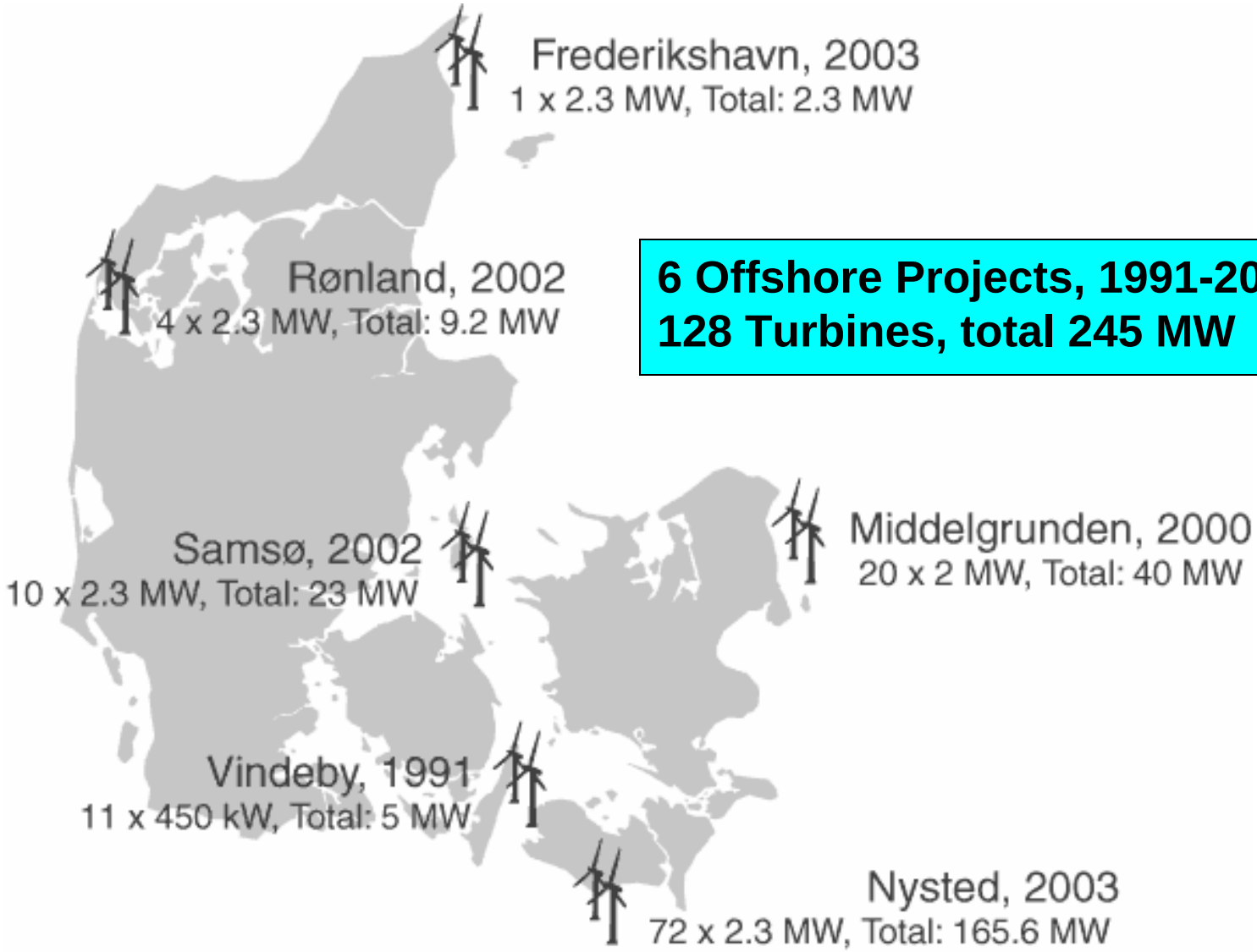
Design for Reliability

Peter Hauge Madsen & Henrik Stiesdal

SIEMENS

SWP Offshore Projects in Operation

SIEMENS



6 Offshore Projects, 1991-2003
128 Turbines, total 245 MW

Nysted – World's Largest Offshore Farm

SIEMENS

- 72 pcs. 2.3 MW
- Take-Over 01.12.03
- Annual output ~600 GWh
- Average Availability since Take-Over 97.3%, with 97.0% first year and 97.6 second year
- Weather downtime accounts for additional availability loss of 0.5%.

