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LCM ANALYTICS

Where could we go from here?

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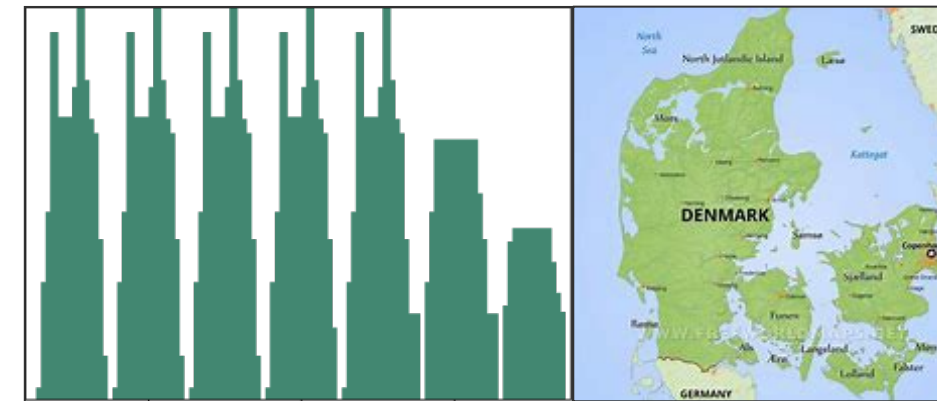
”THE CLASSIC PLAYING FIELD”

FOR OPUS SUITE ANALYTICS

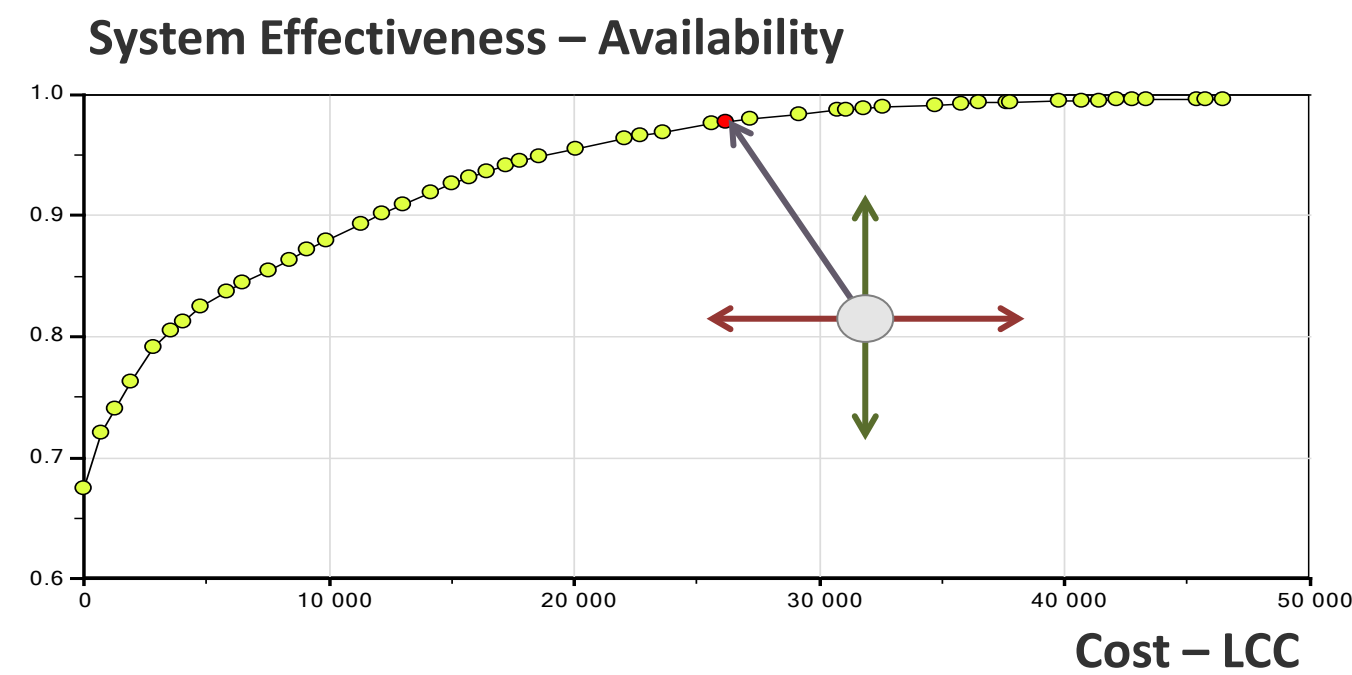


TECHNICAL SYSTEM
(product)

need of
support



OPERATIONAL CONCEPTS
(operations/usage)



capability to
support

SUPPORT SYSTEM
(support)

