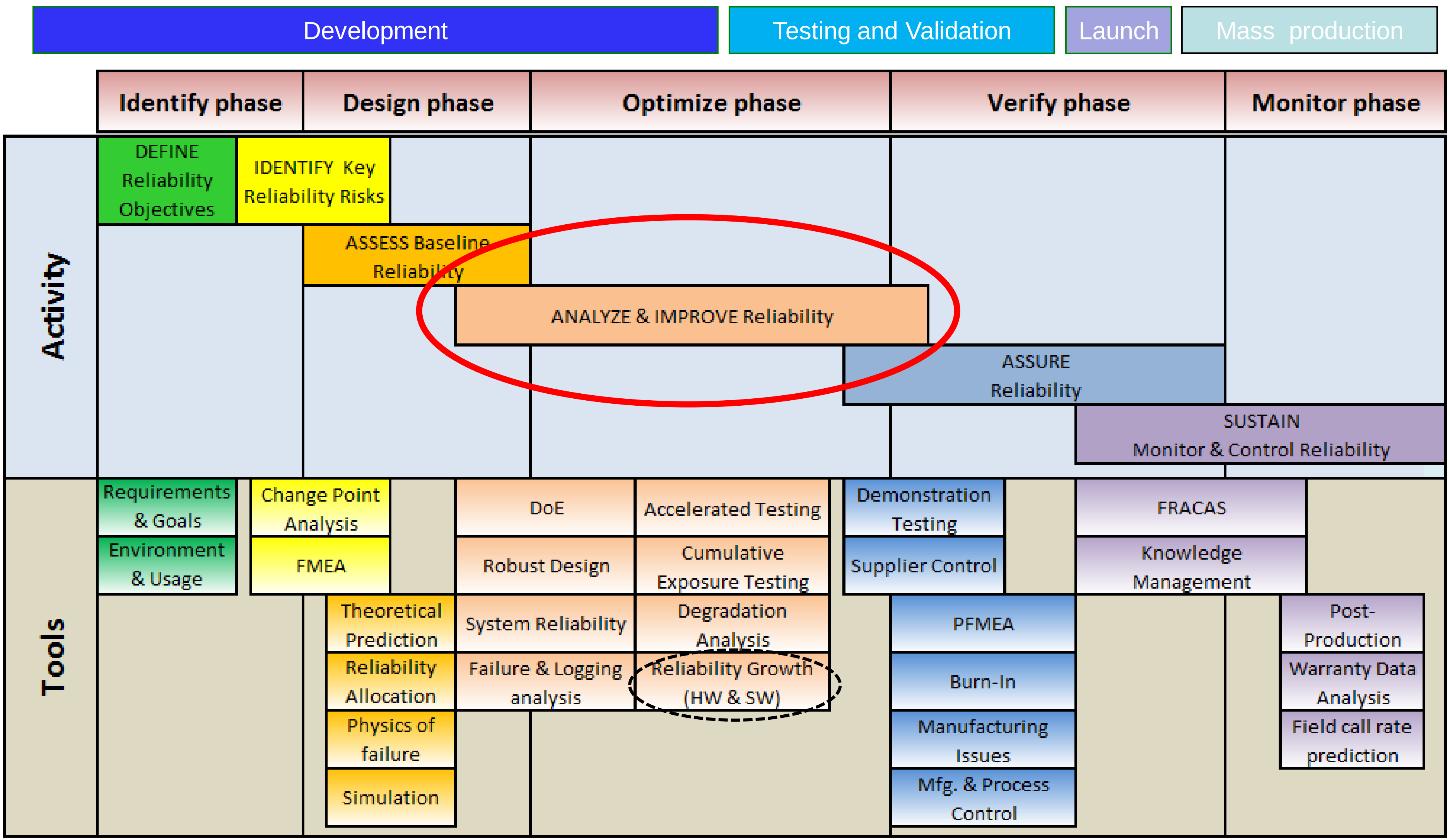
f

Tools:
Physics modeling, Finite element analysis,
Fatigue analysis, Thermal (mechanical) analysis,
Monte Carlo simulation, Markov chains, Copula's



4. **Evaluate the reliability potential of alternative designs**
5. **Develop reliability tests for components, subsystems and system**

Analyze and improve reliability



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Analyze and improve reliability

