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ELMAS – RAMS, Risk Assessment and Use Cases

EuCARD2 WP4 – CERN (Geneva) 22-23.6.2015

Reliability of Accelerators for Accelerator Driven Systems (ADS)

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Outline

1. Brief introduction
   - Ramentor, ELMAS, RAMS, Risk assessment process
2. Concrete use cases
   a) Availability and radiation safety of encapsulation plant
   b) Life Cycle Profit Management (LCPM) of process critical molding cranes – Modernization and improvement scenario analysis
   c) Analysis of Alternative Bypass Lines of Mineral Processing Line
   d) Infrastructure Availability – Design-Phase Data Center
   e) Nuclear Power Plant (NPP) – Sustaining and developing safety, availability and performance factors

Ramentor Inc.

- Founded in 2006 and based in Tampere, Finland
  - Personnel ~10 (Dr. & M.Sc. – Mech. & aut. eng. / Applied math. / Software dev.)
  - Privately owned and independent software and expertise company
- Background: Tampere University of Technology (TUT)
  - Finnish Technology Agency (TEKES) Competitive Reliability Programme 1996-2000
  - Probabilistic approach in reliability and maintenance management 2001-2003
  - RAM Products 2003-2005, RAM Solutions 2006-2008, RAM Efficiency 2008-2010
- Please visit for more information: *www.ramentor.com*

Our goal is to become the leading expert and a partner in the field of Risk Management and RAMS methods and tools

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Ramentor – Experience in Industry Sectors

- Energy Industry:
  - Nuclear Power Plants, District Cooling, …
- Process Industry :
  - Pulp & Paper Mills, Steel Industry, Mineral Processing, Medical, …
- IT Industry:
  - Data Centers, Telecommunication, Broadband connections, …
- Equipment Manufacturers:
  - Cranes, Elevators, Thruster Units, …
- Education and Research Organizations:
  - Universities (technology / applied sciences), CERN, …

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Ramentor – ELMAS Users / Co-developers

Industry Service	Design for Reliability	Quality & Risk mgmt
Caverion, YIT, ALGOL, EMPOWER, ABB, maint partner, Efora	KONECRANES, KONE, ABB, CARGOTEC, CERN, metso, PÖYRY, POSIVA	FINGRID, Fortum, TeliaSonera, VACON, Google, elisa, NOKIA
Operation & Maintenance	**After Sales Support Service & Warranty**	**Research & Education**
UPM, TVO, POHJOLAN VOIMA, Fortum, OUTOKUMPU, Outotec, ruukki, nokian RENKAAT	Rolls-Royce, KONE, KONECRANES, Valmet, CARGOTEC, VACON	TAMPERE UNIVERSITY OF TECHNOLOGY, LAPIN AMK Lapland University of Applied Sciences, SOLTEQ, Jyväskylän AMK, HAMK HÄMEEN AMMATTIKORKEAKOULU

ELMAS – An Acronym

Event	Logic	Modeling	Analysis	Software
• Time to Failure, Distribution • Time to Repair, Distribution • Maintenance actions • Break and downtime loss • Repair Costs • Hazards • Usage and stress profile • External events	• OR • AND • K/N-Voting • XOR-Exclusive • Limits • Conditional probability • Delays • Throughput, fuzzy logic • Dynamic coding	• Fault tree • Event tree • Cause-consequence-tree • Reliability block diagram • Process diagram • Waiting and redundancy • Buffers • Failure modes, RCA	• Simulation • Reliability, Availability • Risk Analysis • Importance measures • Conditional probabilities • Spare part consumption • Resources • FMEA, Classification, RCM, Decision tree, Criticality	• Graphical user interface • Excel export and import • HTML report • Table summary • ERP interface • Project versioning • Template library • Search • Web start

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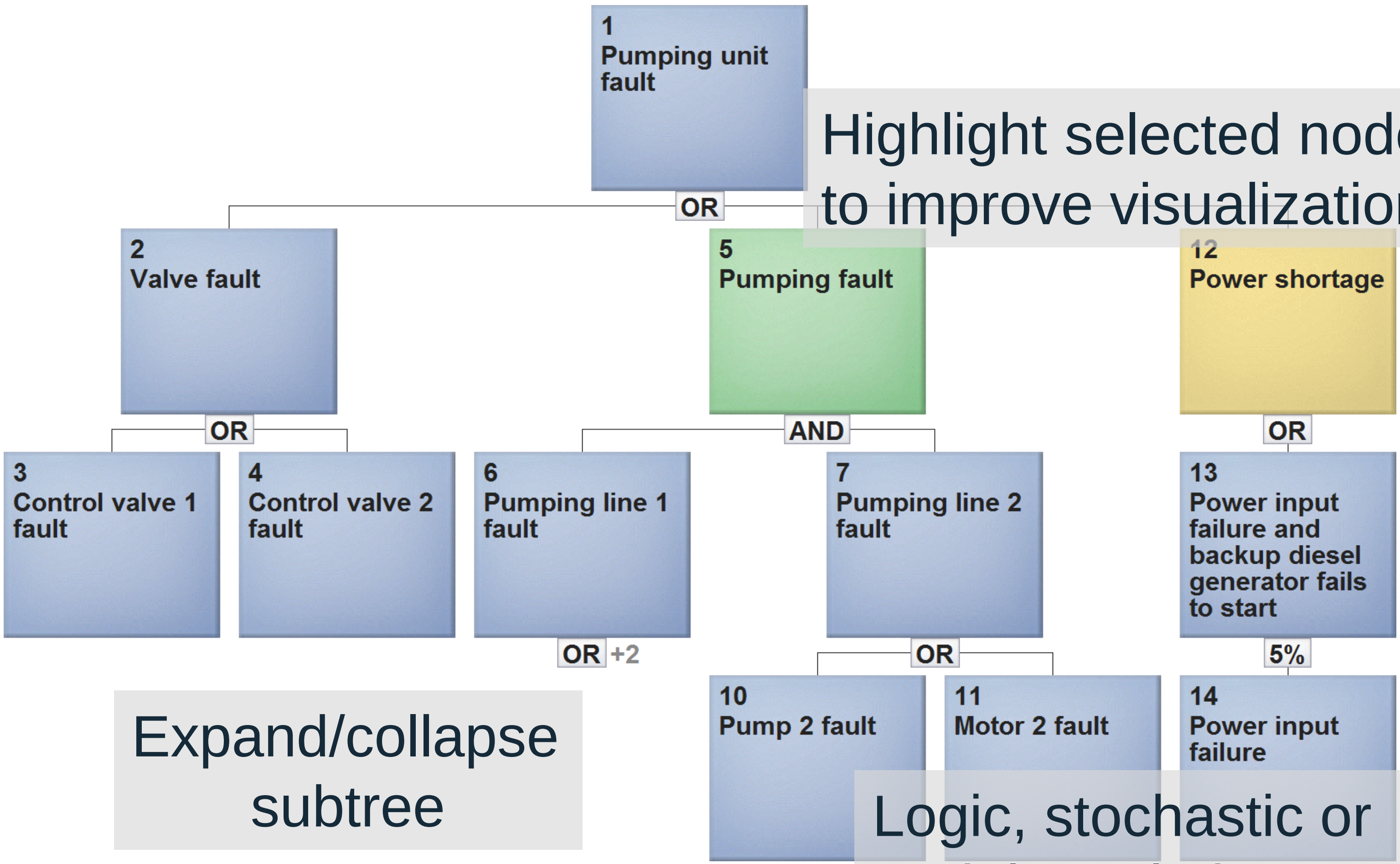
ELMAS – Modelling of a Fault Tree Structure

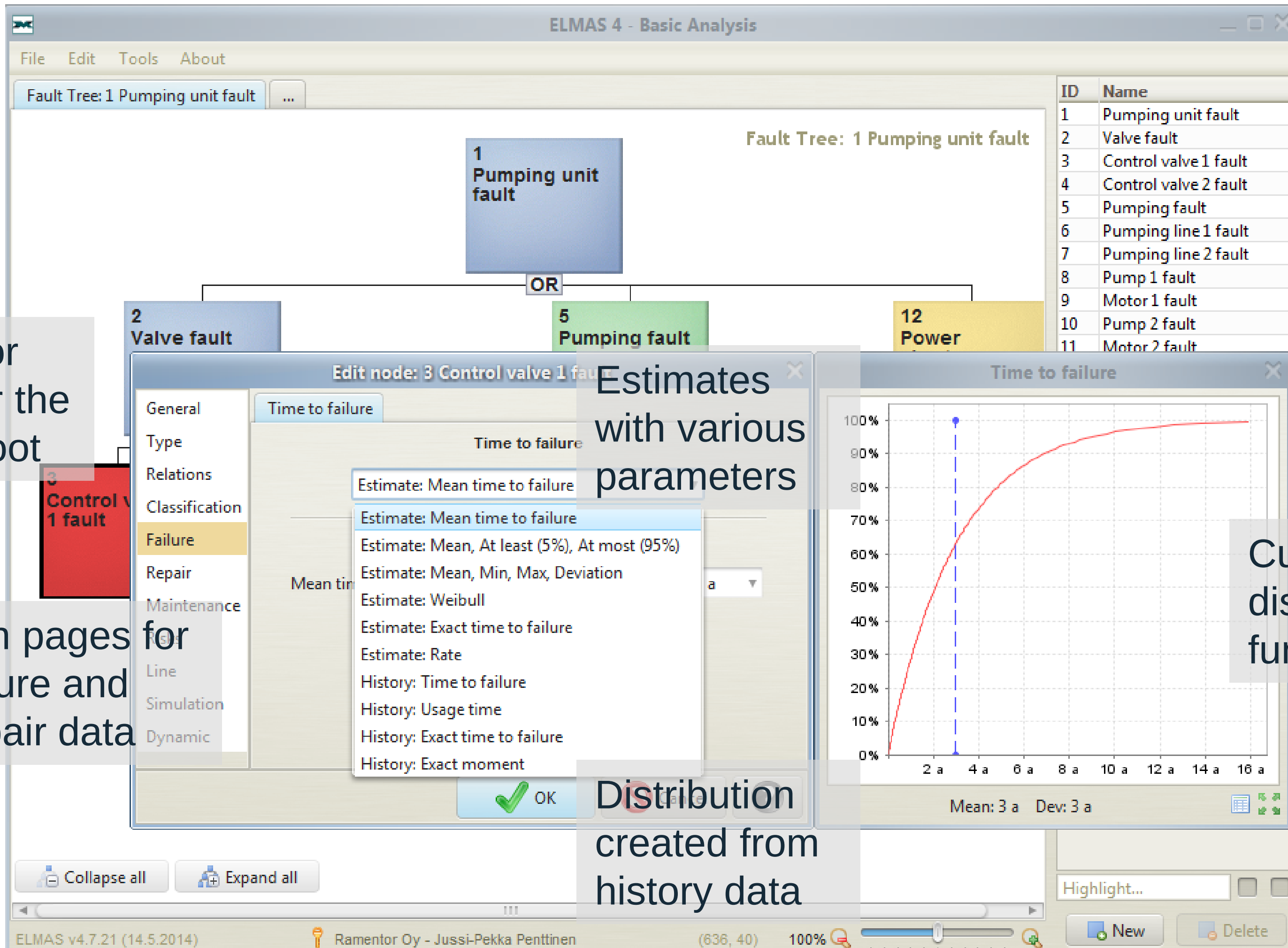


Highlight selected nodes to improve visualization

Expand/collapse subtree

Logic, stochastic or delay relations

ELMAS – Root: Failure/Repair Distribution



Node editor opened for the selected root

Estimates with various parameters

Cumulative distribution function shown

Own pages for Failure and Repair data

Distribution created from history data

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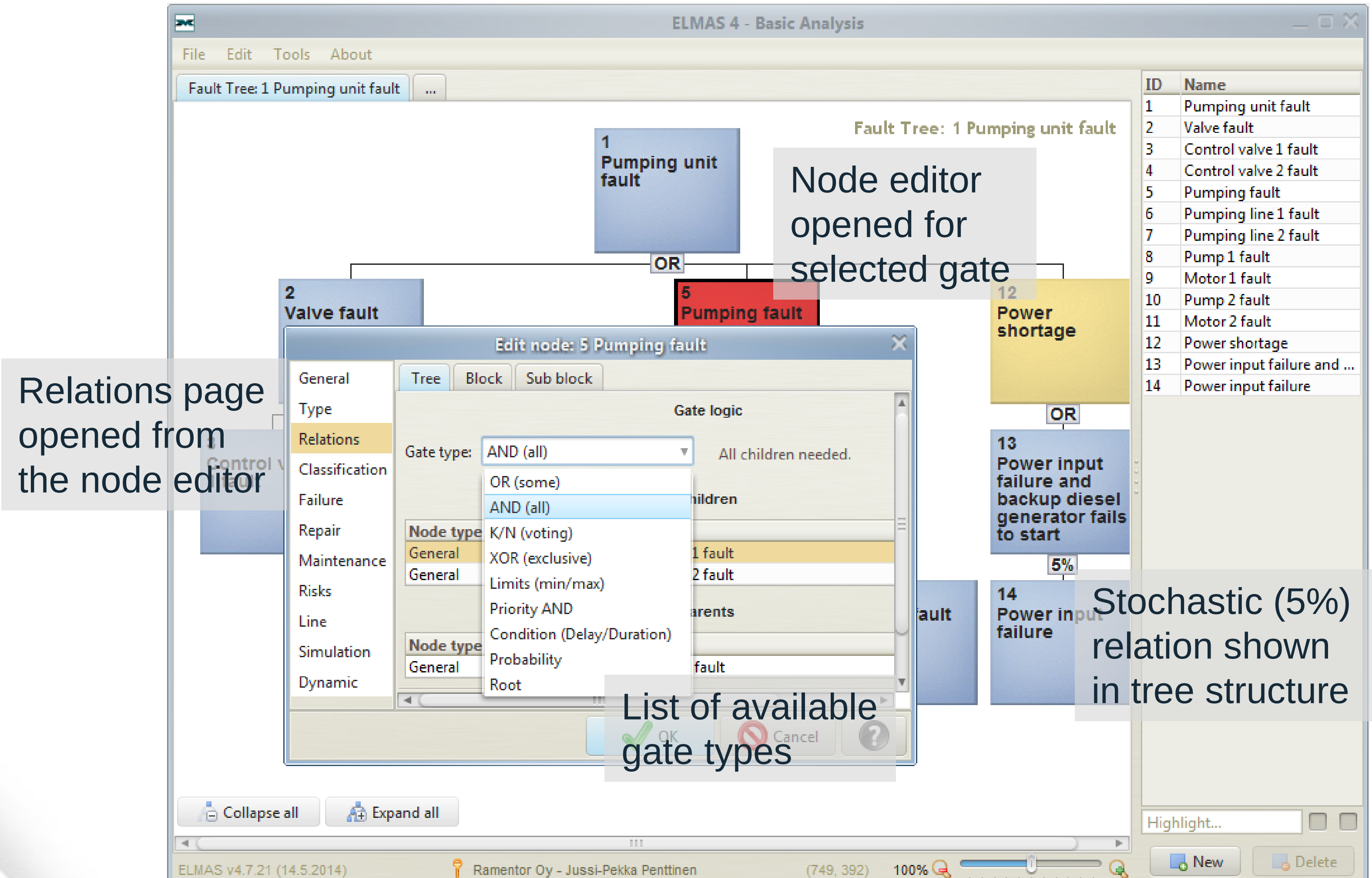
ELMAS – Gate: Logic/Stochastic/Delay