- **analyze/assess impact from different alternatives/decisions on**
 - availability performance – system effectiveness
 - total cost – LCC
- **optimize support (spares dimensioning, maintenance concept (LORA), ...)**
 - operational concepts and product RAMS properties given as input

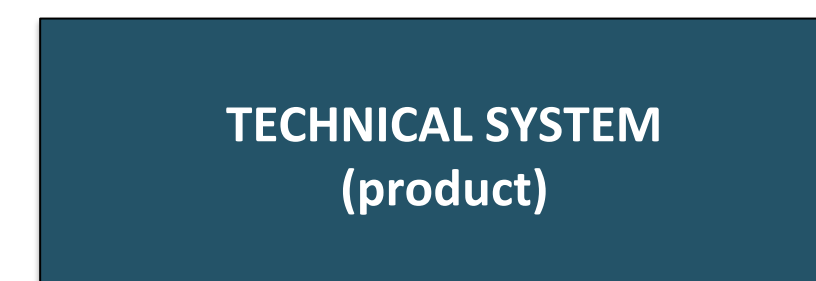
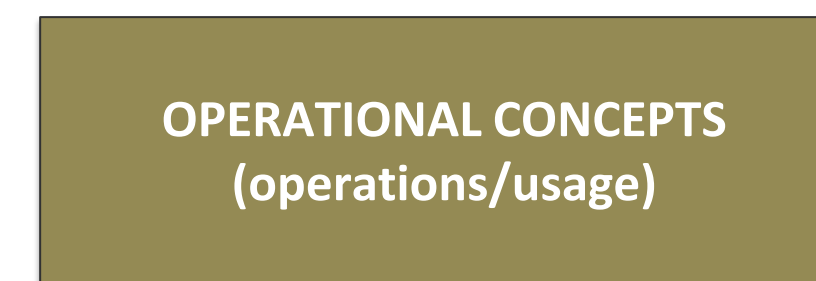
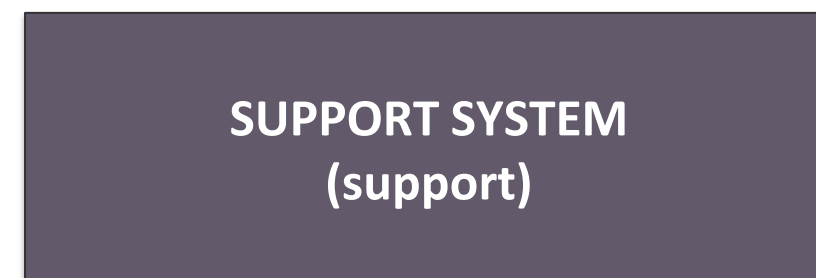
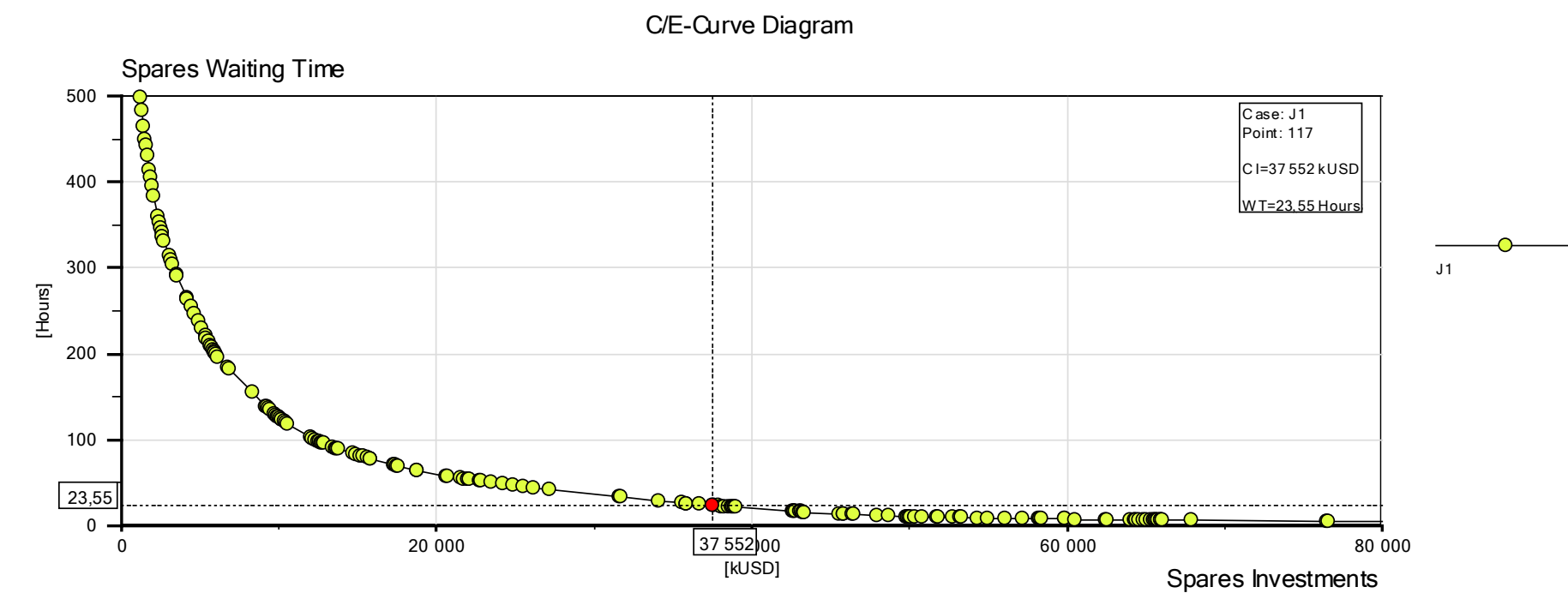
OPTIMIZE SUPPORT