Level of Satisfaction

SIEMENS

Question: Is 97.6% Availability in Second Year Satisfactory?

- Scheduled maintenance accounts for 0.6% availability loss.
- Faults not requiring technician visit (i.e. remotely resetable) account for 0.1% availability loss
- Faults requiring technician visit but requiring no physical correction account for 1.1% availability loss
- Faults requiring technician visit and physical correction account for 0.6% availability loss

Answer: NO! We should have been 1% higher

Does It Matter?

SIEMENS

1% output lost does matter…

- Profit = Revenue – Cost
- Offshore wind is not high profit business, therefore small changes in revenue or cost cause large relative changes in profit.
- For an offshore project with satisfactory profit the revenue/cost ratio will typically lead to a multiplier on revenue changes that is on the order of 4
- Consequently, 1% output lost means 4% less profit.

Does It Matter?

SIEMENS

… and in rough waters the figures would be even worse!

- 1.7% Manufacturer's availability loss at Nysted requiring technician visit becomes 2.2% total availability loss due to weather downtime, i.e. a relative increase of 30%
- On annual basis Nysted has 65 days = 20% with no access
- Consequently, total availability loss is increased by weather downtime ratio x 1.5 (because faults occur more often in high wind)
- For a rougher site with 50% no access, total availability loss would then have been

  $$1.7 \times (1 + 0.5 \times 1.5)\% = 3.0\%$$
- Including scheduled maintenance etc, total availability would have been 96.4%.

Conclusions

SIEMENS

Things are simply different offshore!

- A 97.6% Manufacturer's availability would be OK onshore.
- Offshore it translates into a so-so 96.4% total availability
- Due to the lower overall margins offshore the multiplier on profit is higher than it is onshore. Avoiding 1% availability loss offshore will increase profit by

  $4 \times 1 \times (1 + 0.5 \times 1.5)\% = 7\%$
- For comparison, avoiding 1% availability loss onshore will increase profit by

  $3 \times 1 \times (1 + 0 \times 1.5)\% = 3\%$

Conclusions:

- The dividend on profit from improving availability is a factor of 2 higher offshore
- Something must be done!

ARM Model

SIEMENS

Availability – Reliability – Maintainability Model

- Fundamental Model used by Siemens Power Generation, with basic definitions based on international and national standards
- Classical model has four steps:
  - Step 1: Determine consequence of failure for relevant error types and component failures
  - Step 2: Determine MTBF and MTTR for each relevant error type and component failure
  - Step 3: Calculate reliability using fault tree analysis where relevant
  - Step 4: Evaluate and implement design changes for those components that give rise to largest loss of reliability

ARM Model

SIEMENS

Step 1

- Select relevant error types and components to be considered
- Relevant error types will generally include all error types
- Relevant components will generally include all components down to a level where the component is unlikely to affect availability
- Determine for each error type or component the consequences on energy output (100% output, 0 % output or derating).

ARM Model

SIEMENS

Step 2

- Determine MTBF (Mean Time Between Failure) and MTTR (Mean Time To Repair) for all relevant errors / components
- MTBF must be interpreted broadly and must include
  - Actual failures
  - Errors that do not constitute physical failures
- MTTR must also be interpreted broadly and must include
  - Time to detect and evaluate failure or error
  - Time to make replacement parts available (if relevant)
  - Average access delay as function of required weather window
  - Time for actual repair