ELMAS 4.7

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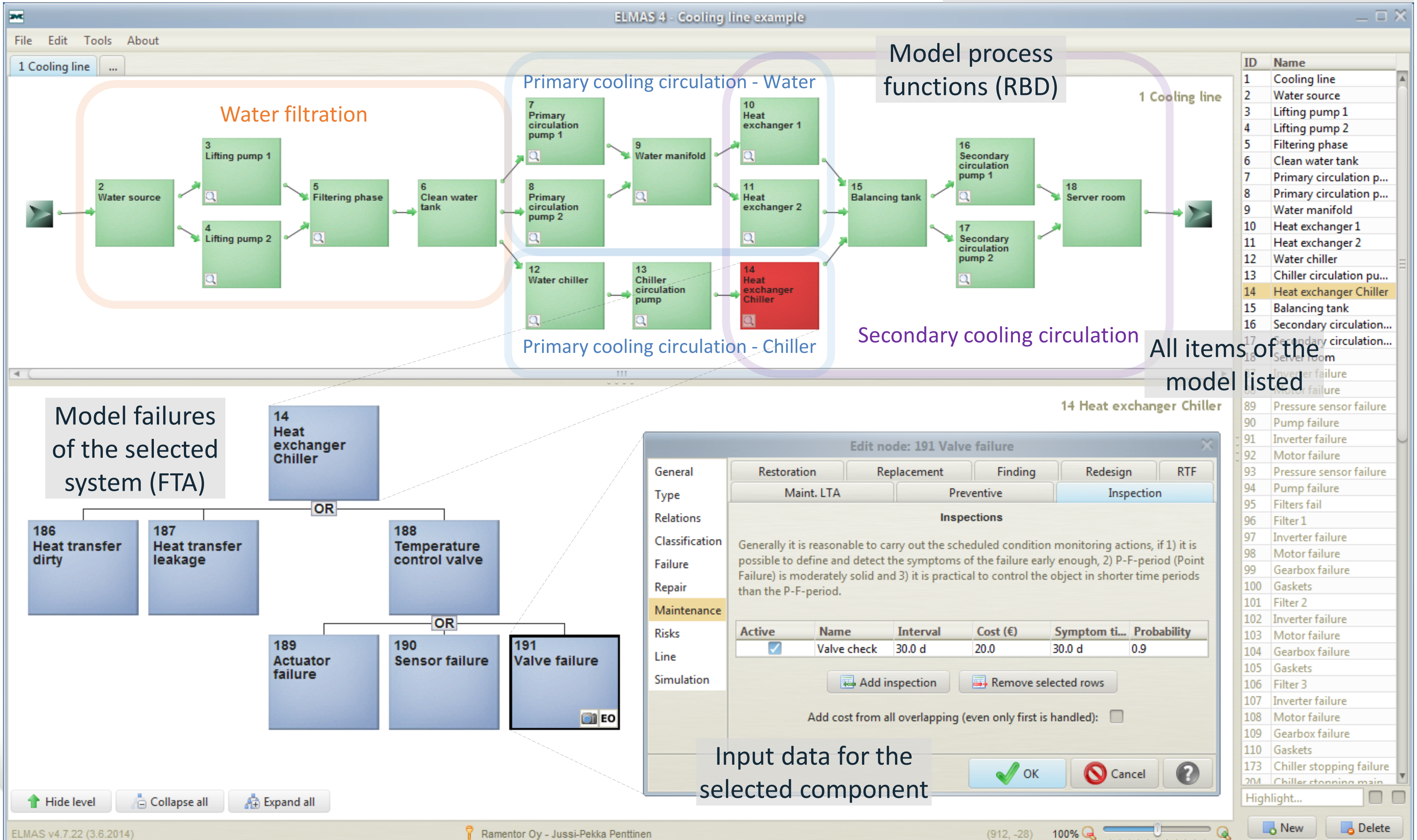
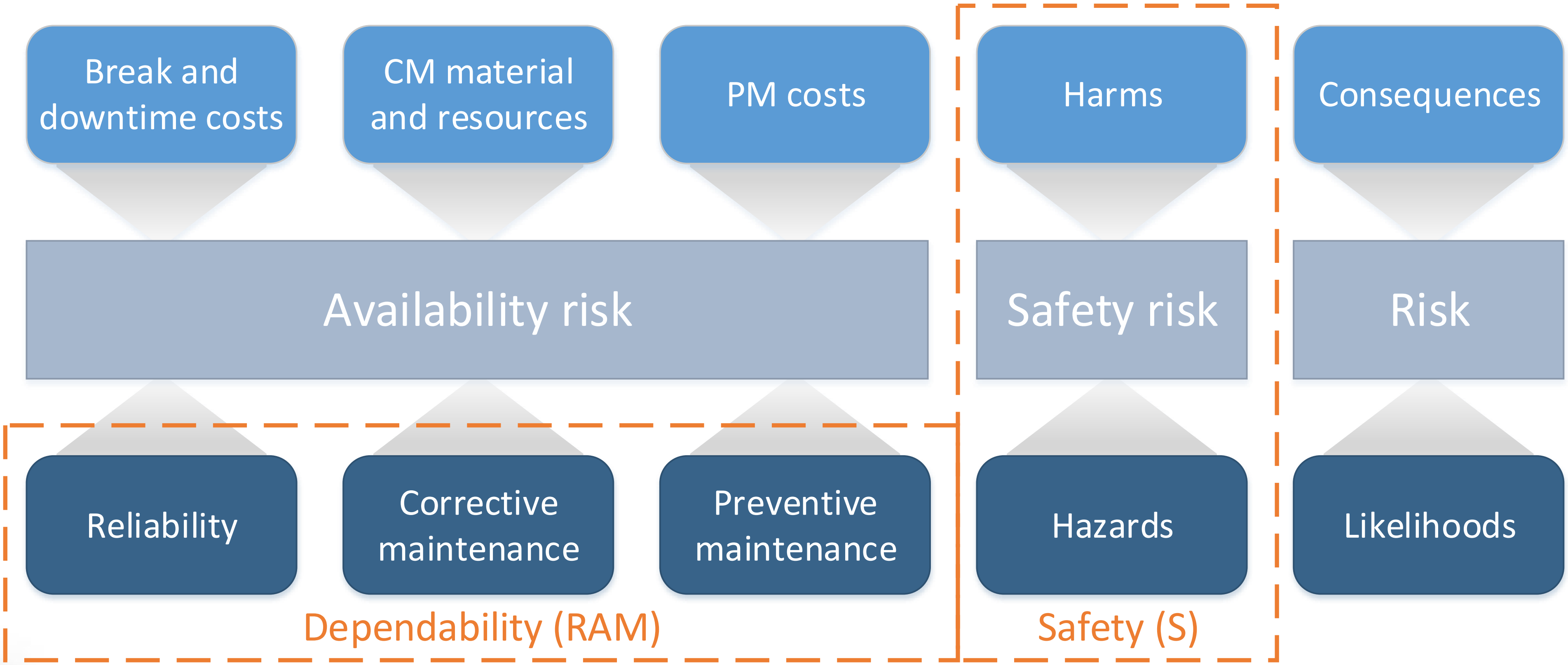
http://www.ramentor.com/products/elmas/



ELMAS – RAMS and Risk



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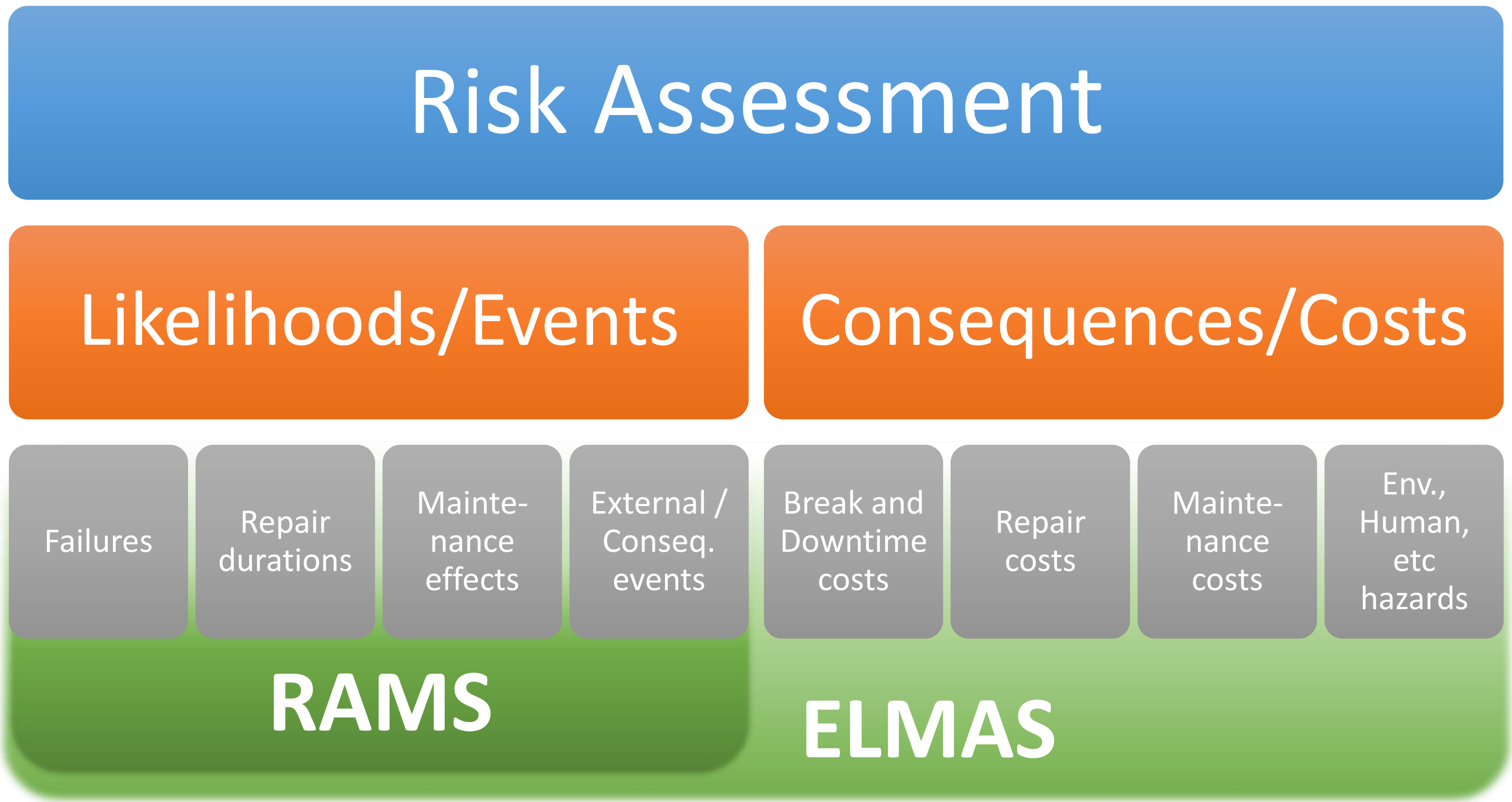
ELMAS – Risk Assessment and RAMS



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ELMAS – Risk Assessment Process (ISO GUIDE 73)

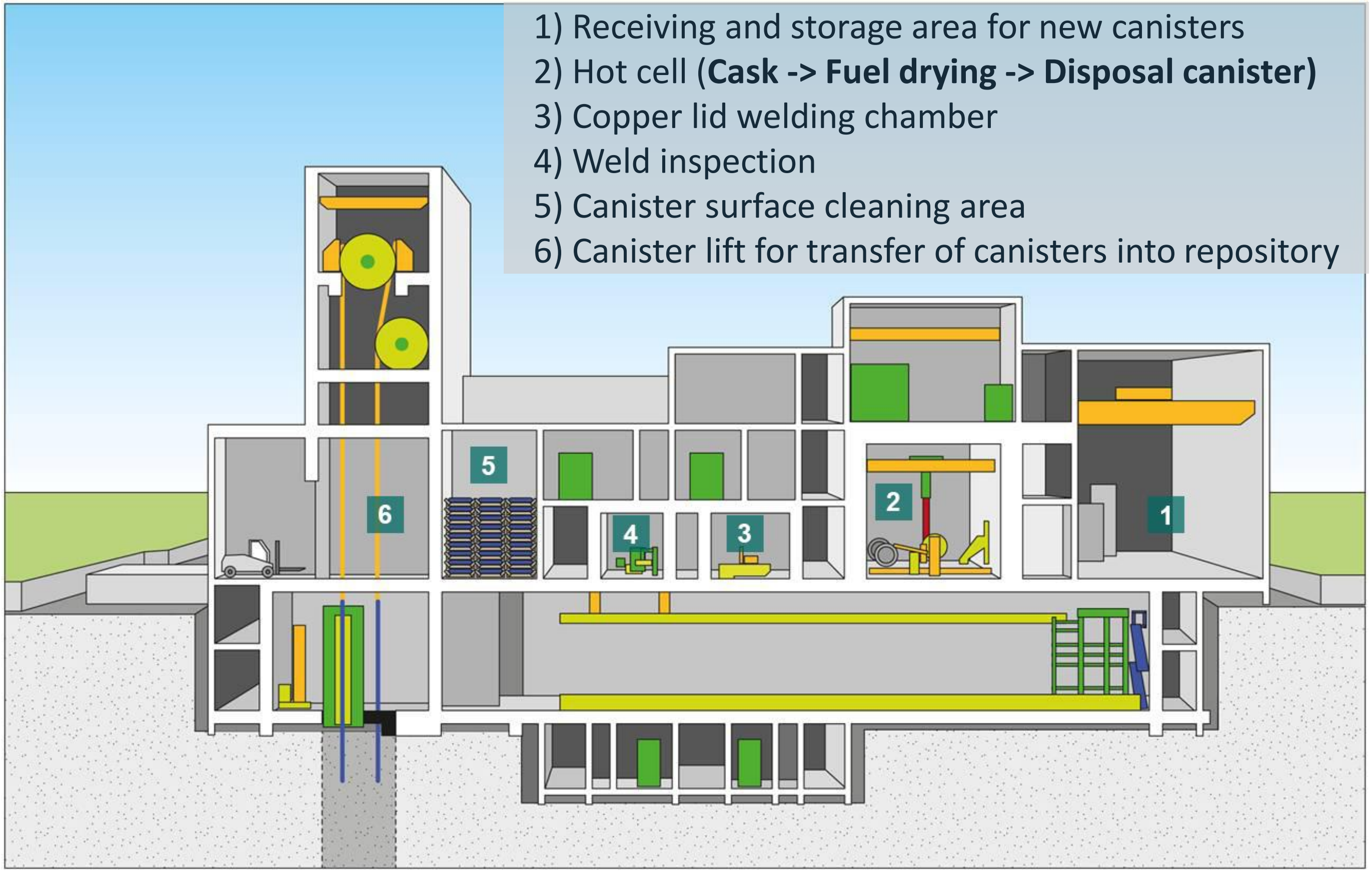
1) Risk identification
   - Find, recognize and describe risks
   - ELMAS: Collect available information to comprehensive model
2) Risk analysis
   - Comprehend the nature and determine the level of risk
   - ELMAS: Stochastic discrete event simulation of the model
3) Risk evaluation
   - Compare analysis results with risk criteria to determine whether the risk and its magnitude is acceptable or tolerable
   - ELMAS: Report explicit results, compare scenarios, …

Case A) – Final Disposal Facility (FDF)

- The purpose of the FDF is to take care of packing the spent nuclear fuel assemblies in canisters and to dispose them permanently into the bedrock
- Aboveground encapsulation plant
  - Spent nuclear fuel is received, dried and packed into final disposal canisters
- Repository (ONKALO)
  - Located deep inside the bedrock, in which the most important section are the tunnels where the encapsulated spent nuclear fuel is disposed of

Case A) – Final Disposal Facility (FDF):

Aboveground Encapsulation Plant



1) Receiving and storage area for new canisters
2) Hot cell **(Cask -> Fuel drying -> Disposal canister)**
3) Copper lid welding chamber
4) Weld inspection
5) Canister surface cleaning area
6) Canister lift for transfer of canisters into repository

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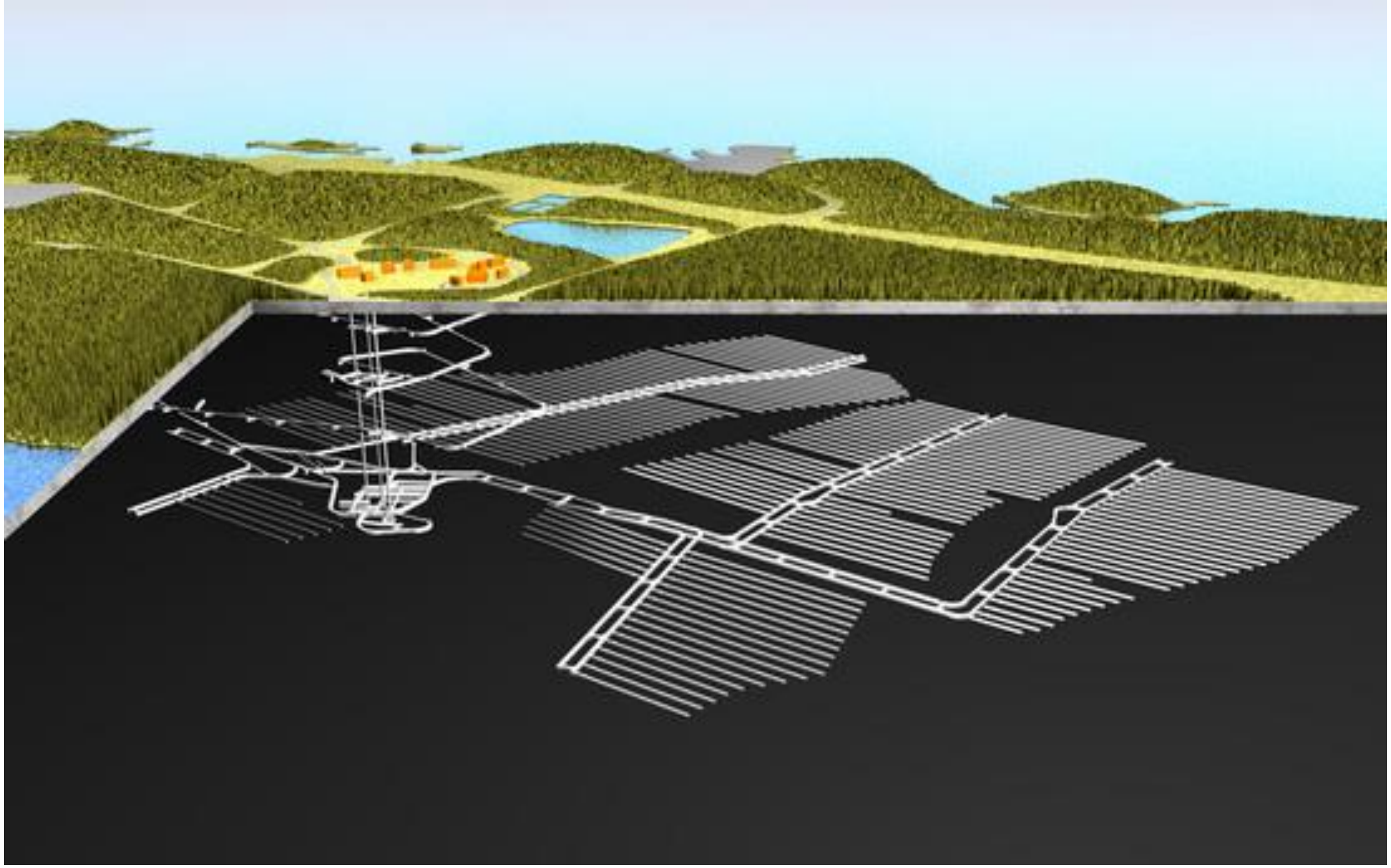
Case A) – Final Disposal Facility (FDF):