THE CORE OF OPUS10



OPUS10

- **what quantities of spare components/parts are needed**
 - limit/minimize impact on unavailability from spares delays/shortages
 - by providing safety stock at workshops and nodes in the supply chain
 - at minimum cost (investment, bound capital)?
- **spares optimization formulation and modeling framework**
 - first OPUS model in 1970
- **extensions/improvements to OPUS (OPUS10) over the years, e.g.,**
 - unlimited, flexible indenture levels and echelons
 - endurance scenarios
 - supply flexibility – lateral support
 - revised data model (RDM)
- **increased design space – LORA**
 - maintenance concept
 - resource dimensioning/requirements
 - minimize delays at minimum LSC



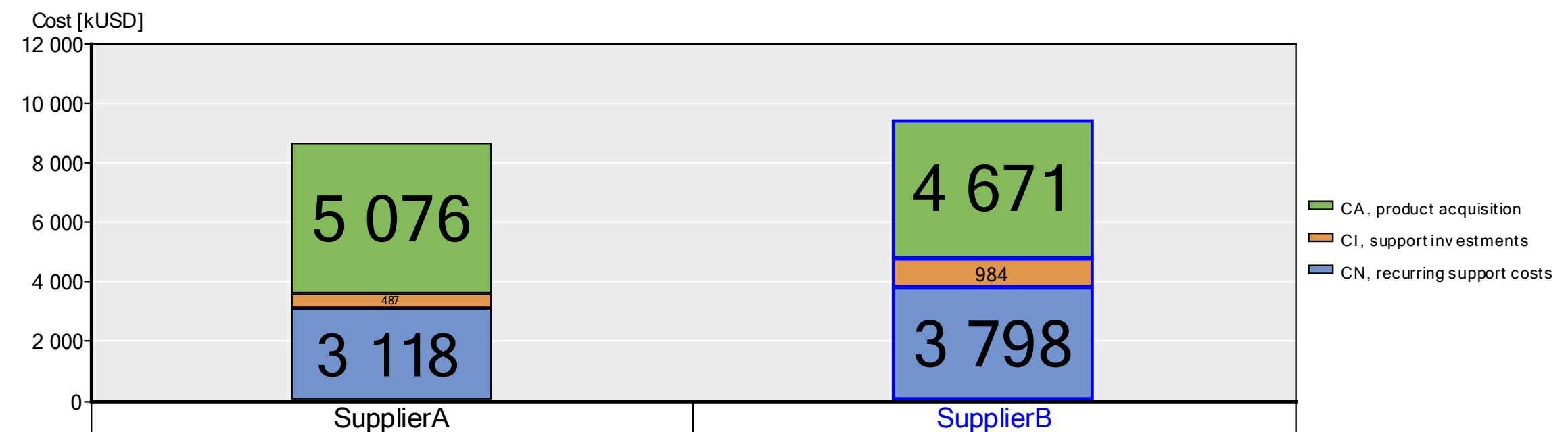
ASSESS AND ANALYZE LCC

THE CORE OF CATLOC



CATLOC

- what about other cost elements?
- scope of CATLOC
 - model LCC – cost breakdown – user-defined or from template
 - describe how a cost element is to be assessed – explicitly or through underlying parameters and formulas
 - assess/predict LCC for different alternatives of interest
 - study robustness and sensitivity
 - establish cost drivers
- classical application
 - LCC-based acquisition – tender evaluation with respect to LCC
- “unlimited applicability”
 - everything is user-defined



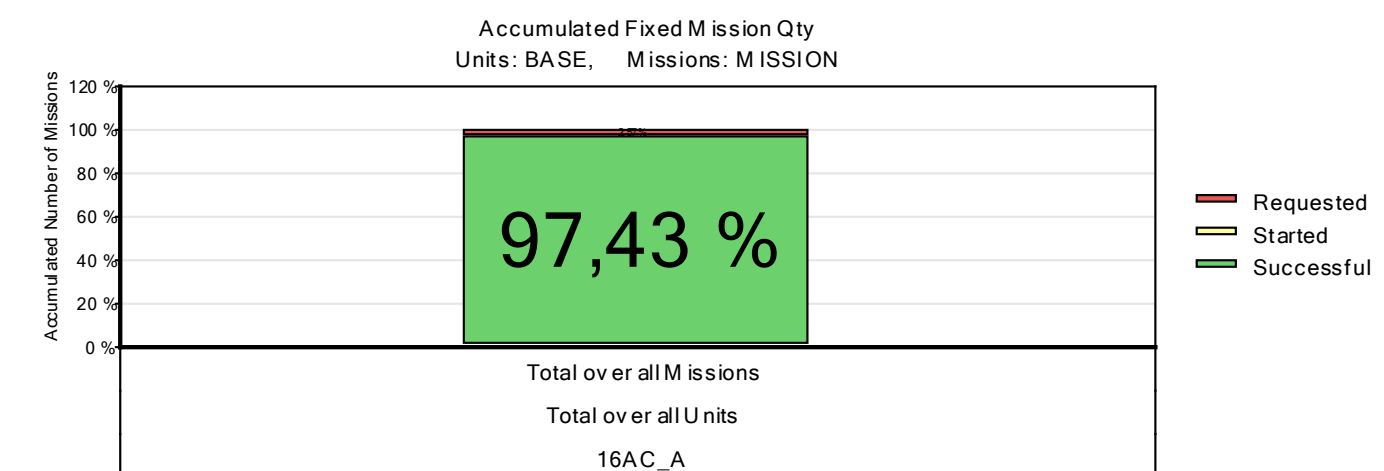
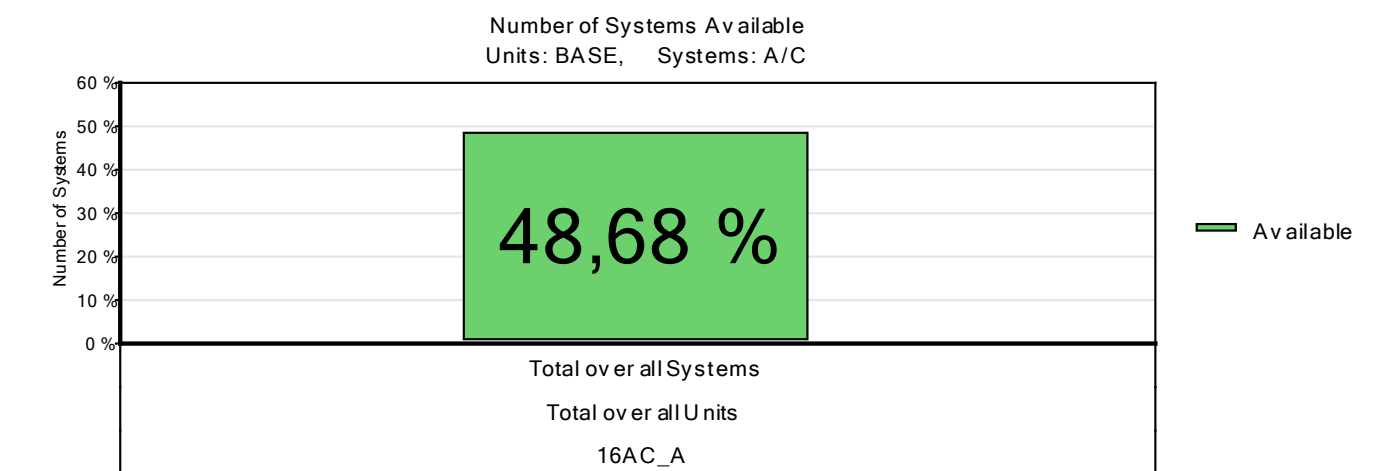
SIMULATION TO REFLECT SYSTEM EFFECTIVENESS