ARM Model

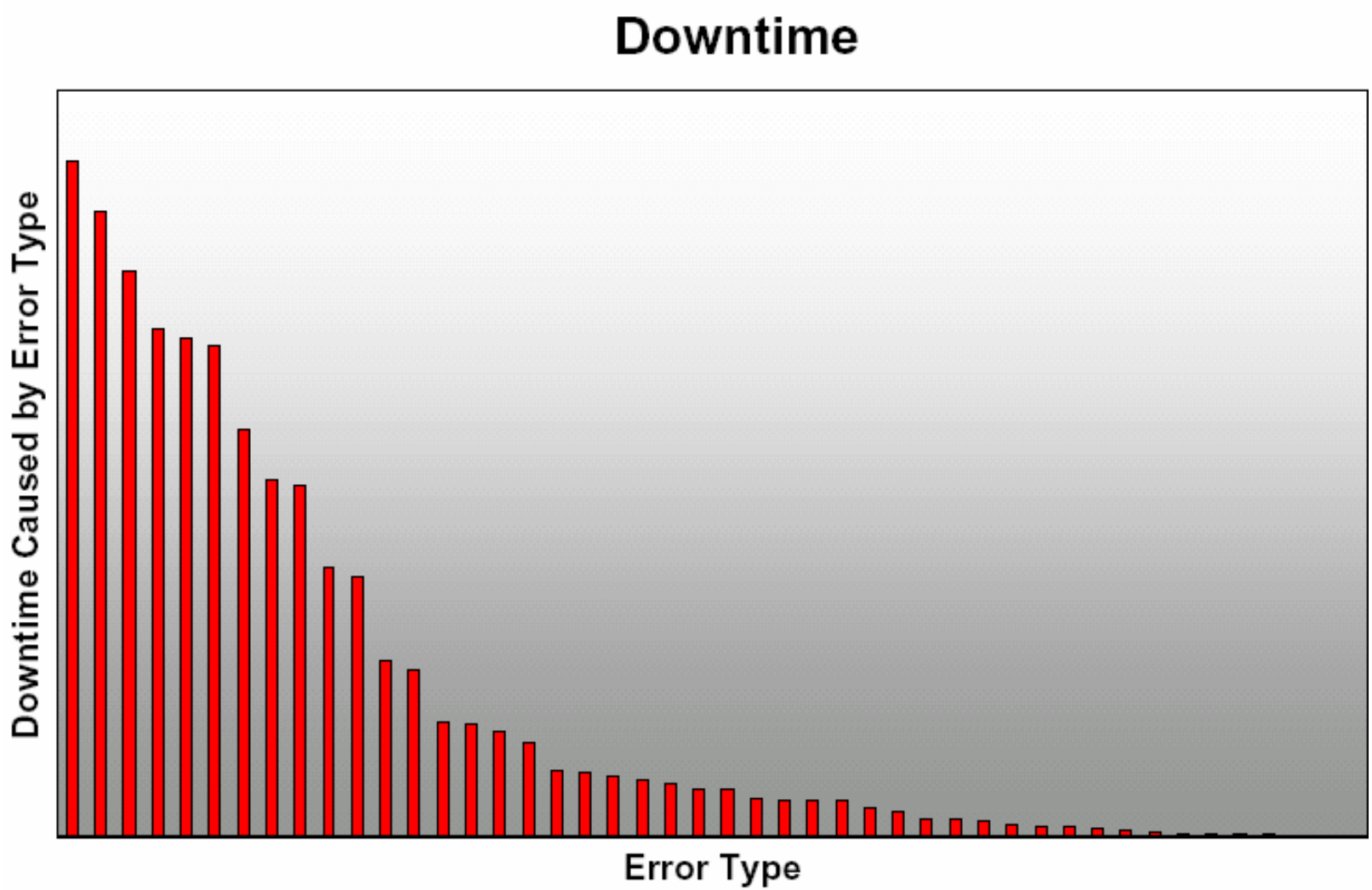
SIEMENS

MTBF info is not readily available

- Offshore turbines are typically new models with limited operating experience
- Unlike for power plant equipment reliable component databases are not available
- MTBF changes over component lifetime