Repository (ONKALO)

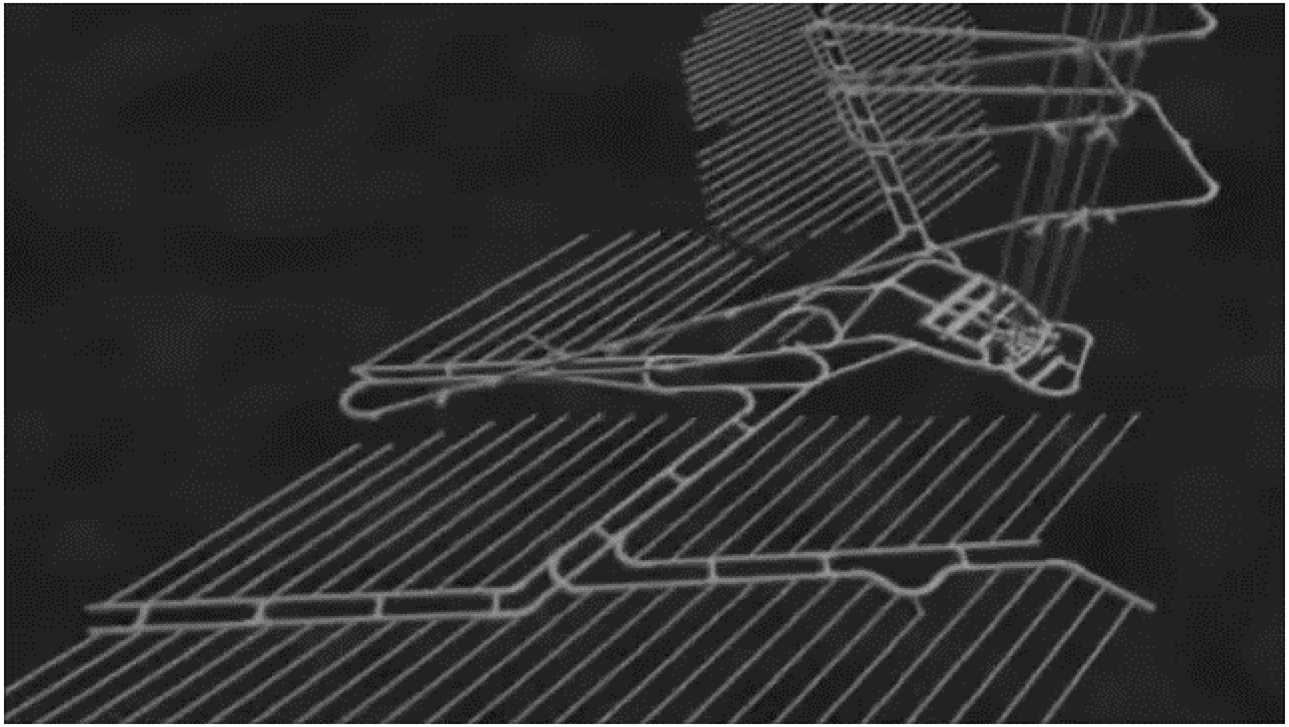


Case A) – Final Disposal Facility (FDF):
Encapsulation Plant Case Description

- ELMAS analyses were made by Pöyry for Posiva
  - Availability and radiation safety of encapsulation plant
- **Transportation cask -> Fuel drying -> Disposal canister**
  - Availability models: Docking, Lifting, Moving (AGV), Welding, …
- Design review and management of required changes
  - PSAM12 publication: Virtanen, Penttinen, Kiiski, Jokinen
- Safety models and reports
  - Ventilation system: Cooling, heating, filtering, low pressure
  - STUK (The Radiation and Nuclear Safety Authority in Finland)

Case A) – Final Disposal Facility (FDF):

Fuel Handling Cell Equipment Example (1/5)



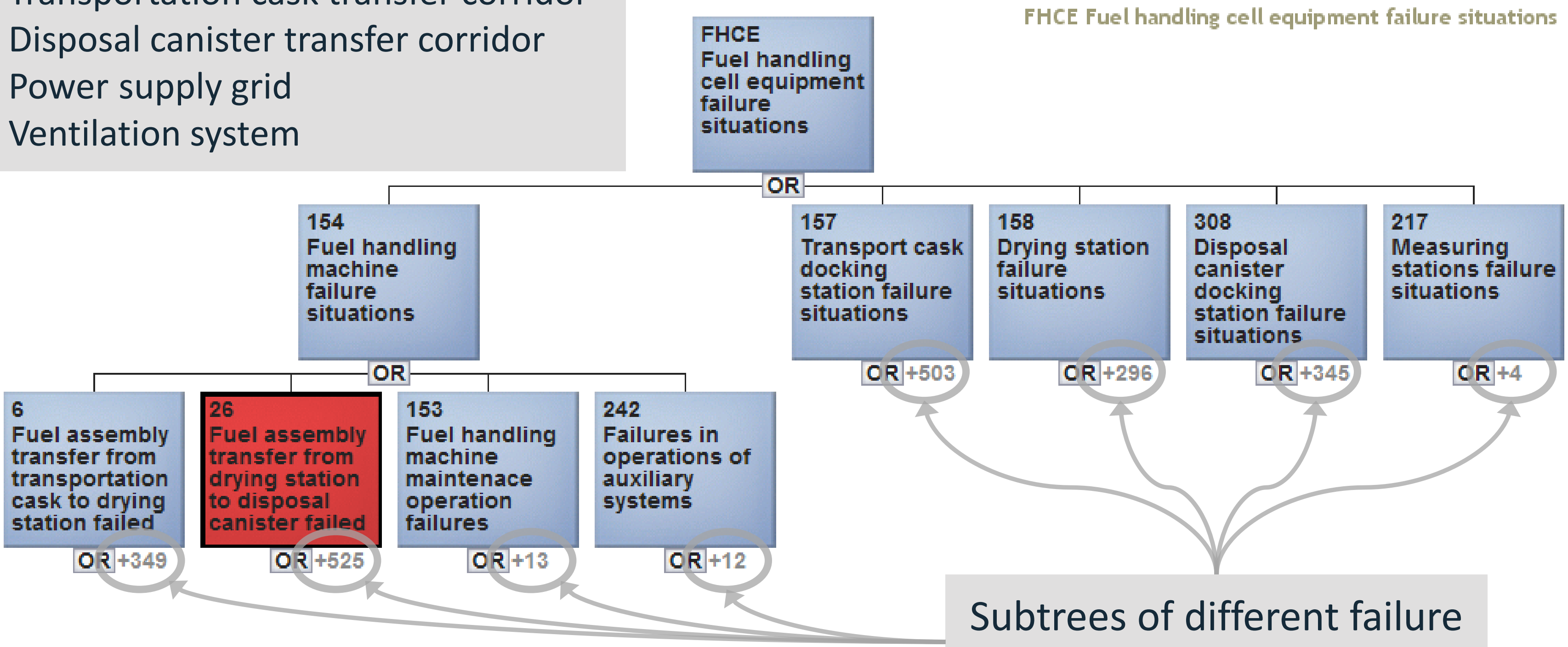
Full video: https://youtu.be/hZI3AYI85n8

Case A) – Final Disposal Facility (FDF):
Fuel Handling Cell Equipment Example (2/5)

Similar availability models also for:

- Receiving and storage are
- Transportation cask transfer corridor
- Disposal canister transfer corridor
- Power supply grid
- Ventilation system

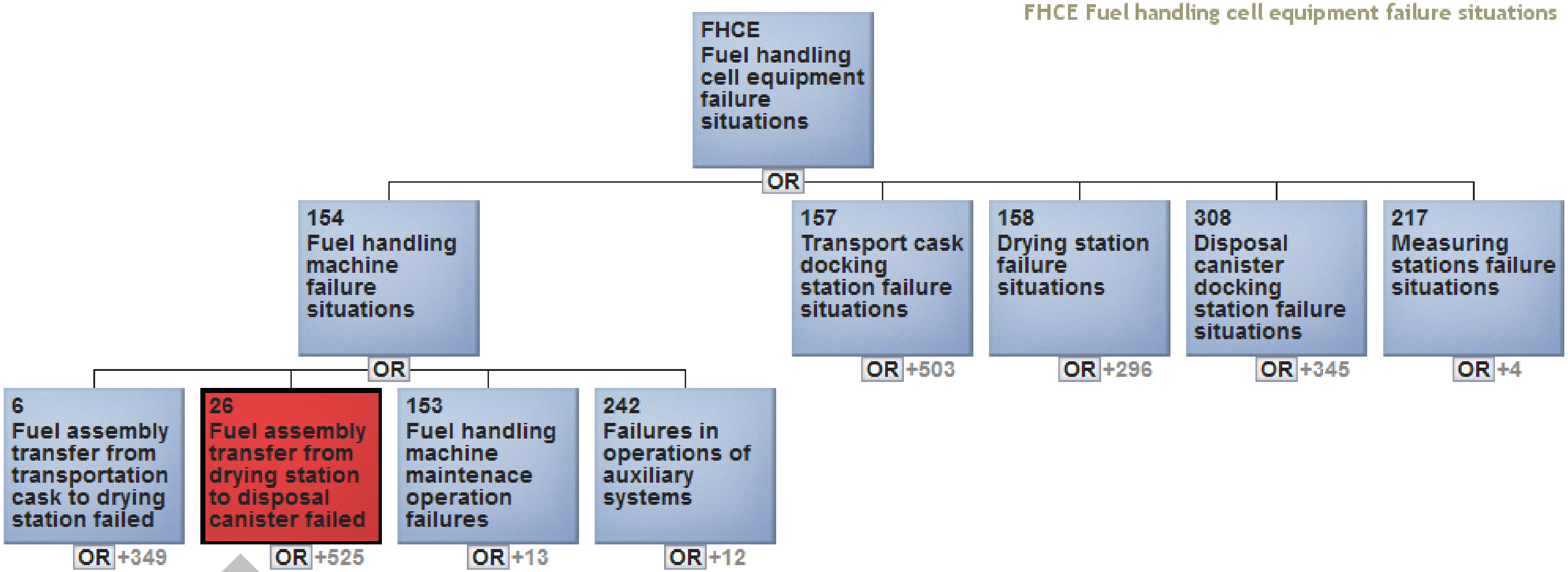
Small part of the full FDF availability model



Subtrees of different failure situations are hidden

Case A) – Final Disposal Facility (FDF):

Fuel Handling Cell Equipment Example (3/5)



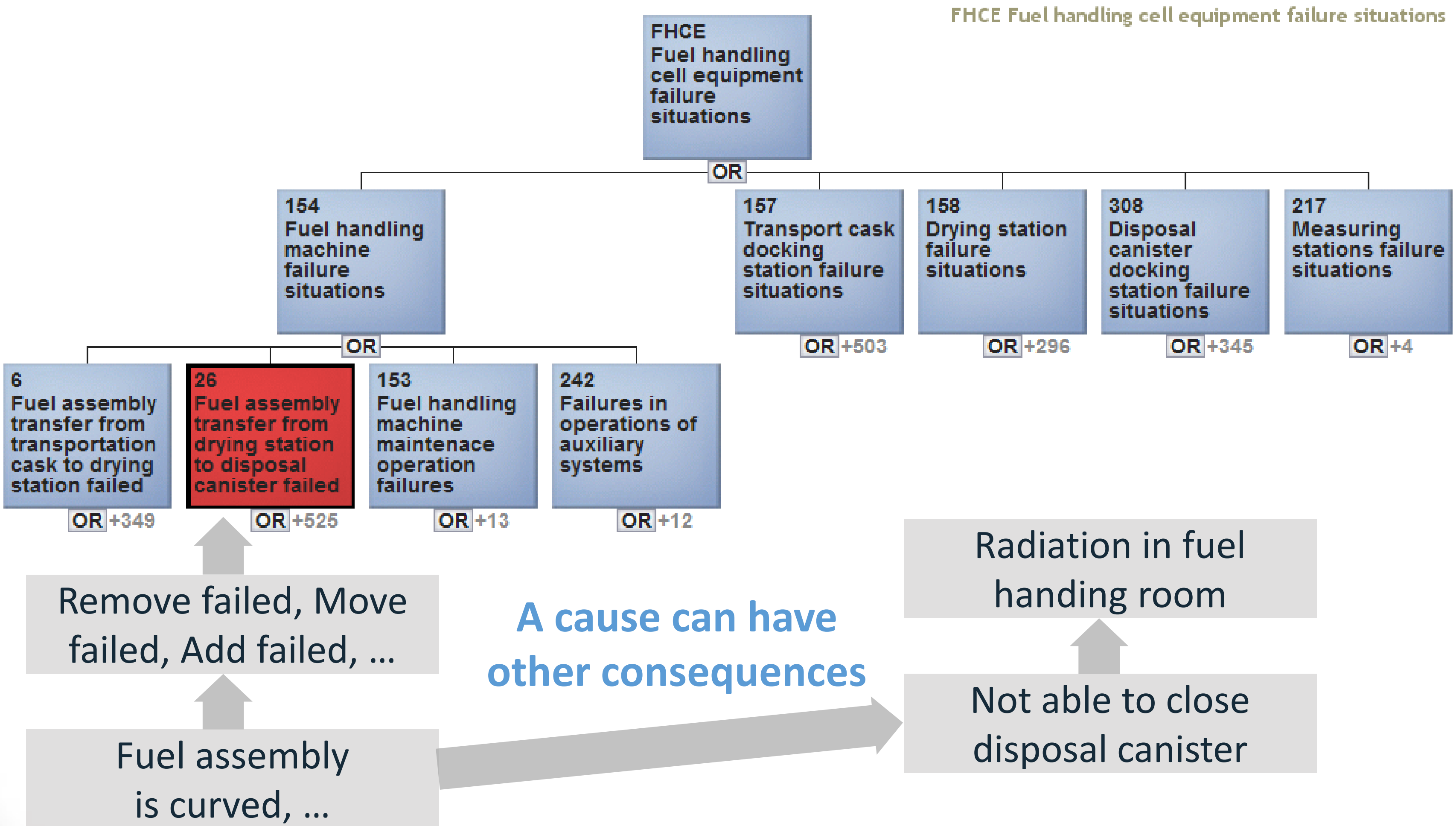
Remove failed, Move failed, Add failed, …

Fuel assembly is curved, …

More detailed causes for availability risk

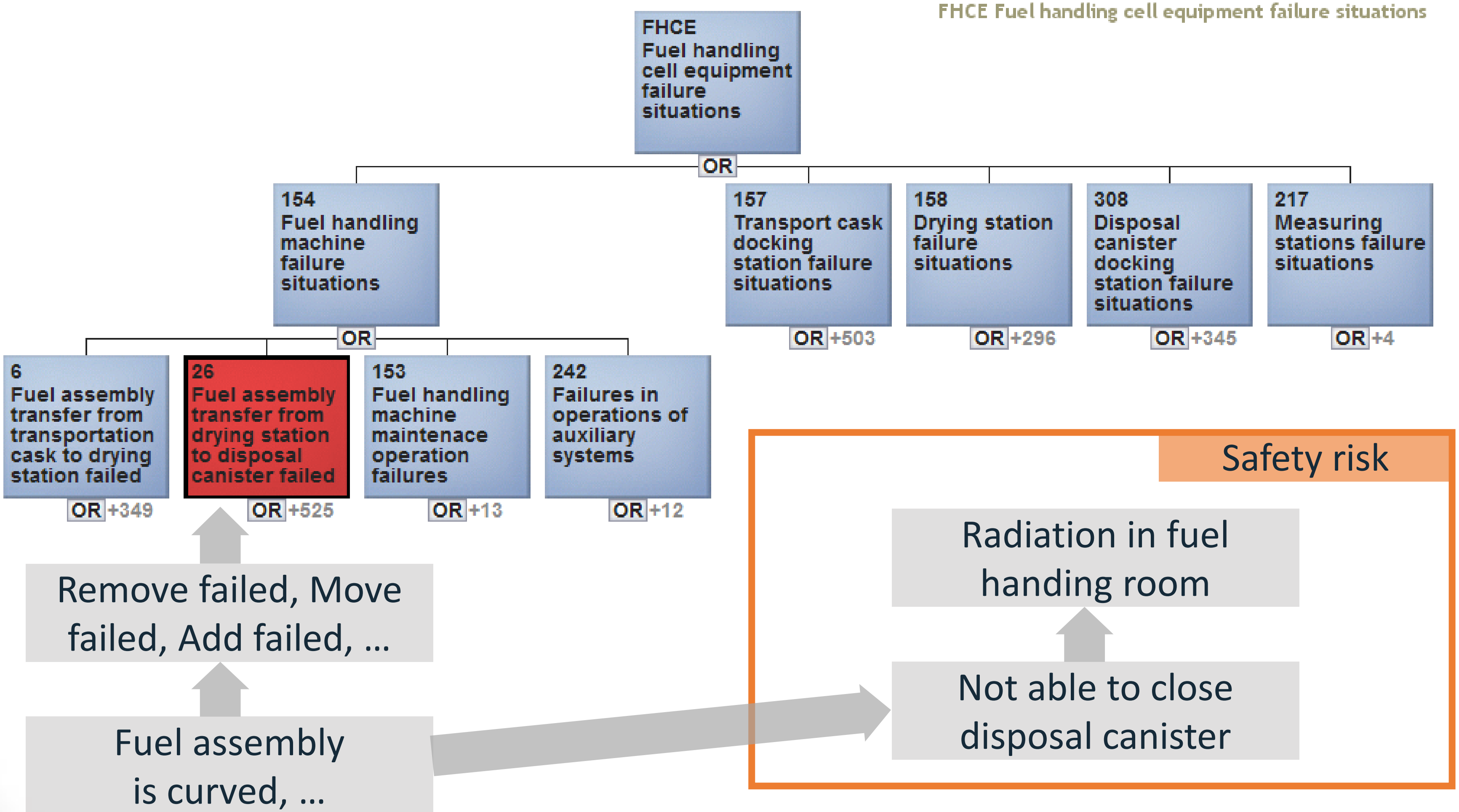
Case A) – Final Disposal Facility (FDF):