- In this phase multiple components / subsystems are being acquired or built, and prototypes are being assembled. Most of the ‘traditional’ testing and analysis takes place in this phase.
- Objectives are:
  1. Discover unknown failure modes. They should be added to the FMEA (update priorities).
  2. Understand the effect (and interactions) of critical use, design, and environmental parameters.
  3. Quantify & demonstrate the life of a product / component
  4. Identify areas for design improvement

Analyze and improve reliability

- Activities:
  - A. Identification dominant failure mechanisms
    - HALT / Multiple Environmental Over Stress Testing (MEOST)
  - B. Model effect of stress/condition factors, components and design parameters on life-time
    - Accelerated Life Time
    - DoE (under stressed conditions)
    - Cumulative exposure testing
    - Degradation testing
    - etc.
  - C. Test software robustness
  - D. Predict reliability product design
  - E. Update risk analysis (Product FMEA)

$$T(\boldsymbol{x}) = e^{\alpha_0 + \sum \alpha_j x_j + \sum \alpha_{ij} x_i x_j}$$

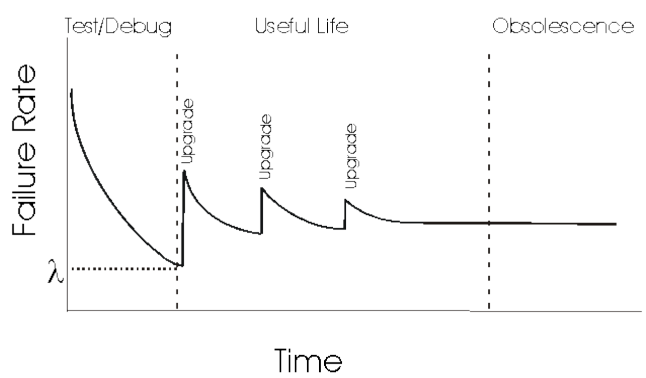
$$\boldsymbol{R}(\boldsymbol{t}, \boldsymbol{x}) = \boldsymbol{e}^{-\alpha\left\{\int_0^t \varepsilon(\tau, x)\, d\tau\right\}^{\beta}}$$

$$\boldsymbol{D}(\boldsymbol{t}, \boldsymbol{x}) = \boldsymbol{D}_0 \times \boldsymbol{e}^{f(t,x)}$$

Intermezzo (1/3): What is software 'reliability'?

- Software reliability is not a function of time;
- Software will not change in time, no wear-out;
- Two terms are related to software:
  - **Fault**: a defect in the software, e.g. a bug in the code, that may cause a failure
  - **Failure**: a deviation of the observed behaviour from the required behaviour
- Faults need not necessarily cause failure. Consequently, the perceived robustness depends upon how the software is used (=operational profile).

✑ Maybe we should talk about software **robustness**



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Intermezzo (2/3): Software robustness models

- Over 200 models have been developed since the early 1970s.
  - E.g. Jelinski-Moranda, Littlewood-Verall, Musa-Okumoto, Yamada, Duane etc
- No single model completely represent software robustness
- The sw models contain the following parts:
  - Assumptions (grouped/ungrouped data, immediate repairs or not, (im-)perfect repair, different severities allowed, etc)
  - A mathematical function: is usually a higher order exponential or logarithmic

Basic model:

$$\lambda(\mu) = \lambda_0 \left[1 - \frac{\mu}{\nu_0} \right]$$

$\lambda(\mu)$: failure intensity
λ_0: initial failure intensity at the start of execution
μ: average cumulative number of failures at a given point in time
ν_0: total number of failures over infinite time