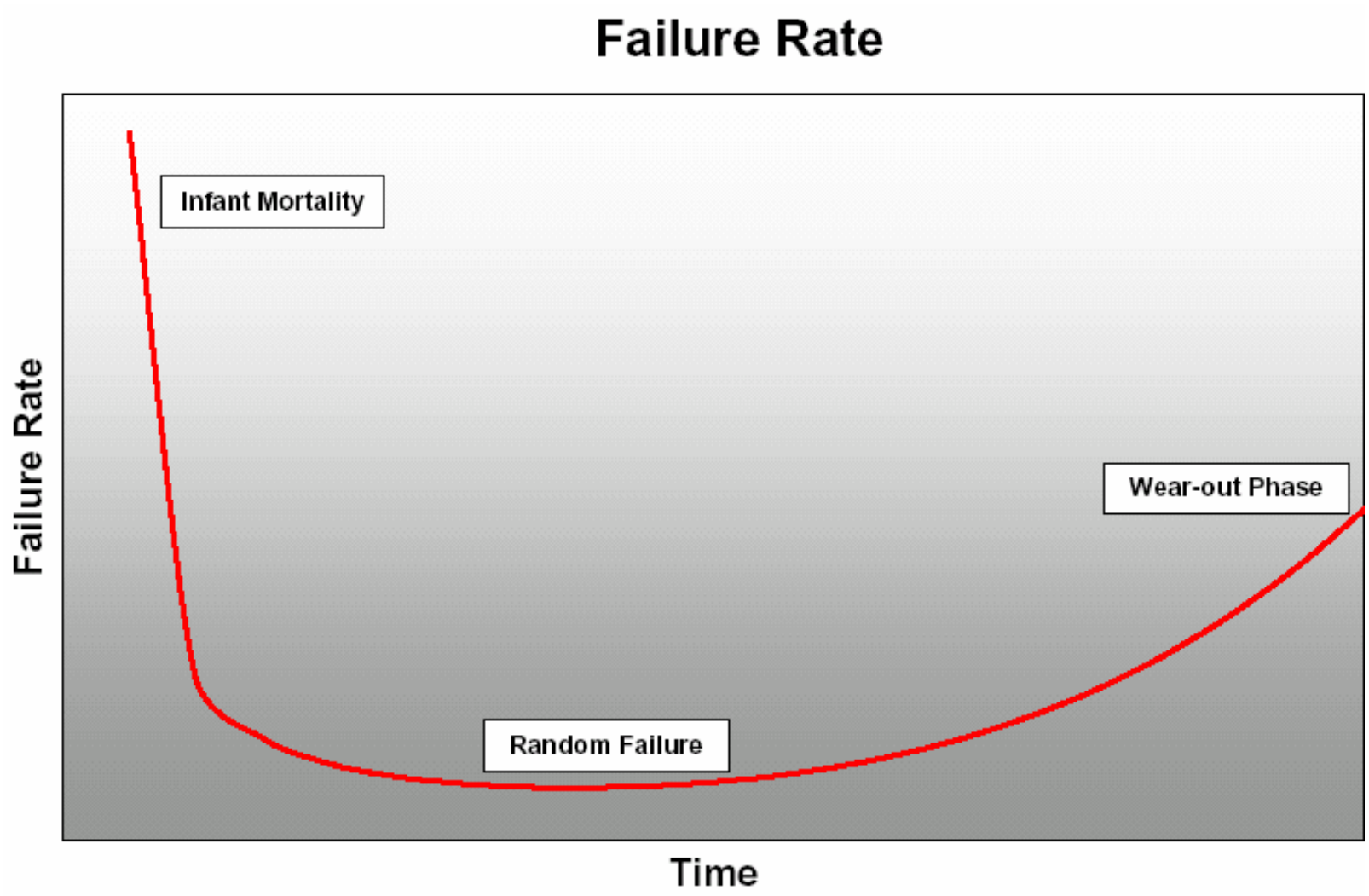
ARM Model

SIEMENS



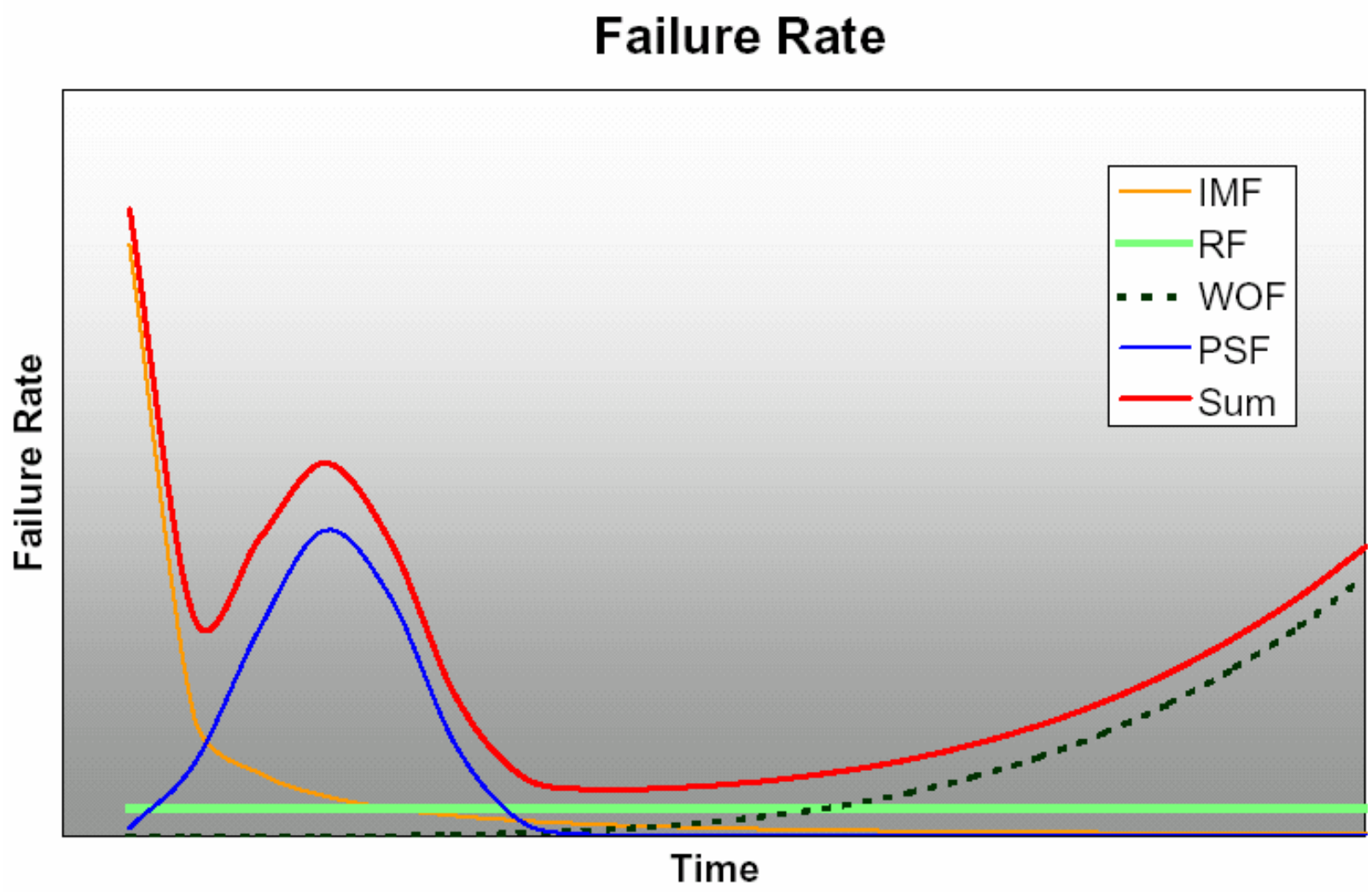
ARM Model

SIEMENS



ARM Model

SIEMENS



ARM Model

SIEMENS

Step 3

- Determine reliability by multiplying MTBF with MTTR and with consequence
- Use fault tree analysis where appropriate to identify cross-relations
- Use Monte-Carlo simulation if required to combine probability functions

Step 4

- Determined action plan on basis of components having highest cost on availability

ARM Model

SIEMENS

What is Easy in the ARM Model?

- Selection of relevant error types and components, and determination of consequences – part is already done for type approval
- Post-processing of results – fault tree, probability functions, etc.

What is More Difficult?

- Calculation of MTTR under offshore conditions – but experience is quickly gathered

What is REALLY Difficult?

- Prediction of MTBF

How is Reliability Ultimately Improved?

SIEMENS

Continue "Classical" Activities…

- Type approval including fault tree analysis with focus on safety
- Design validation based on engineering review and prototype testing
- High focus on QA at main subsuppliers
- Close dialogue with competent clients

… introduce ARM Model…

- Carry out formal ARM analysis
- Base MTBF on best combination of past experience and information from other fields of application
- Calibrate model results on existing and new projects

… and Face the Consequences!

Consequences

SIEMENS

Early Findings from Application of ARM Model:

- Use higher grade of sensor quality
- Use new generation of hydraulic fittings
- Change concept of redundancy (with due respect for safety)
- Maintain pressure on main component suppliers for ability to dismantle in nacelle