Fuel Handling Cell Equipment Example (4/5)



Case A) – Final Disposal Facility (FDF):

Fuel Handling Cell Equipment Example (5/5)



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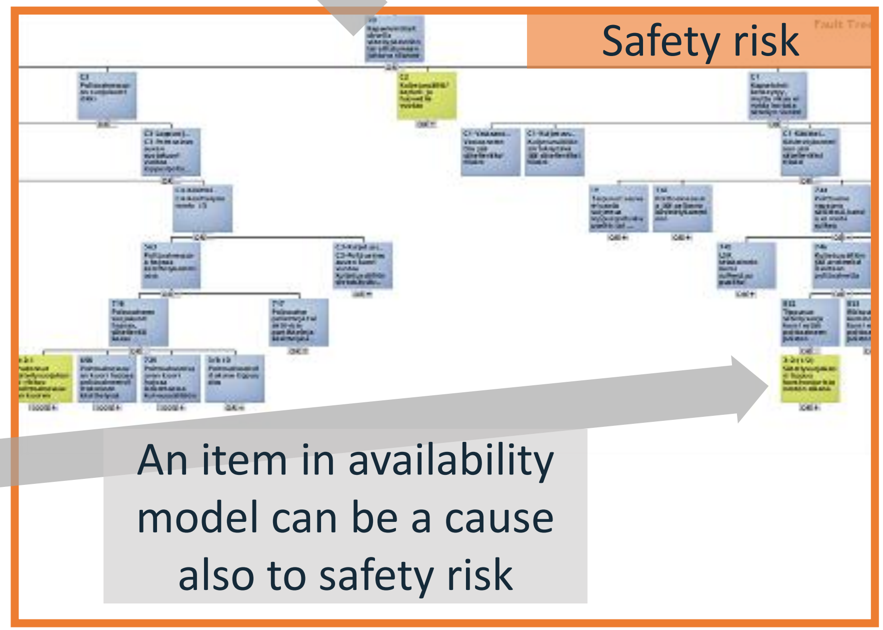
Case A) – Final Disposal Facility (FDF):

Combined Risk Model – Availability/Safety

All items and their causalities related to availability and safety risks are collected to a comprehensive model:
Availability and Radiation Safety of Encapsulation Plant



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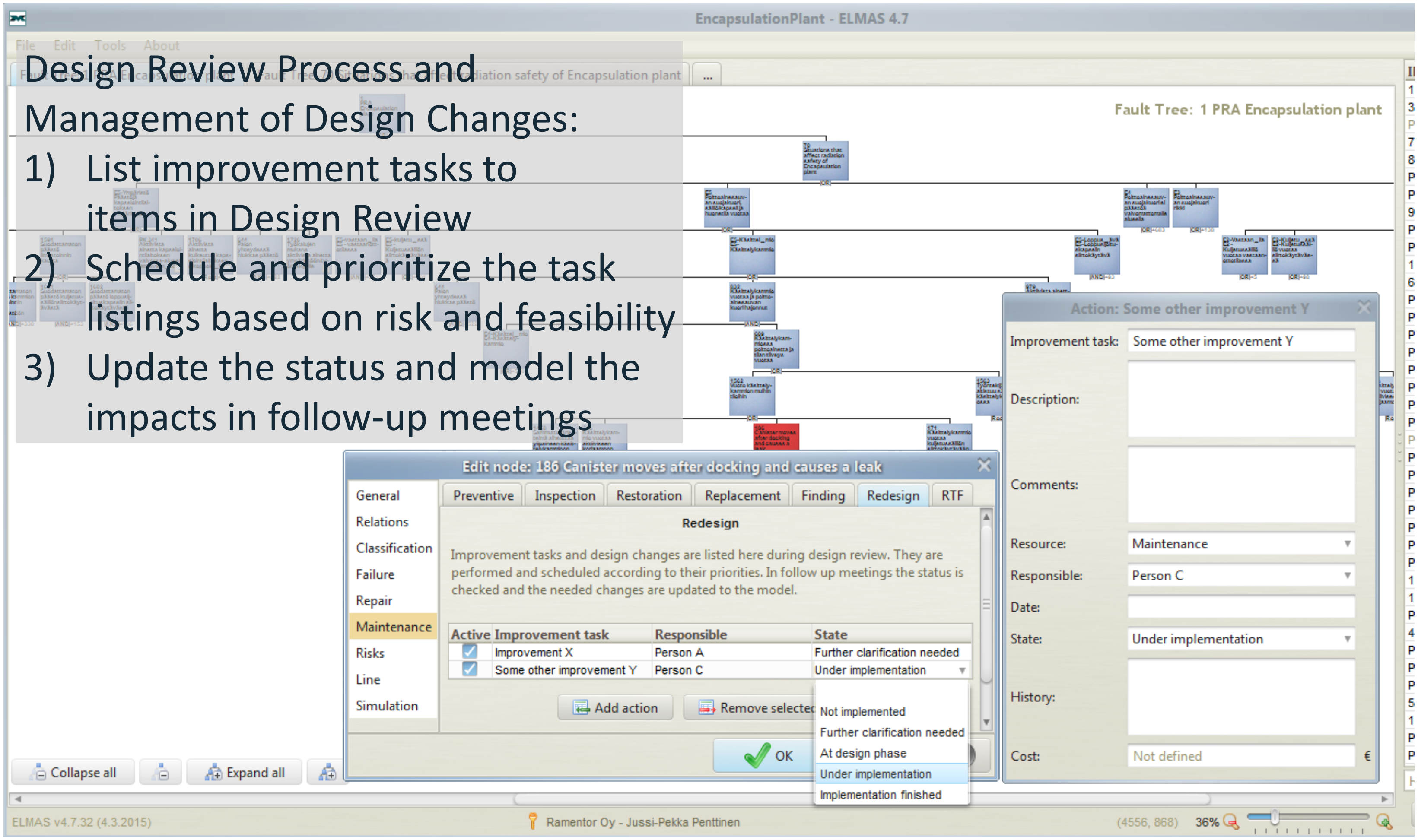
Case A) – Final Disposal Facility (FDF):

Design Review / Change Management

Design Review Process and Management of Design Changes:

1) List improvement tasks to items in Design Review
2) Schedule and prioritize the task listings based on risk and feasibility
3) Update the status and model the impacts in follow-up meetings



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Case A) – Final Disposal Facility (FDF):

Key Findings and Improvements

- Comprehensive availability and safety model created
- Several changes were made based on design reviews
  - Improved identification of unexpected impacts of the design changes on all related systems and to risks
  - Early stage identification of the problem areas became possible
- STUK statement 12/02/2015 (construction license):
  - Nuclear waste facility can be built to be safe
- Failure tolerance analysis can utilize the created models
  - Required for STUK later (operating license)
  - Common cause failures, Defense in depth levels, …

Case B) – Life Cycle Profit Management (LCPM)

- Aims to **maximize the life cycle profit of an investment**
- Guides development work and investment decisions to **focus on overall costs** (not just investment costs)
  - All relevant cost factors from specification to decommission
- Emphasizes to take unavailability into consideration
  - Production loss
  - Break costs
  - Overtime work costs

Case B) – Life Cycle Profit Management (LCPM):

Molding Crane

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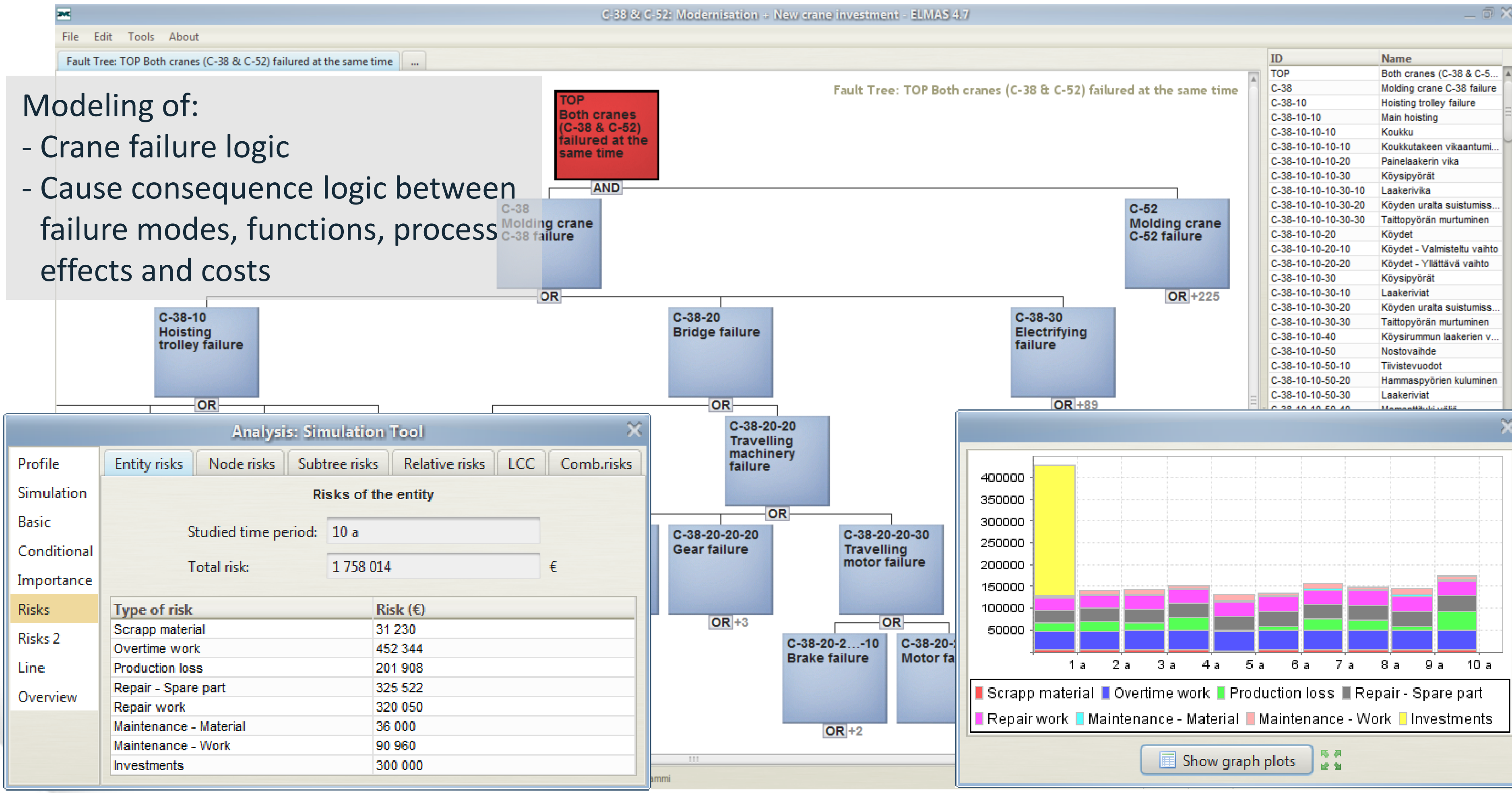
Case B) – Life Cycle Profit Management (LCPM):
Molding Cranes Case Description

- Scenario analysis of two process critical molding cranes
  - Work rhythm 3 shifts/day and 5 days/week
  - One crane can handle 75% of the process flow
  - Overtime works can be used at weekends if necessary
- Comparison of 3 scenarios:
  1. Current situation
  2. Modernization of auxiliary hoisting & corrective action planning based on improvements potentials
  3. Modernization of auxiliary hoisting & renewal of older crane

Case B) – Life Cycle Profit Management (LCPM):
Modeling, Simulation and Analysis

Figures are fictional

Modeling of:
- Crane failure logic
- Cause consequence logic between failure modes, functions, process effects and costs



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Case B) – Life Cycle Profit Management (LCPM):
Comparison of Scenarios

Figures are fictional

C-38 & C-52 Scenario analysis (10 a)	Scenario 1: Current situation	Scenario 2: C-38 modernisation & C-52 corrective actions	Change	Scenario 3: C-38 modernisation & C-52 renewal	Change
C-38 & C-52 failures	27.6	20.0	27.5 %	16.8	39.1 %
C-38 & C-52 failure time	4 d 16 h	3 d 14 h	1 d 2 h	3d 5h	1 d 11 h
C-38 & C-52 unplanned unavailabilit	~ 0.128 %	~ 0.098 %	23.4 %	~ 0.088 %	31.3 %
C-38 failures	375.3	305.9	18.5 %	306.3	18.4 %
C-38 failure time	97 d 23 h	75 d 4 h	22 d 19 h	75 d 3 h	22 d 21 h
C-38 unplanned unavailability	~ 2.68 %	~ 2.06 %	23.1 %	~ 2.04 %	23.9 %
C-52 failures	365.7	359.0	1.8 %	226.6	38.0 %
C-52 failure time	115 d	91 d 4 h	23 d 20 h	58 d 23 h	12d 12h
C-52 unplanned unavailability	~ 3.15 %	~ 2.50 %	20.6 %	~ 1.54 %	51.1 %
Costs					
Scrapp material	45 870	33 510	26.9 %	25 590	44.2 %
Overtime work	636 214	496 953	21.9 %	390 539	38.6 %
Production loss	199 243	150 539	24.4 %	112 872	43.3 %
Repair - Spare part	411 001	368 415	10.4 %	282 830	31.2 %
Repair - Work	375 465	358 243	4.6 %	275 880	26.5 %
Maintenance - Material	36 600	36 600	0.0 %	36 000	1.6 %
Maintenance - Work	94 320	94 320	0.0 %	90 960	3.6 %
Replacement costs	0	8 081		0	
Unavailability costs	1 798 713	1 546 661	14.0 %	1 214 671	32.5 %
Investment costs	0	60 000		300 000	
Overall costs	**1 798 713**	**1 606 661**	10.7 %	**1 514 671**	15.8 %

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Case B) – Life Cycle Profit Management (LCPM):
Comparison of Scenarios

Figures are fictional

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Scrapp material	45 870	33 510	[illegible] %	[illegible]	[illegible] %
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Investment costs	0	60 000		300 000	
Overall costs	**1 798 713**	**1 606 661**	10.7 %	**1 514 671**	15.8 %

Scenario 3 has the largest investment costs but the lowest overall costs due to residual unavailability

Case B) – Life Cycle Profit Management (LCPM):

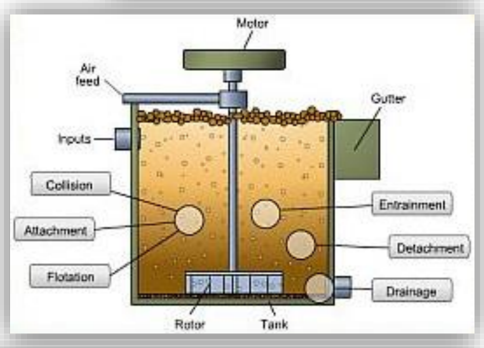
Key Findings and Improvements

Figures are fictional

- Based on LCPM analysis, scenario 3, modernisation of auxiliary hoisting & renewal of older crane, improves the life cycle profit:
  - **Production loss reduced ~43 %**
  - **Overtime work costs reduced ~39 %**
  - **Simultaneous failures reduced ~39 %** and unavailability ~31 %
  - Total cost risk (including investments) reduced by ~16 % and 280 000 € during the 10 years period
  - Investment payback time ~5 years