Intermezzo (3/3): Statistical testing procedure

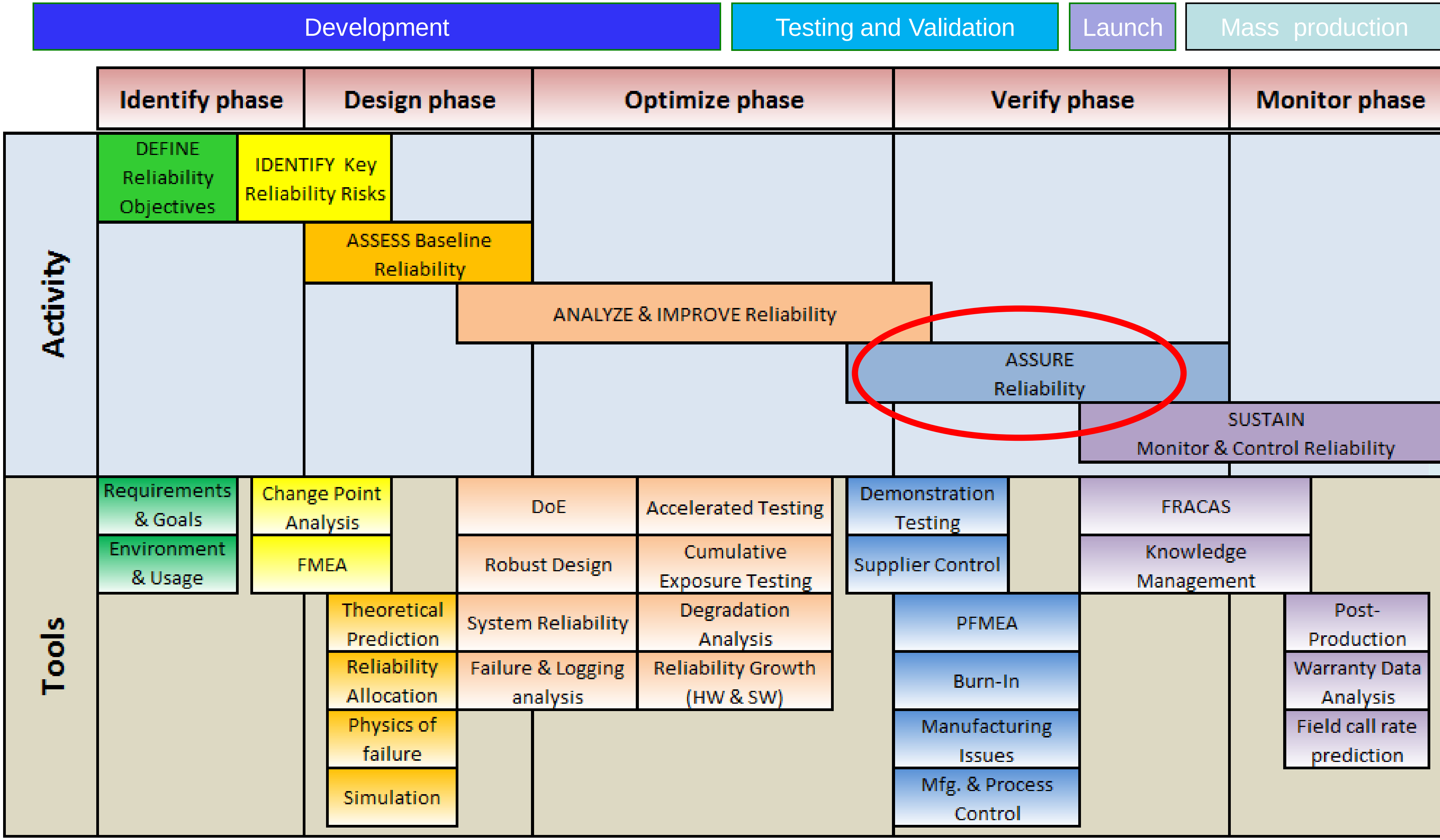
1. Determine operational profile (use cases) of the sw
2. Generate a set of test data corresponding to these profiles
3. Apply test, measuring amount of actual test time between consecutive failures
4. Fit several models to the observed data: take the one that fits best

Typical questions that can be answered:

- How many failures are left?
- What is the probability of no failures in a given time period?

Ref: Musa (2004), Pham (2006), Ramos (2009)