THE CORE OF SIMLOX



SIMLOX

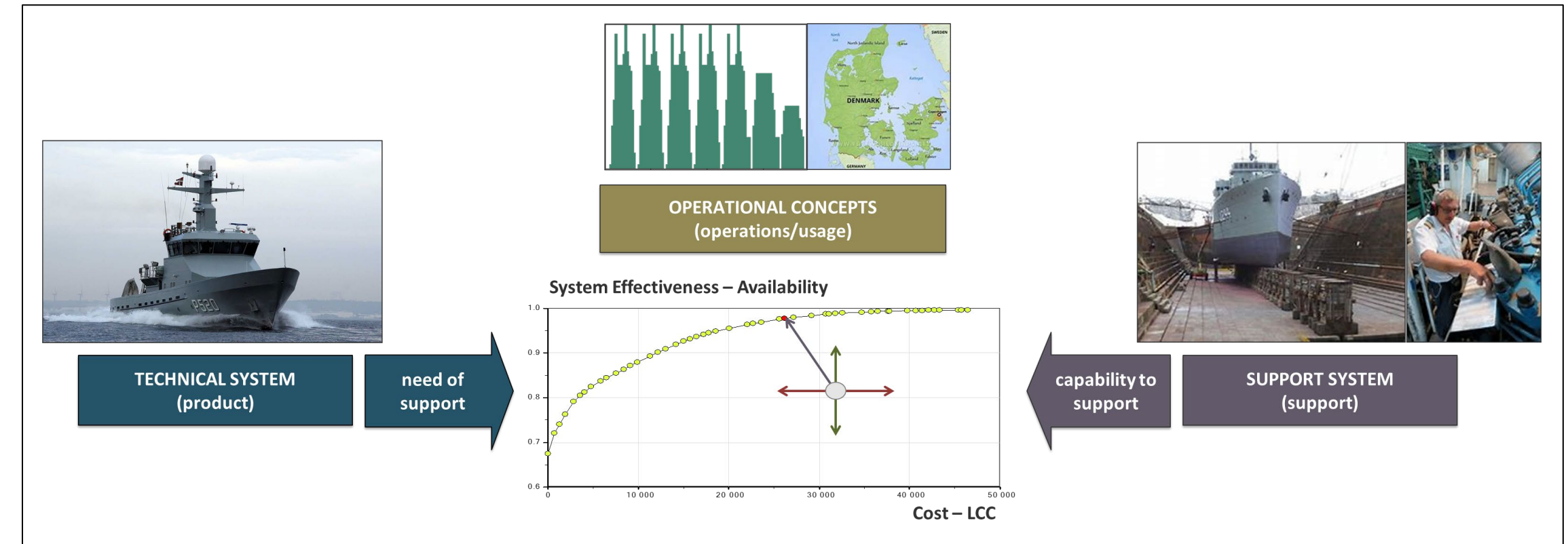
- **what about system effectiveness considering**
 - time-variability in operational concepts – product availability varying over time
 - shared responsibility across a group of products – a unit
 - different requirements for different missions – quantity-wise
 - different requirements on product state for different modes of operation – functional block diagrams (FBD's)
 - platform-type products (ships) with on-board maintenance and storage capability
 - etc.
- **produce KPI's that better reflect system effectiveness**
 - mission success rate – ability to do
 - mission-related readiness – ability to take on
 - over time
 - etc.
- **“easy using simulation”**
 - much harder using an analytical modeling approach