Case C) – Mineral Processing Line

- Flotation process
  - Six processing tanks
  - Installed in series
  - Forming three tank pair units
- Goal of process
  - Recover metal particles from the slurry flowing through the tanks
  - with the help of rising air bubbles from the bottom of the processing tank



Case C) – Mineral Processing Line (MPL):

Case Description

- The main goals of the project were:
  1) **Determine the availability and OEE** of the analyzed process line
  2) **Locate critical failure modes** for the line operation
  3) **Create methods for increasing the OEE value** of the process
- Project team (Experts from Ramentor and client) created a model
  - All mechanical and automation components included
  - Components of processing tanks and supporting systems included
  - Also process and user-related faults included
- Overall equipment effectiveness (OEE)
  - In addition to availability also performance (and quality) included

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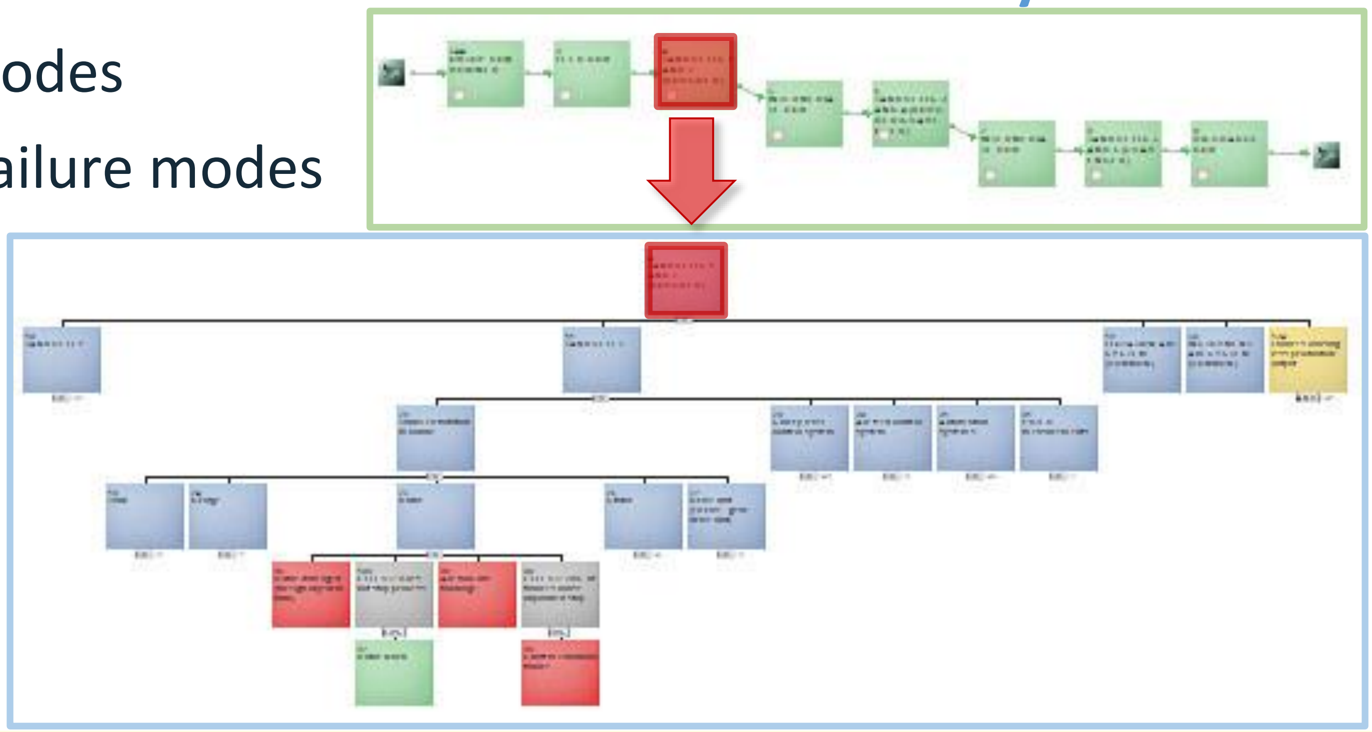
Case C) – Mineral Processing Line (MPL):
ELMAS Project Model

- The **flow characteristics** model of the flotation process was combined with extensive **fault tree analytics**
- 600 nodes
- 200 failure modes



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Case C) – Mineral Processing Line (MPL):

Key Findings

1) The failure events slowing down the production had a major effect on the line OEE value (High availability, Low OEE)
   - Failures stopping the production caused **30%** of the total loss
   - Failures slowing down the process **70%** of the total loss

➡ **Focus on the situations slowing down the process**

2) About **10%** of the failure modes caused over **83%** of the total lost production

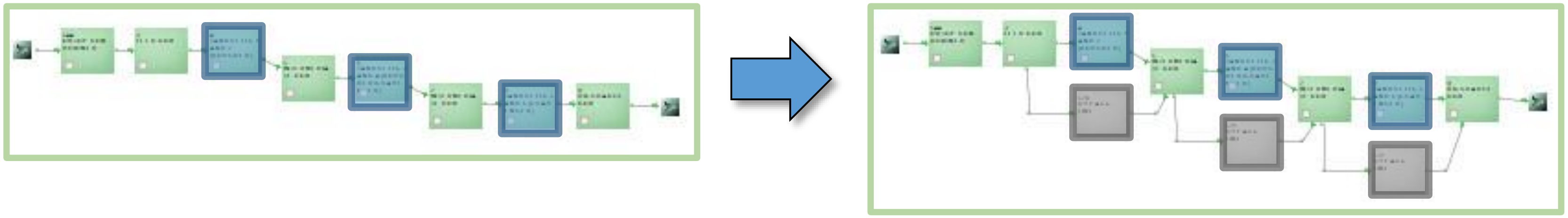
➡ **Focus on the highest imact failure modes**

Case C) – Mineral Processing Line (MPL):

Improvement – Maintenance bypass lines

- The effect of maintenance bypass lines installation shown
  - Direct the process flow around when a tank pair on repair
  - Only minor slowing down for the process during bypass

Tank pairs   Maintenance bypass lines



- MPL manufacturer can justify the investment to customer
  - Lost production decreases by millions of euros during 10 years
  - The installation is quite inexpensive -> Very good investment!

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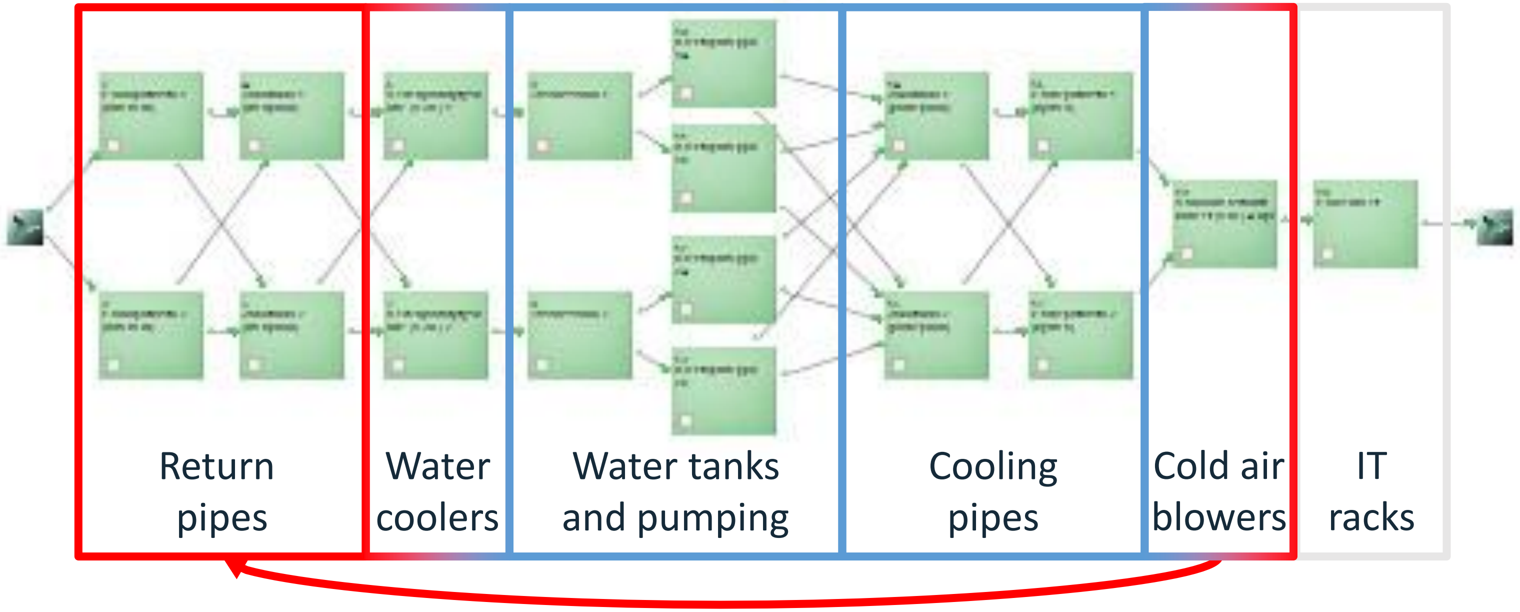
Case D) – Infrastructure Availability:

Design-Phase Data Center

- Availability study of a Data Center infrastructure
  - Including: Cooling system, Power input for the cooling, IT racks



+ Power input system (National grid inputs, Internal grid, UPS) for equipment and IT racks

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Case D) – Infrastructure Availability:
Case Description

- The main goals of the project were:
    1) Calculate the infrastructure availability
    2) Modifying the design structure to meet the highest Tier level 4 i.e. 99.995% availability (standard TIA-942)

Tier Level	Requirements
1	• Single non-redundant distribution path serving the IT equipment • Non-redundant capacity components • Basic site infrastructure with expected availability of 99.671%
2	• Meets or exceeds all Tier 1 requirements • Redundant site infrastructure capacity components with expected availability of 99.741%
3	• Meets or exceeds all Tier 1 and Tier 2 requirements • Multiple independent distribution paths serving the IT equipment • All IT equipment must be dual-powered and fully compatible with the topology of a site's architecture • Concurrently maintainable site infrastructure with expected availability of 99.982%
4	• Meets or exceeds all Tier 1, Tier 2 and Tier 3 requirements • All cooling equipment is independently dual-powered, including chillers and heating, ventilating and air-conditioning (HVAC) systems • Fault-tolerant site infrastructure with electrical power storage and distribution facilities with expected availability of 99.995%

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Case D) – Infrastructure Availability:

Key Findings

1) The availability of the original design was at Tier level 3
   - The required highest Tier level 4 was not met
2) 8 hand valves were the source of highest availability risk
   - Minimum cooling power for operation is 75%
   - Repair of any of these 8 critical hand valves causes drop to 50% cooling power
3) The power input line was extremely reliable even without the backup generator
   - Discussions started considering the need of a backup generator

Case D) – Infrastructure Availability:

Improvement – Eight new hand valves

- Effect of installing eight new hand valves shown
  - Now also the original eight critical hand valves can be isolated
  - Possible to repair/change any valve on the cooling line without lowering the cooling power below the required 75%
- Tier level 4 was met

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Case E) – Nuclear Power Plant (NPP):

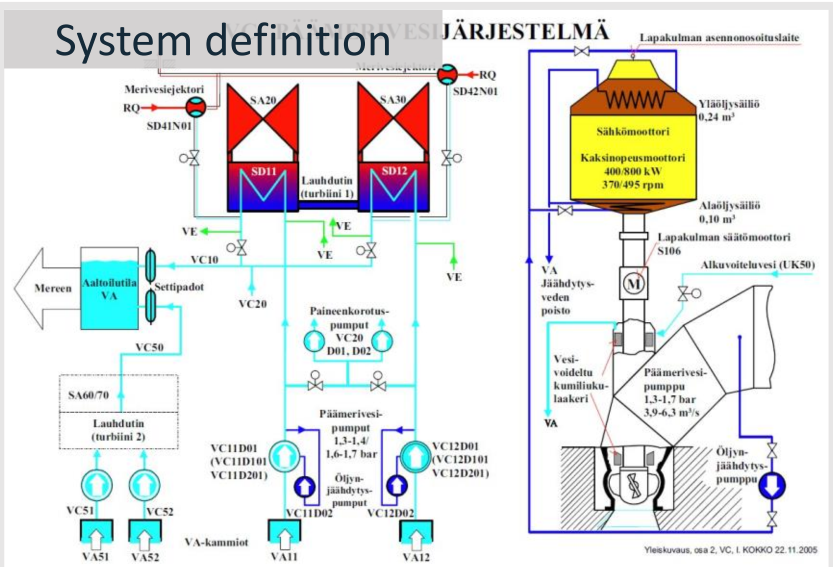
Project Scope

- RCM analysis of Main Cooling Water Pumping System
  1) Main function: Cooling of turbine condensers
  2) Secondary function: Cooling of auxiliary systems of secondary cooling circuit
- The Main Cooling Water Pumping System Includes:
  1) Sea water input, output and filtering system
  2) Main sea water system (pumps, motors, tubes, sea water ejectors etc.)
  3) Initial lubrication water system
  4) Cleaning system of condenser tubes

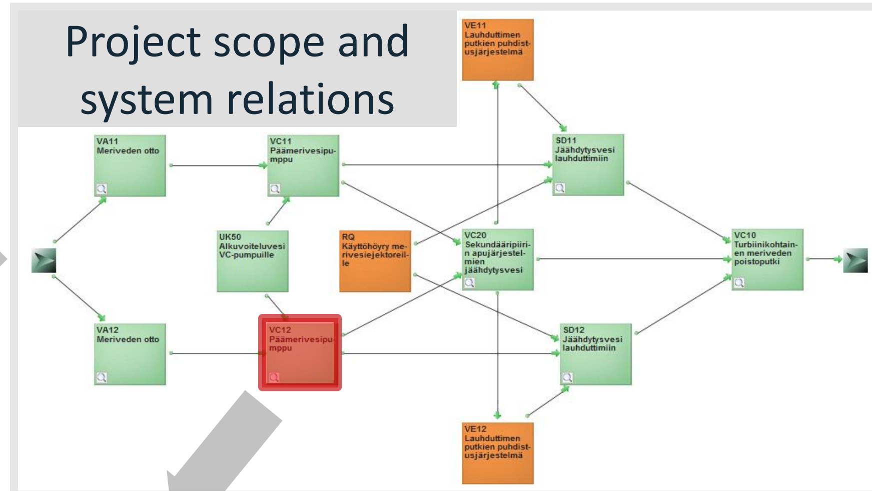
Case E) – Nuclear Power Plant (NPP):

ELMAS Project Model

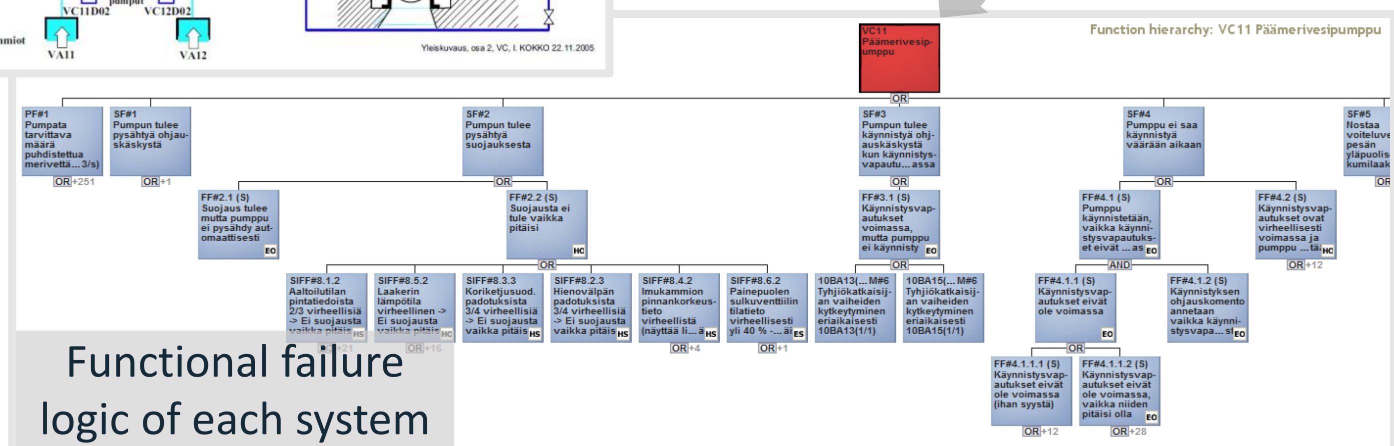
System definition



Project scope and system relations



Functional failure logic of each system



Case E) – Nuclear Power Plant (NPP):
Customer Demands

1. RCM analysis must include
   - All functions and functional failures
   - Safety, reliability, availability and maintainability aspect
   - All necessary cost types for comprehensive risk analysis
   - Maintenance action planning and optimization for critical equipment
2. RCM/ELMAS methodology training during the project

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Case E) – Nuclear Power Plant (NPP):

Key Findings & Value Added

- **Reduced** preventive **maintenance costs** by ~20%
- **Reduced overall cost risks** by ~10%
- Advanced criticality classification for equipment
- **List of critical spare parts**
  - Recommendations for spare part policy
- Motivation for improvements in use of operative IT-systems
- Scenarios for risks & equipment life cycle management