Assure reliability



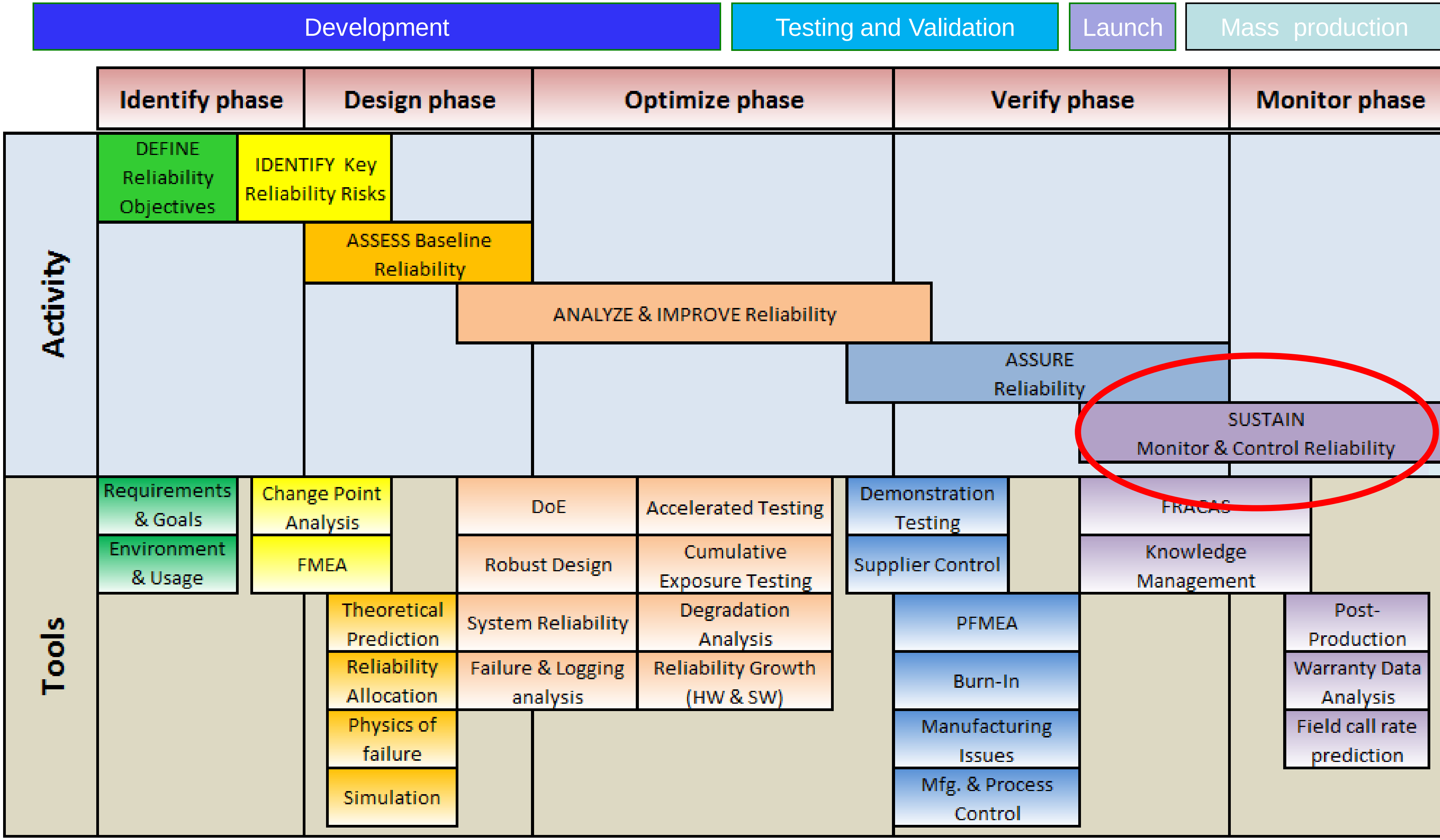
Verify / assure reliability performance

- Does the product meet the reliability requirements?
  - The inherent reliability of the design will probably degrade when deployed through manufacturing.

Steps:

1. Reliability test on products from semi-industrial line
   - Accelerated Life Time verification in large scale test: update prediction life time
   - HALT or MEOST stress tests on about 10 components / products to identify the weakest link
2. Update FMEA & use DMAIC on issues
3. Reliability on products from industrial production line: ALT & Real-time tests
4. Supplier Quality evaluation
5. Repeat 'step 2'
6. Develop Control Plan