OPUS SUITE

SUMMARY

- **powerful analysis capabilities**
 - “place the point” thru modeling and simulation
- **powerful optimization capabilities**
 - “generate cost-effective support” – sparing, LORA
- **strategic questions/decisions – design space**
 - what products?
 - quantity of products?
 - what support concept (maintenance, supply)?
 - quantity of spare components needed?
 - maintenance capacity required?
 - quantity of maintenance resources needed?
 - ...
- **“the strategic platform”**
 - can be adjusted/modified
 - but not on a daily, weekly, monthly basis



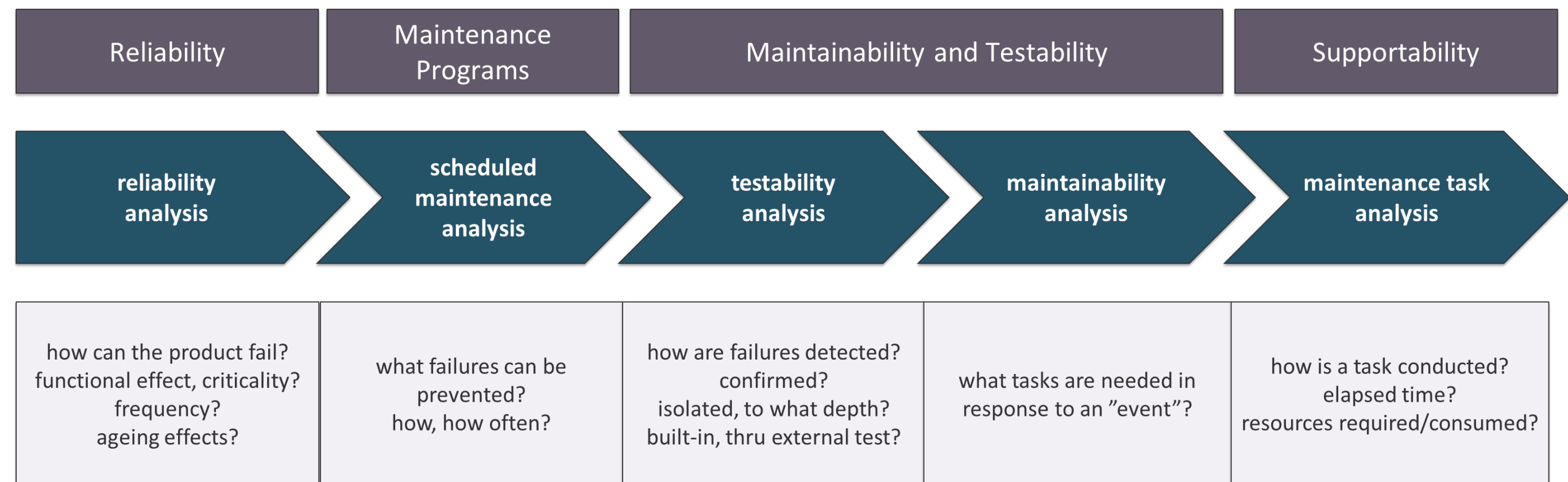
LCM ANALYTICS

WHERE COULD WE GO FROM HERE?

- **tactical/operations questions/decisions – design space**
 - allocation of products, equipment, resources
 - deployed operations
 - operations and maintenance planning
 - based on counters and intervals
 - based on state of the products – predictive maintenance
 - based on state in the support system
 - ...

- **what about other strategic decisions?**
 - product RAMS properties (LSAR)

- **maintenance program for the product?**
 - balanced, cost-effective?