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Summary – Applied ELMAS Features

- Cause-consequence relations model applied in each case
  - Fault tree applied in each case (Logic and stochastic relations)
  - Block diagram applied in two cases (Production flow)
  - Fuzzy relation in one case (75% operation with one crane)
  - Dynamic relations applied in one case (Change logic of backup)
- Failure and repair time definition for items in each case
  - Cumulative distribution function (parameter estimation / history data)
- Stochastic discrete event simulation made in each case
  - Different analysis results (risks, availability, …) and reports
- Management of improvement tasks of items in one case
  - List tasks -> Prioritize and schedule -> Update model

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Risk management, Risk assessment, Dependability – Standards and Theory

ISO GUIDE 73:2009 (1/2)

Risk management. Vocabulary

- **Risk**:
  - Effect of uncertainty on objectives
  - Objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process).
- **Risk management**:
  - Coordinated activities to direct and control an organization with regard to **risk**

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ISO GUIDE 73:2009 (2/2)

Risk management. Vocabulary

- **Risk assessment**:
  - Overall process of **risk identification**, **risk analysis** and **risk evaluation**

- **Risk identification**: Process of finding, recognizing and describing **risks**
- **Risk analysis**: Process to comprehend the nature of **risk** and to determine the **level of risk**
- **Risk evaluation**: Process of comparing the results of **risk analysis,** with **risk criteria** to determine whether the **risk** and/or its magnitude is acceptable or tolerable

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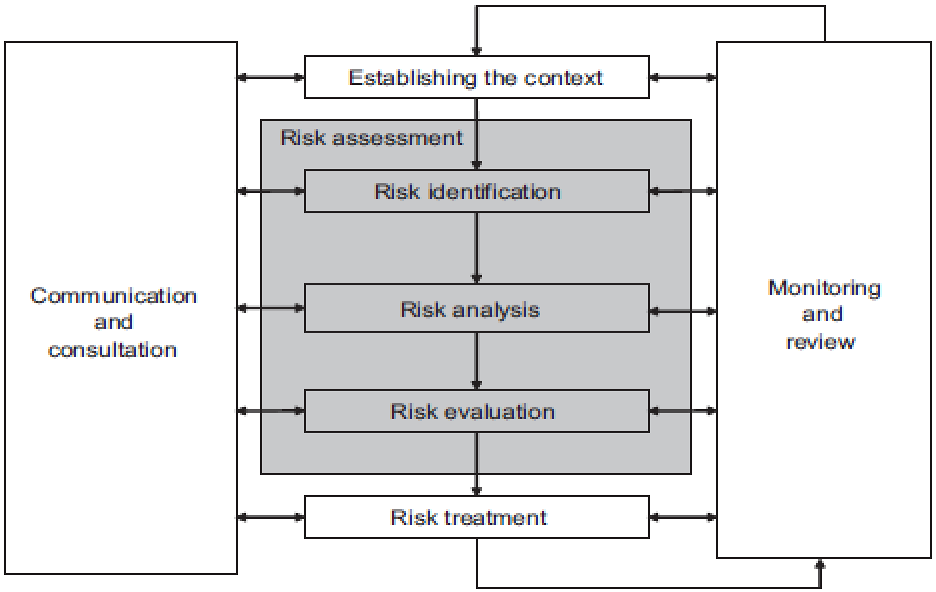
EN 31010:2010

Risk management. Risk assessment techniques

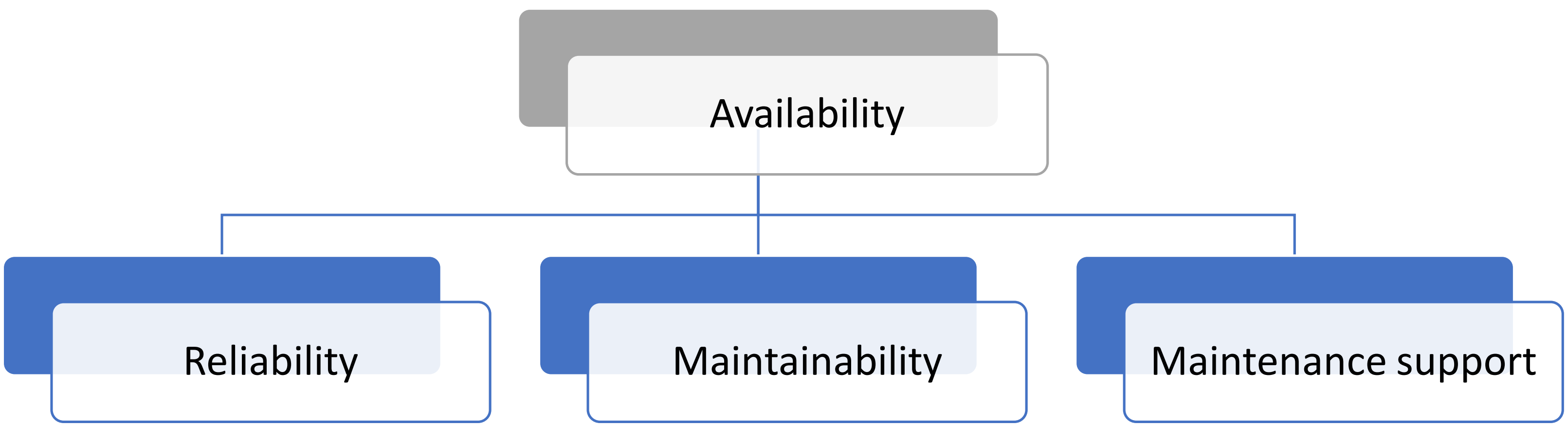


Contribution of risk assessment to the risk management process

IEC 50(191):1990

Electrotechnical vocabulary. Dependability and quality of service

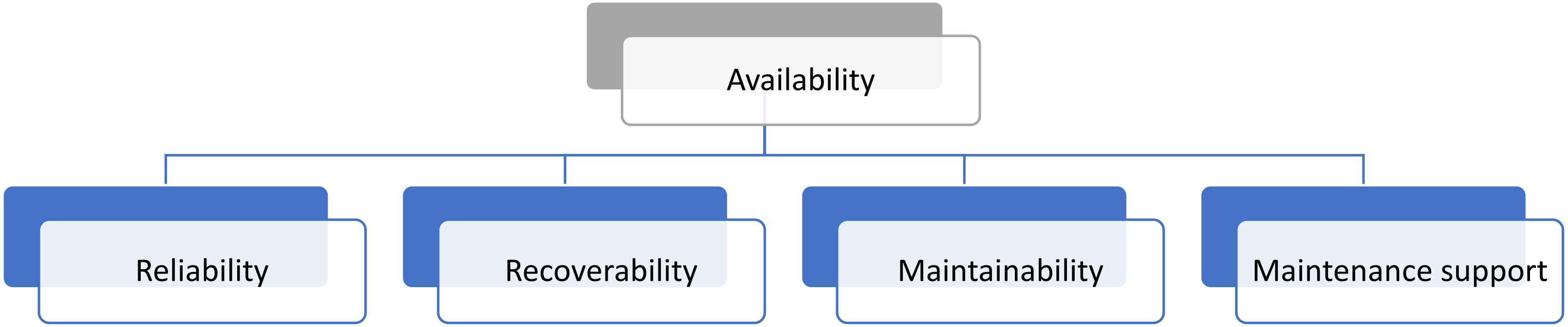
- **Dependability**:
  - The collective term used to describe the **availability** performance and its influencing factors: **reliability** performance, **maintainability** performance and **maintenance support** performance.



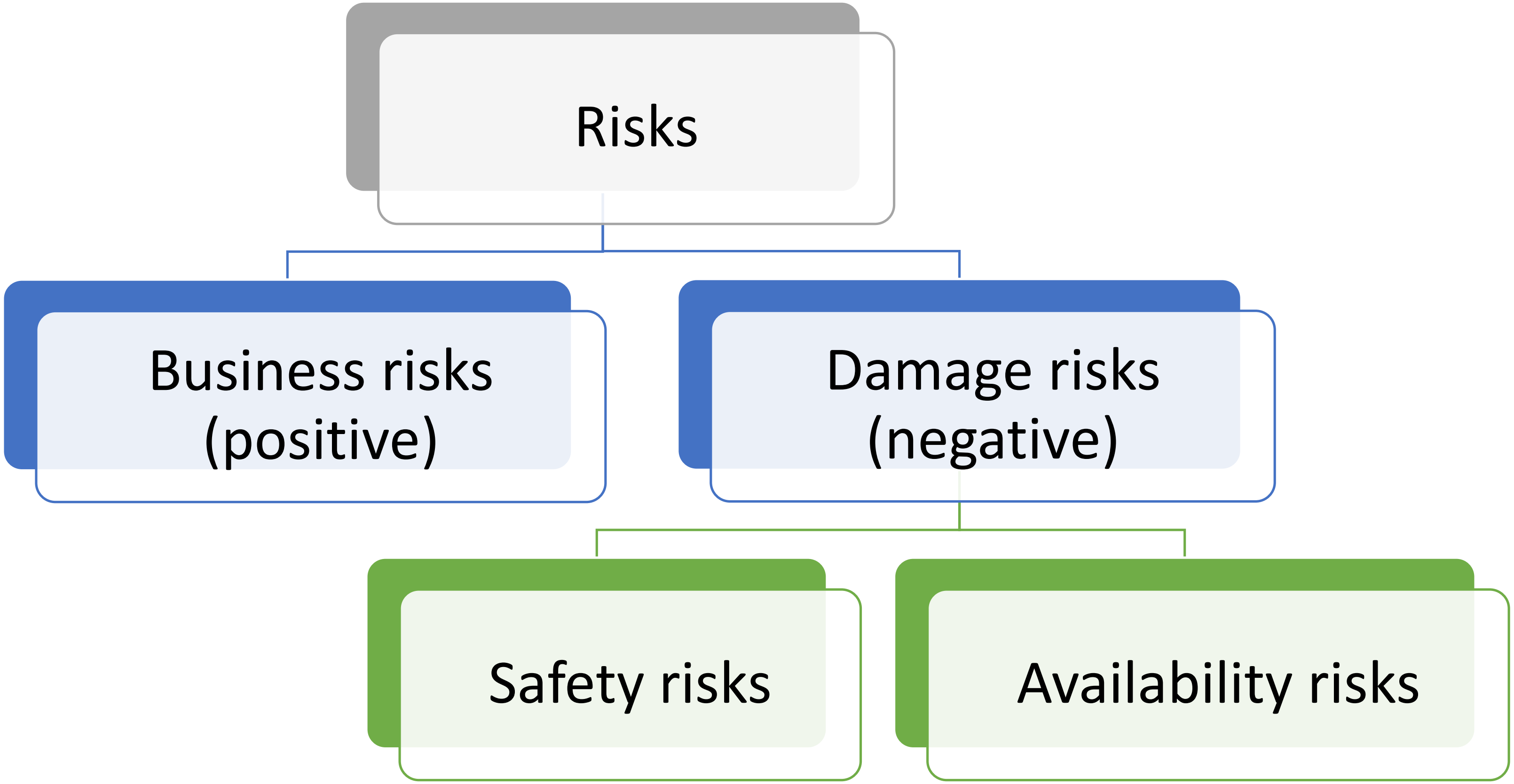
EN 13306:2010

Maintenance. Maintenance terminology

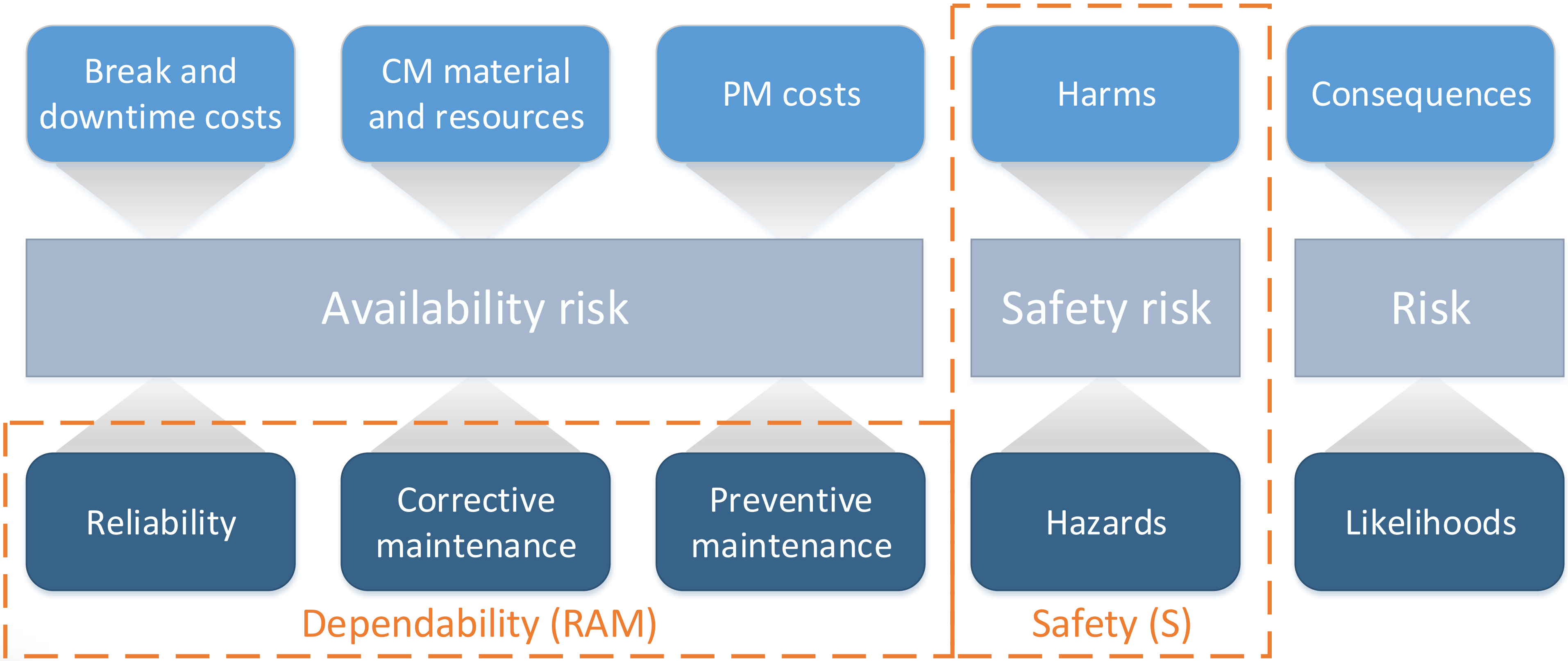
- **Dependability**:
  - Ability to perform as and when required
  - Dependability characteristics include availability and its influencing factors (reliability, recoverability, maintainability, maintenance support performance) and, in some cases, durability, economics, integrity, safety, security and conditions of use.