Sustain reliability

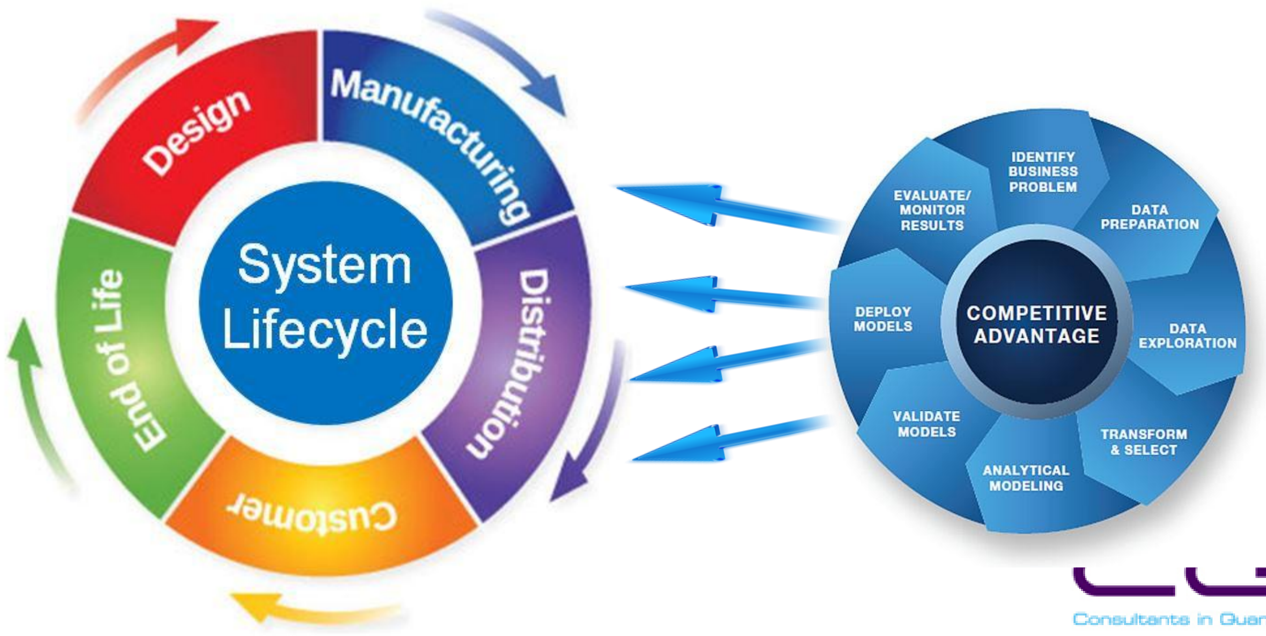


Sustain

- Objective: monitor and control the reliability
- Tools:
  - Manufacturing quality control / HASS
  - Extensive use of burn-in
  - Supplier control
  - Warranty analysis
  - Field call rate prediction
  - Failure Reporting, Analysis and Corrective Action System (FRACAS)
  - Updating and maintaining knowledge base
  - Safe launch

What knowledge, capabilities, and processes are needed, and how to mobilise your resources to face the challenge? (1/2)

1. Processes and procedures for development, manufacturing, and maintenance geared towards supporting quality and reliability (DfR).
2. Testing, verification & validation: for substantial statistical power a large installed base is desirable.
3. Highly trained and experienced reliability engineers (competence owner + local experts). Appoint a council of experts with appropriate decision power.
4. Use of data science and smart analytics ➔ deep understanding of the system and its use to support decision making and risk mitigation in all phases of the life cycle.



What knowledge, capabilities, and processes are needed, and how to mobilise your resources to face the challenge? (2/2)

5. Develop an easy to use & dedicated software tool, that is applicable for your business. The purpose of such a tool is to:
   - Automate the manual combination of proven reliability models.
   - Prevent errors by rigorous data checking.
   - Integrate the estimation of reliability figures during development cycles.
   - Takes into account actual user profiles.
6. Continuous verification of the reliability predictions and models that involves:
   - Life time testing in laboratories under controlled environments.
   - Field evidence, which is vital for the verifications in application conditions.
7. Compliany with IEC regulations and beyond.

What are the untapped opportunities for boosting your business?

1. Shape the market with reasonable reliability & warranty claims.
2. Reduce CoNQ (mainly FCR)
3. Reliability is a design parameter, and not an outcome ➔ design optimization (costs)
4. Reduction T2M
5. Change business model: from product to a system-as-a-service
   - The supplier offers a complex system with a long-term contract. The customer pays for the performance in terms of throughput, speed, uptime, service, energy consumption, etc.

Summary

- We presented an approach for designing reliable products by fact-based decision making
  - Prediction of reliability early in the design phase
  - Derive the relationships between reliability CTQs and the design parameters, and use conditions
  - Provide fact-based evidence at milestones
  - Make sure you fully understand, capture and share why the product works
  - Description of activities, models, and roles to meet the challenge
  - Opportunities

Questions?