SCHEDULED MAINTENANCE

INTRODUCTION

- **scheduled maintenance – what does it entail?**

- husbandry of equipment
- function checks

- inspections – condition checks
- preventive tasks
- service life limits

- **scheduled maintenance always cost money**

- and sometimes causes unavailability/down time

- **how often?**

- interval-based

- **motivation?**

- ageing effects – varying hazard rate

- **why?**

- to keep the equipment in shape
- to check the functional status of the equipment

- to assess the state/condition of the equipment
- to avoid/reduce risk of failure on the equipment
- to avoid/reduce risk of failure on the equipment

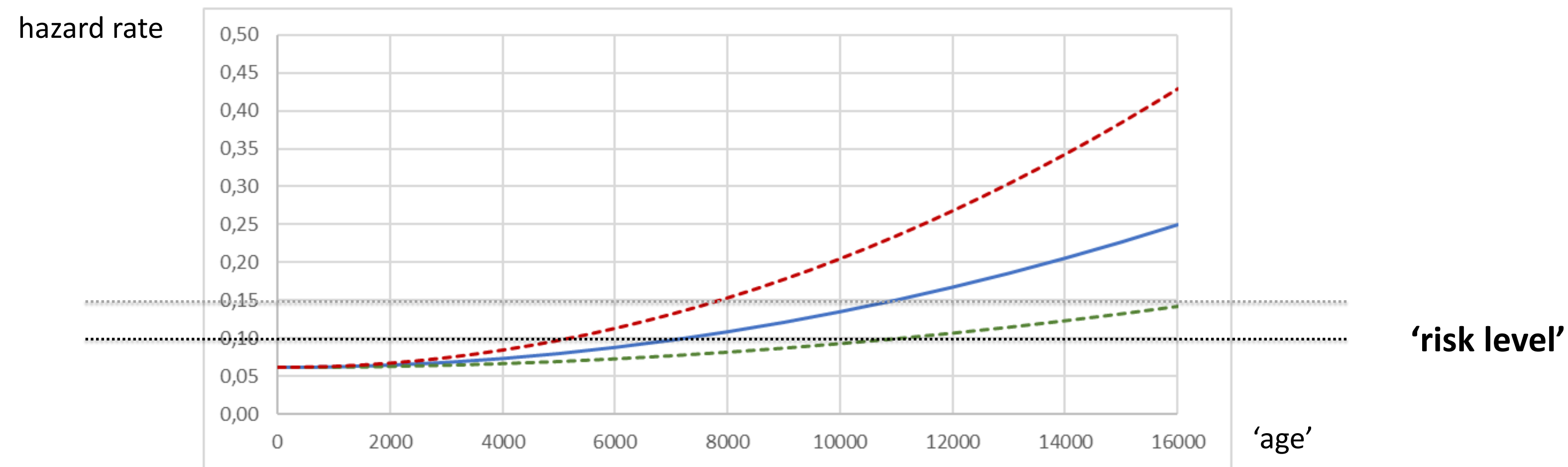
- **when?**

- condition-based

AGEING EFFECTS

HAZARD RATE

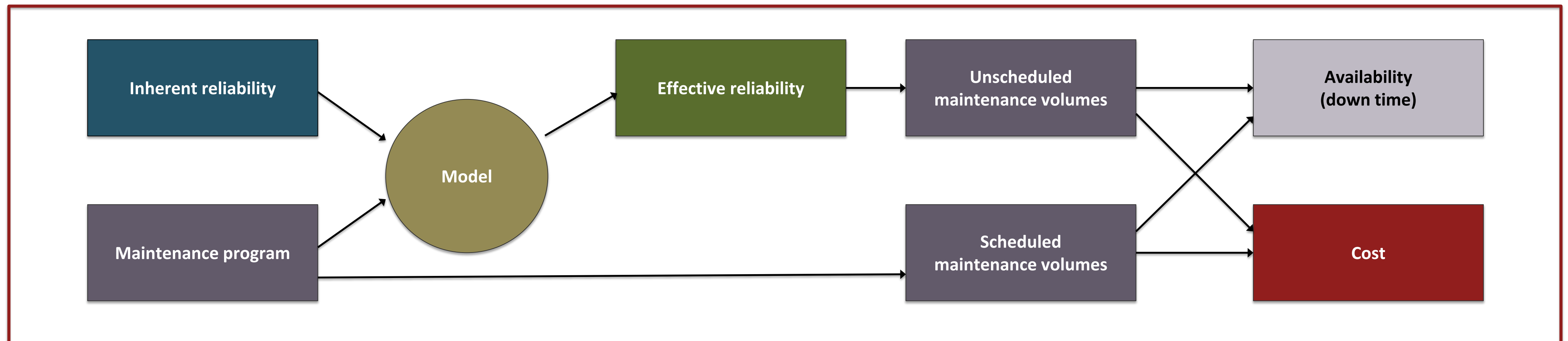
- **hazard rate – hazard function**
 - the instantaneous risk (frequency) of failure at ‘age’ t – given survival to up to this ‘age’