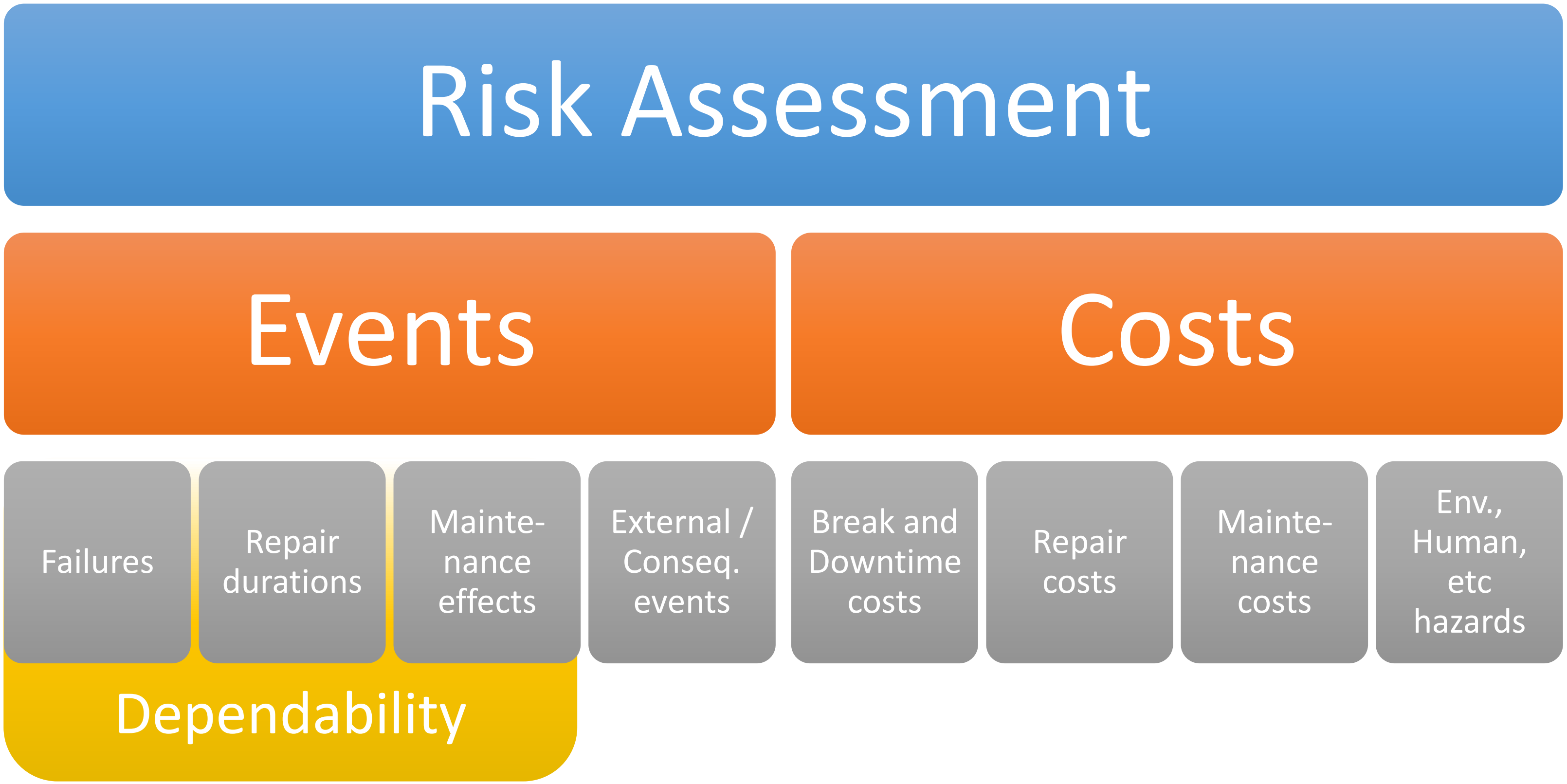
Risks – 1/2


Risks
Business risks (positive)
Damage risks (negative)
Safety risks
Availability risks

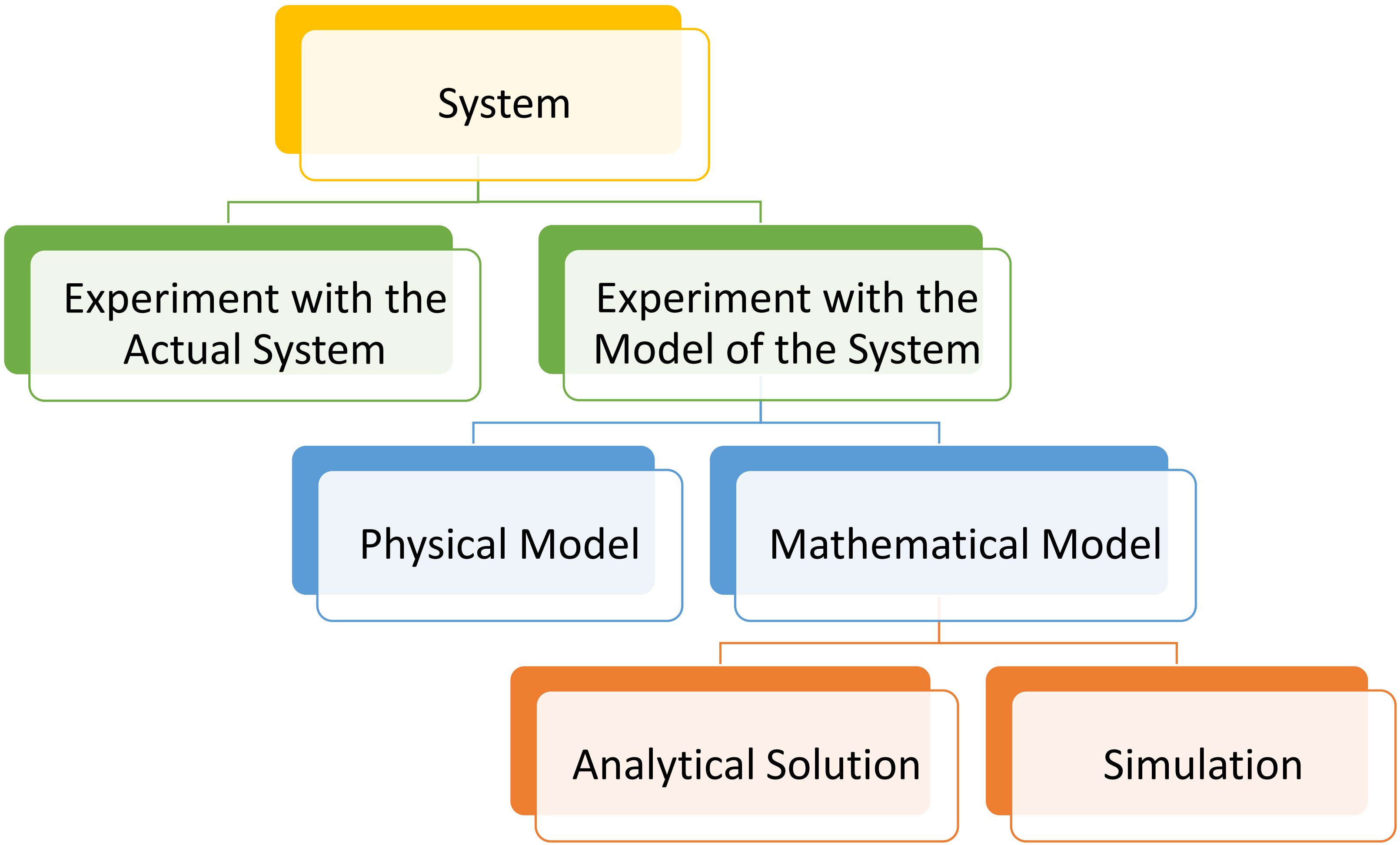
Risks – 2/2


Break and downtime costs
CM material and resources
PM costs
Harms
Consequences
Availability risk
Safety risk
Risk
Reliability
Corrective maintenance
Preventive maintenance
Hazards
Likelihoods
Dependability (RAM)
Safety (S)

Risk Assessment and Dependability



Ways to Study a System



Methods: Tools and Techniques

– EN 31010:2010 Risk management. Risk assessment techniques

Qualitative tools and techniques

- Failure modes and effects analysis (FMEA)
  - Identify the ways in which components, systems or processes can fail to fulfil their design intent. Identifies all potential failure modes of the various parts of a system, the effects these failures may have on the system, the mechanisms of failure and how to avoid the failures, and/or mitigate the effects of the failures on the system.
- Reliability centered maintenance (RCM)
  - Identify the policies that should be implemented to manage failures so as to efficiently and effectively achieve the required safety, availability and economy of operation for all types of equipment.
- Root cause analysis (RCA), 5 times “Why?”
  - Identify the root or original causes instead of dealing only with the immediately obvious symptoms.
- Hazard and operability studies (HAZOP)
  - Identify risks to people, equipment, environment and/or organizational objectives.
- Check-lists
  - Lists of hazards, risks or control failures that have been developed usually from experience, either as a result of a previous risk assessment or as a result of past failures.

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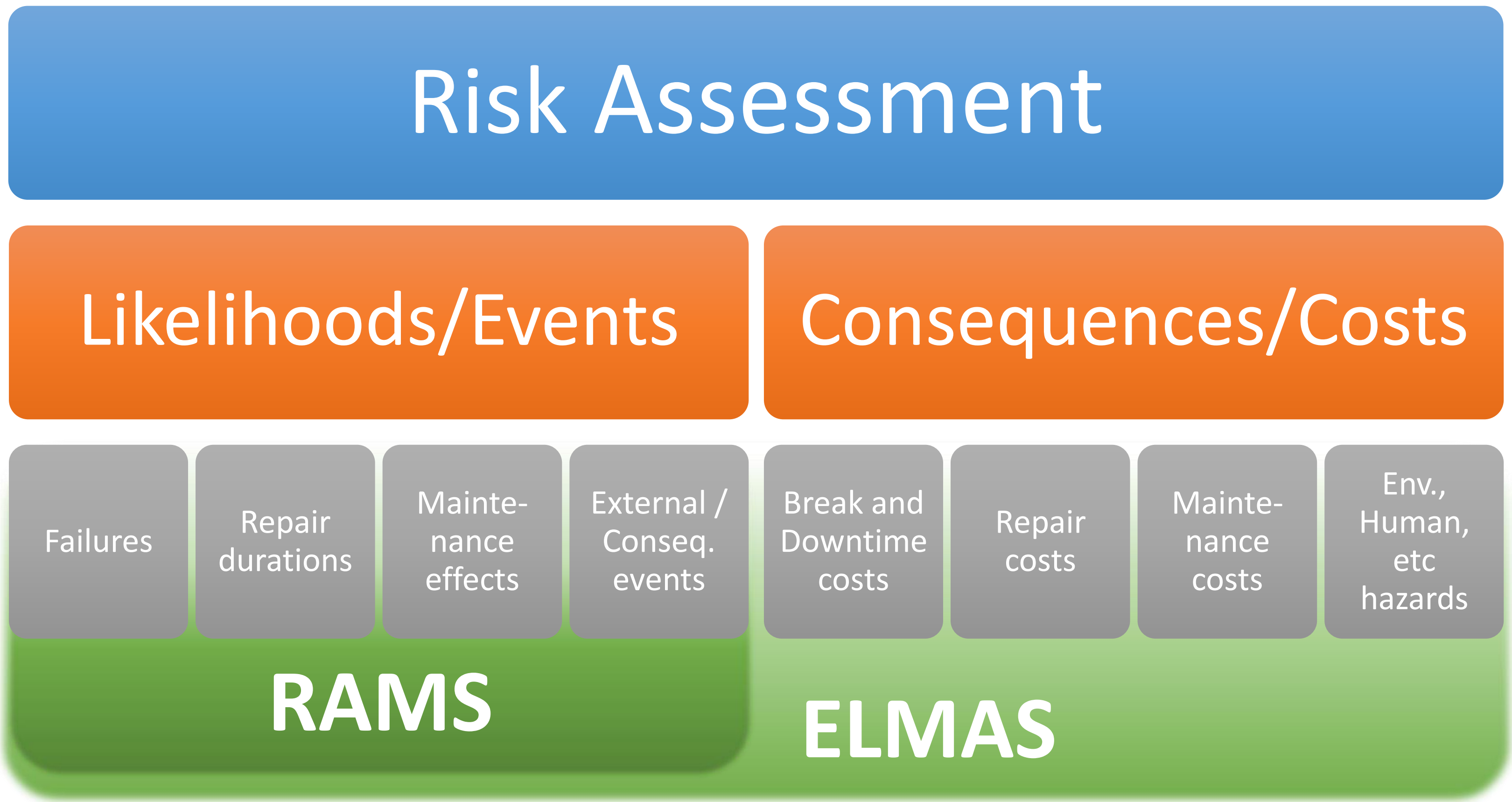
Quantitative tools and techniques

- Fault tree analysis (FTA)
  - A technique which starts with the undesired event (top event) and determines all the ways in which it could occur. These are displayed graphically in a logical tree diagram. Once the fault tree has been developed, consideration should be given to ways of reducing or eliminating potential causes/sources.
- Event tree analysis (ETA)
  - Using inductive reasoning to translate probabilities of different initiating events into possible outcomes.
- Monte Carlo simulation
  - For systems that are too complex for the effects of uncertainty on them to be modelled using analytical techniques
- Cause and consequence analysis
  - A combination of fault and event tree analysis that allows inclusion of time delays. Both causes and consequences of an initiating event are considered.
- Failure modes and effects and criticality analysis (FMECA)
  - FMECA extends an FMEA so that each fault mode identified is ranked according to its importance or criticality.

Event Logic Modelling and Analysis Software

– ELMAS Overview

ELMAS – Risk Assessment and RAMS



ELMAS

Event

- Time to Failure, Distribution
- Time to Repair, Distribution
- Maintenance actions
- Break and downtime loss
- Repair Costs
- Hazards
- Usage and stress profile
- External events

Logic

- OR
- AND
- K/N-Voting
- XOR-Exclusive
- Limits
- Conditional probability
- Delays
- Throughput, fuzzy logic
- Dynamic coding

Modeling

- Fault tree
- Event tree
- Cause-consequence-tree
- Reliability block diagram
- Process diagram
- Waiting and redundancy
- Buffers
- Failure modes, RCA

Analysis

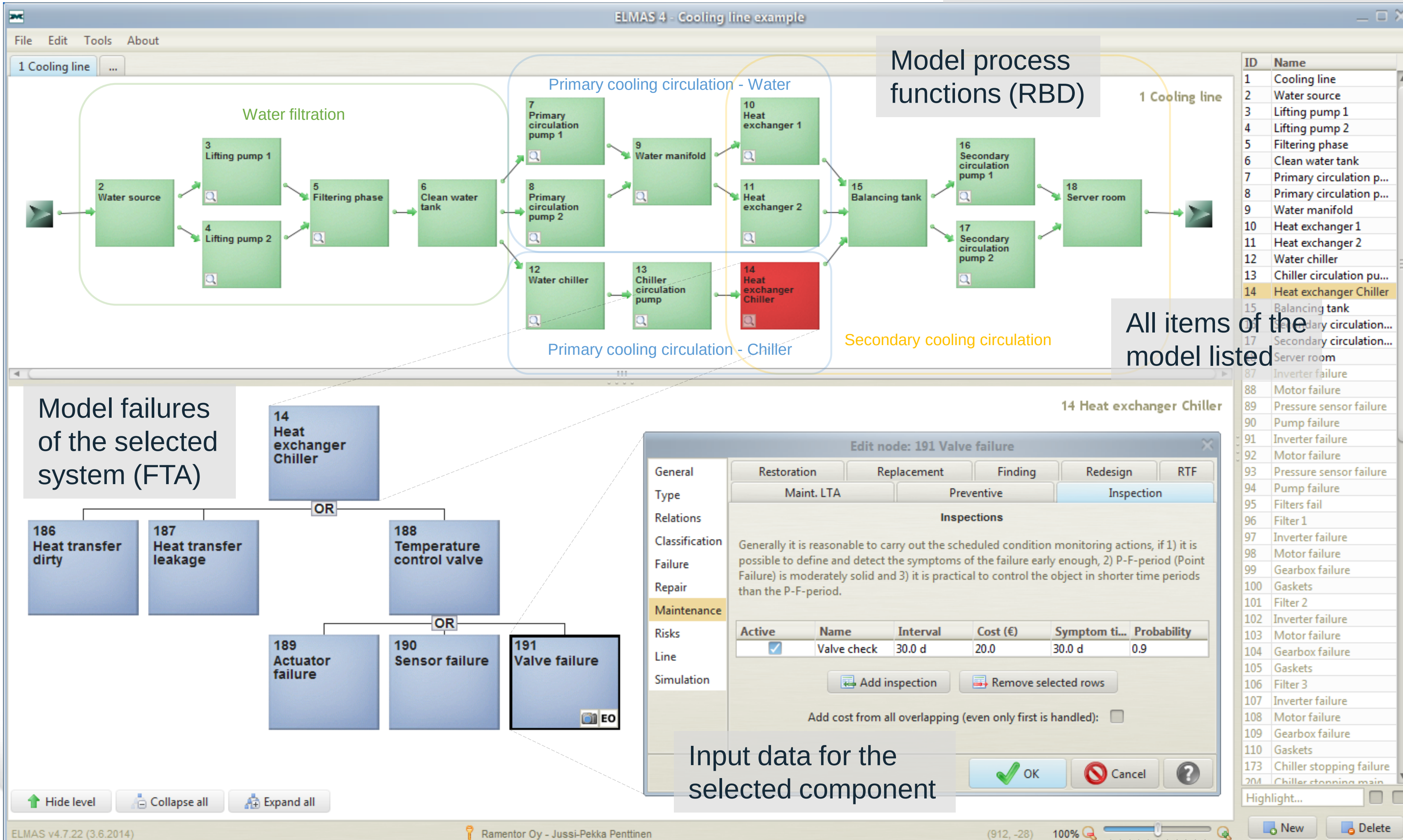
- Simulation
- Reliability, Availability
- Risk Analysis
- Importance measures
- Conditional probabilities
- Spare part consumption
- Resources
- FMEA, Classification, RCM, Decision tree, Criticality