- **intervene at a certain ‘risk level’**
 - conduct preventive task, replace
 - to reduce risk level – ‘push to the left’
- **assess ‘risk level’**
 - statically – statistically
 - dynamically – from inspections or sensor-values
- **what ‘risk level’ shall we accept?**

RELIABILITY-CENTERED MAINTENANCE (RCM)

- **scheduled maintenance always cost money**
 - and sometimes causes unavailability/down time
- **all preventive measures must have a proven positive effect on reliability**
 - Reliability-Centered Maintenance
- **what tasks and intervals ('risk levels') are cost-effective?**



”RCM MODEL”

- **modeling framework defined**

- the mathematics in place

- **input**

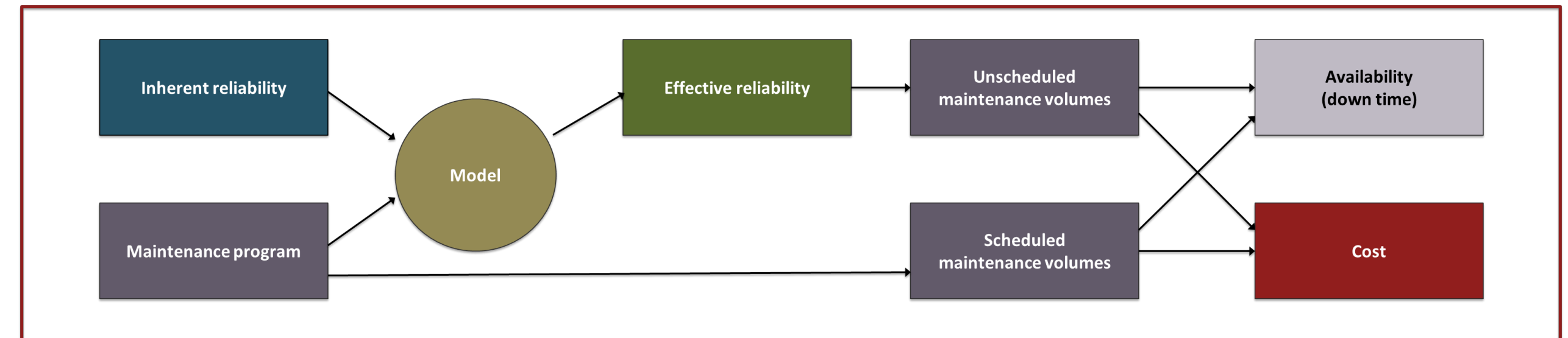
- inherent reliability
- maintenance program

- **output**

- effective reliability
- unscheduled and scheduled downtime
- cost of unscheduled and scheduled maintenance

- **application**

- optimization – tune intervals (‘risk levels’) for minimum impact on availability at minimum cost
- screen a proposed maintenance program in terms of impact on availability and cost
- ...



for $t \in [\tau_i, \tau_{i+1}), i = 0, \dots, M - 1,$

$$R(t) = \frac{R^0(t - \tau_i + a_i)}{R^0(a_i)} \cdot \prod_{j=1}^i \frac{R^0(L_j + a_{j-1})}{R^0(a_{j-1})} = \frac{R^0(t - \tau_i + a_i)}{R^0(a_i)} \cdot R_i$$

and for $t \geq \tau_M,$

$$R(t) = \frac{R^0(t - \tau_M + a_M)}{R^0(a_M)} \cdot \prod_{j=1}^M \frac{R^0(L_j + a_{j-1})}{R^0(a_{j-1})} = \frac{R^0(t - \tau_M + a_M)}{R^0(a_M)} \cdot R_M$$

CONCLUDING REMARKS

- **ability to screen and set up cost-effective maintenance programs**
 - sounds exciting?
 - powerful capability? lacking capability?
 - currently relying on OEM recommendations? formed on what basis? tuned over time?
- **also applicable for predictive maintenance**
 - ‘risk level’ rather than ‘age’
 - machine learning links sensor-values to ‘risk levels’
- **analysis capability outside current scope of Opus Suite**
 - would you want such a tool – modeling framework productified?
- **LCM analytics**
 - one direction we could go from here
- **cost-effective products with well-balanced RAMS properties**

Thank you.