Software

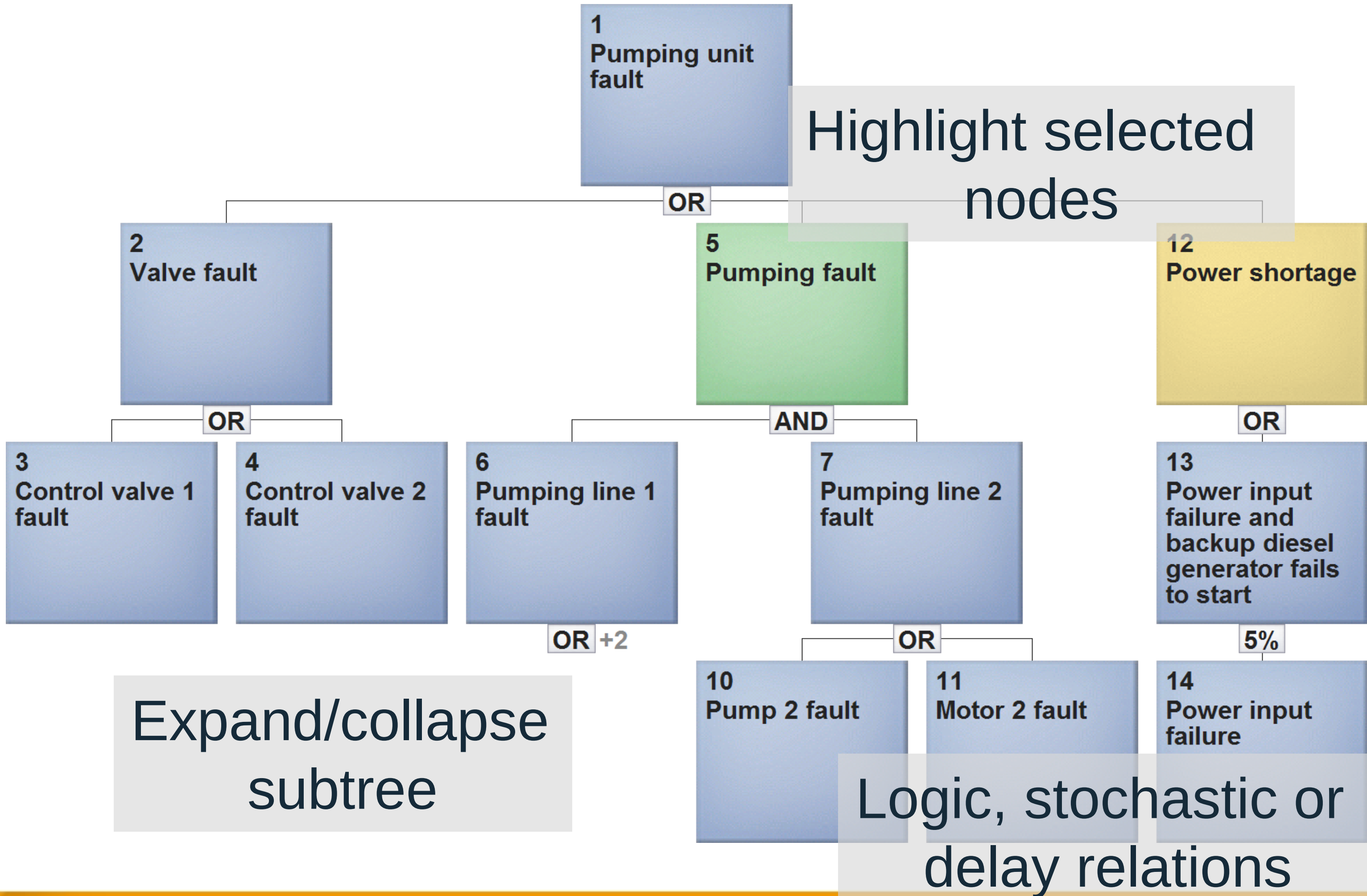
- Graphical user interface
- Excel export and import
- HTML report
- Table summary
- ERP interface
- Project versioning
- Template library
- Search
- Web start

ELMAS 4.7

http://www.ramentor.com/products/elmas/



Modelling of a Fault tree structure



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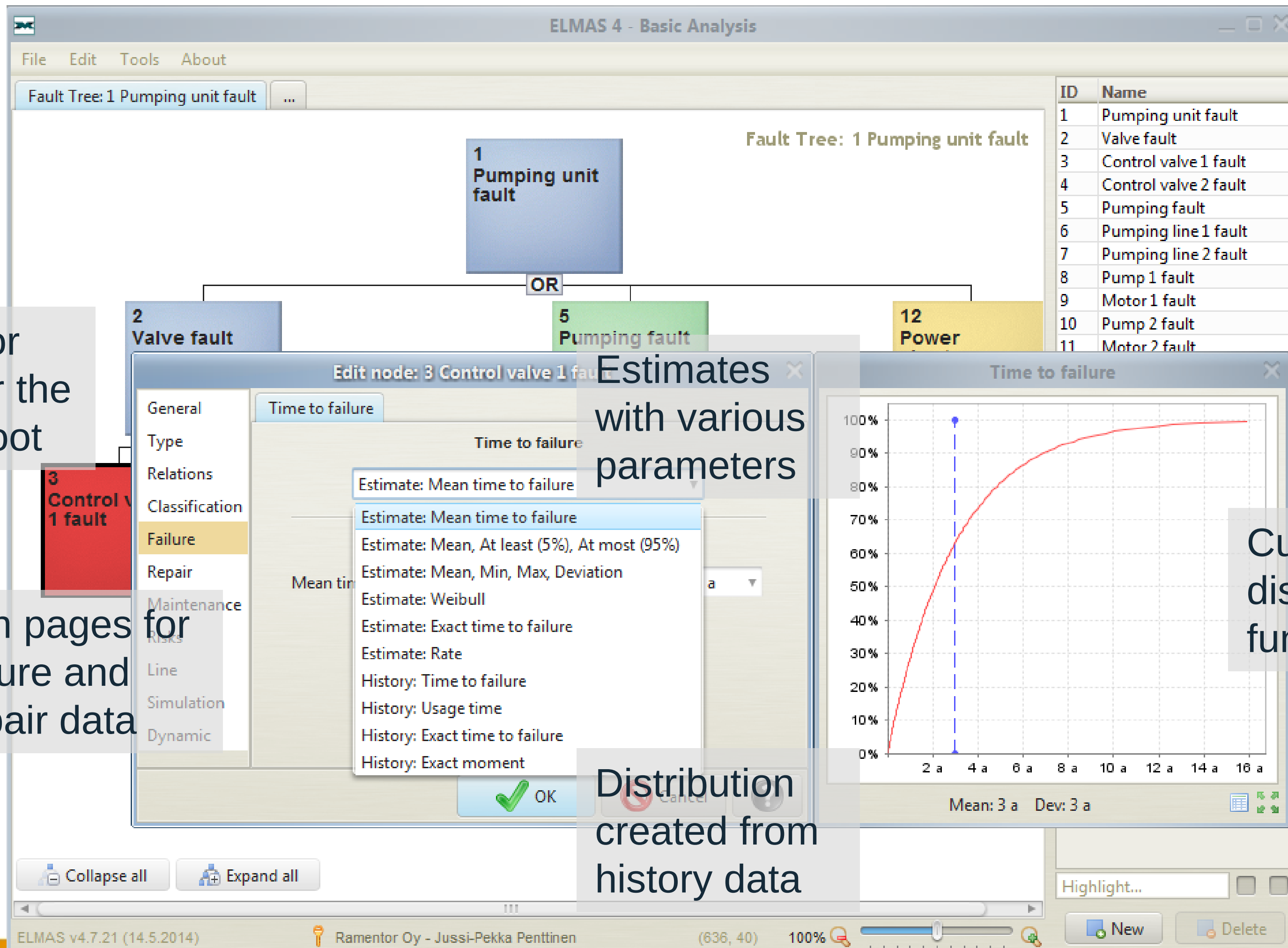
Failure and Repair distribution for root



Node editor opened for the selected root

Estimates with various parameters

Cumulative distribution function shown

Own pages for Failure and Repair data

Distribution created from history data

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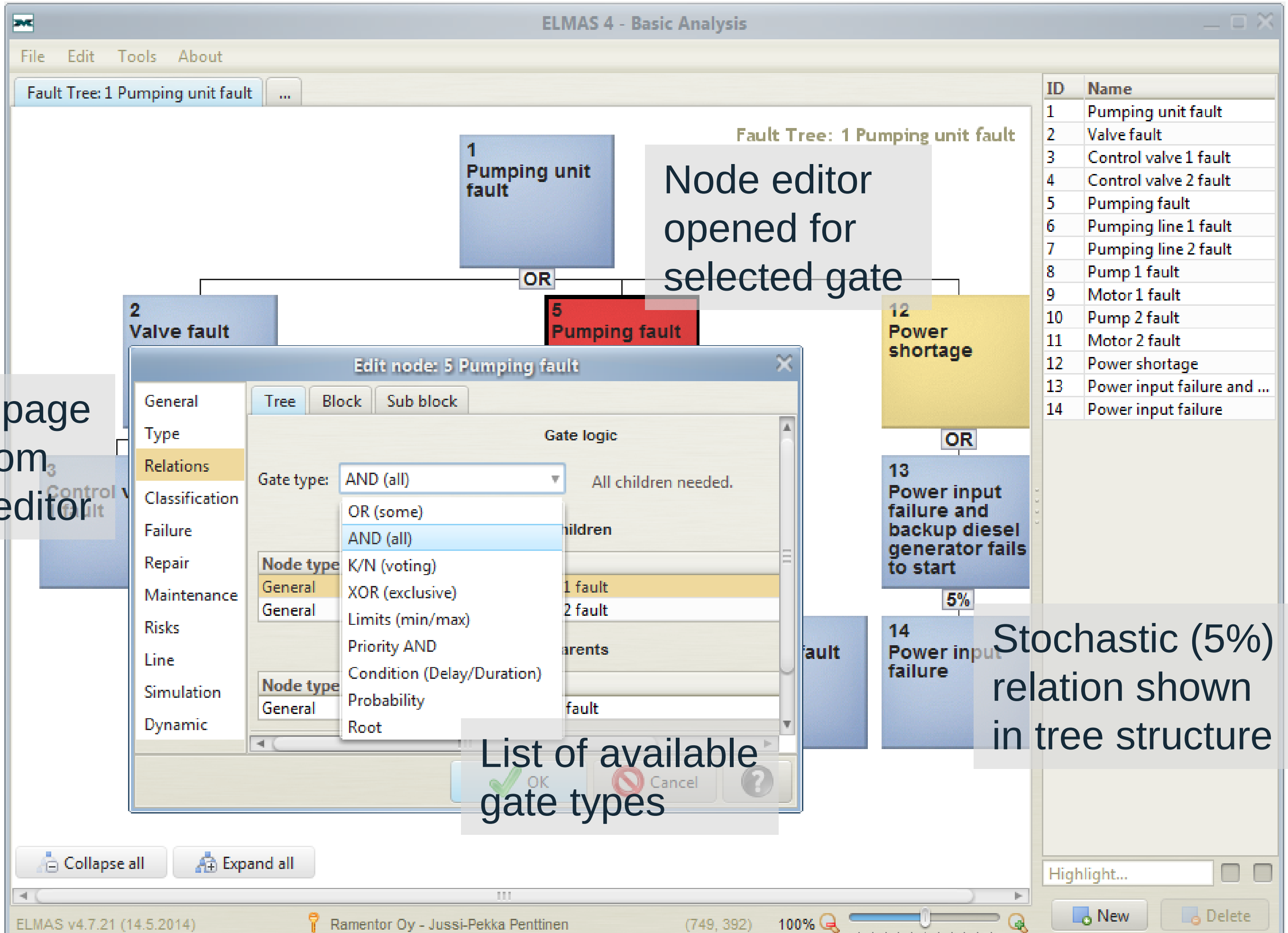
Logic, Stochastic and Delay gates



Node editor opened for selected gate

Relations page opened from the node editor

Stochastic (5%) relation shown in tree structure

List of available gate types

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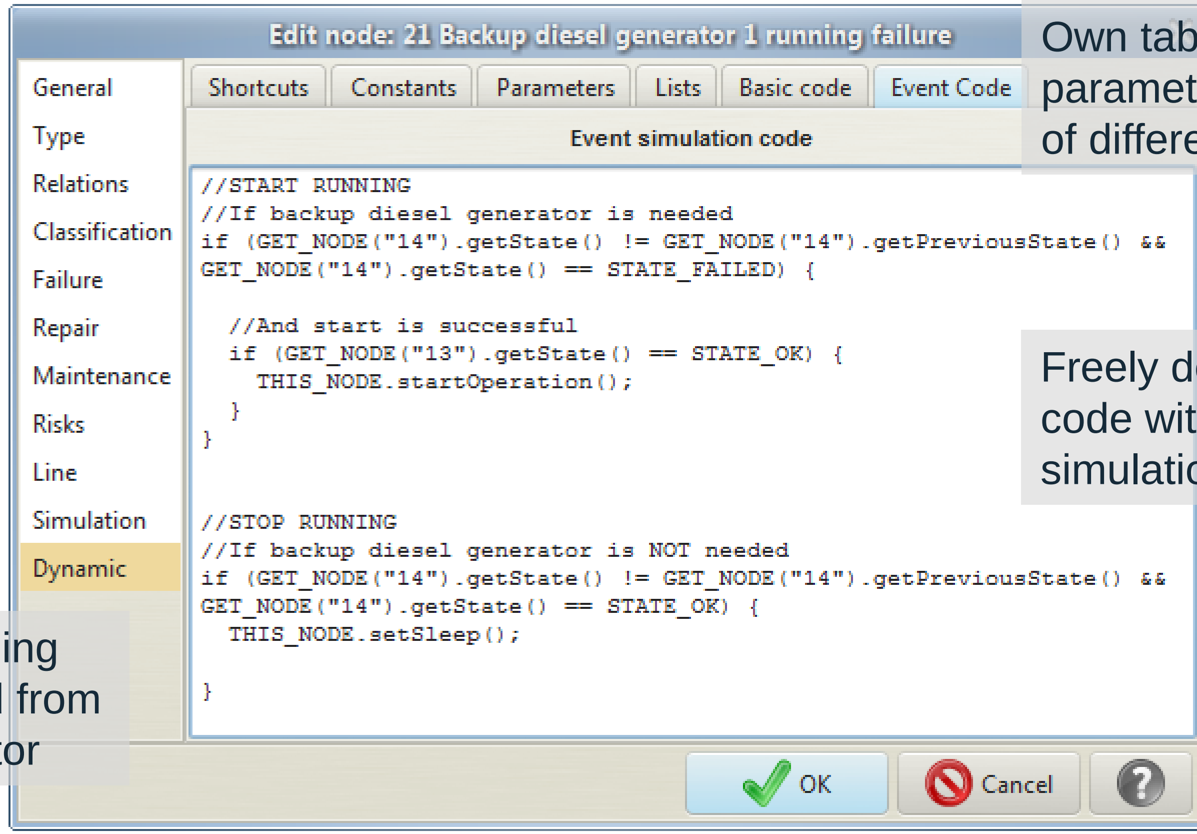
Dynamic parameters and Coding



Own tabs to define used parameters and codes of different situations

Freely defined Java code with links to simulation states

Dynamic coding page opened from the node editor

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Other node properties

- Maintenance actions, intervals, costs and resources
  - Preventive, Inspection, Restoration, Replacement, Failure finding
- Expenses related to risk analysis (static or stochastic)
  - Break and downtime loss, repair and resource costs, spare parts
- Throughput of a production line
  - Fuzzy logic operations
- Node classification based on selected criteria
  - FMEA, Criticality

Stochastic simulation and results

Studied period tab from basic results page opened

Analysis: Simulation Tool

Profile | Simulation | **Basic** | Conditional | Importance | Risks | Risks 2 | Line | Classification

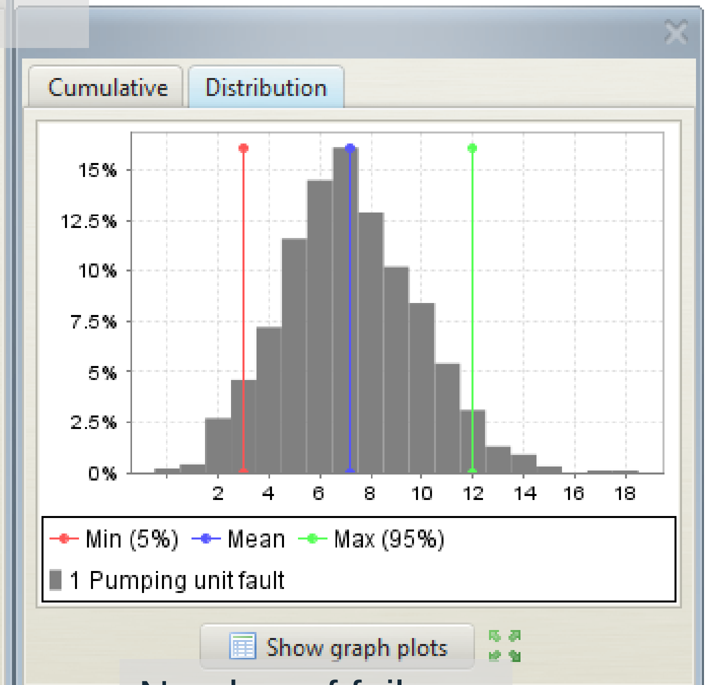
Availability | Unreliability | Mean times | **Studied period**

Failures during studied period

Studied time period: 10 a

ID	Name	Failed time	Failures
1	Pumping unit fault	3 d 6 h	7.192
2	Valve fault	2 d 6 h	6.724
5	Pumping fault	43.1 s	0.006
12	Power shortage	1 d 21 min	0.465
3	Control valve 1 fault	1 d 3 h	3.351
4	Control valve 2 fault	1 d 3 h	3.376
6	Pumping line 1 fault	2 d 23 h	6.373
7	Pumping line 2 fault	3 d 2 h	6.624
13	Power input failure and backup di...	1 d 21 min	0.465
8	Pump 1 fault	1 d 23 h	3.967
9	Motor 1 fault	23 h 36 min	2.409
10	Pump 2 fault	2 d 28 min	4.09
11	Motor 2 fault	1 d 1 h	2.537
14	Power input failure	22 d 18 h	9.722

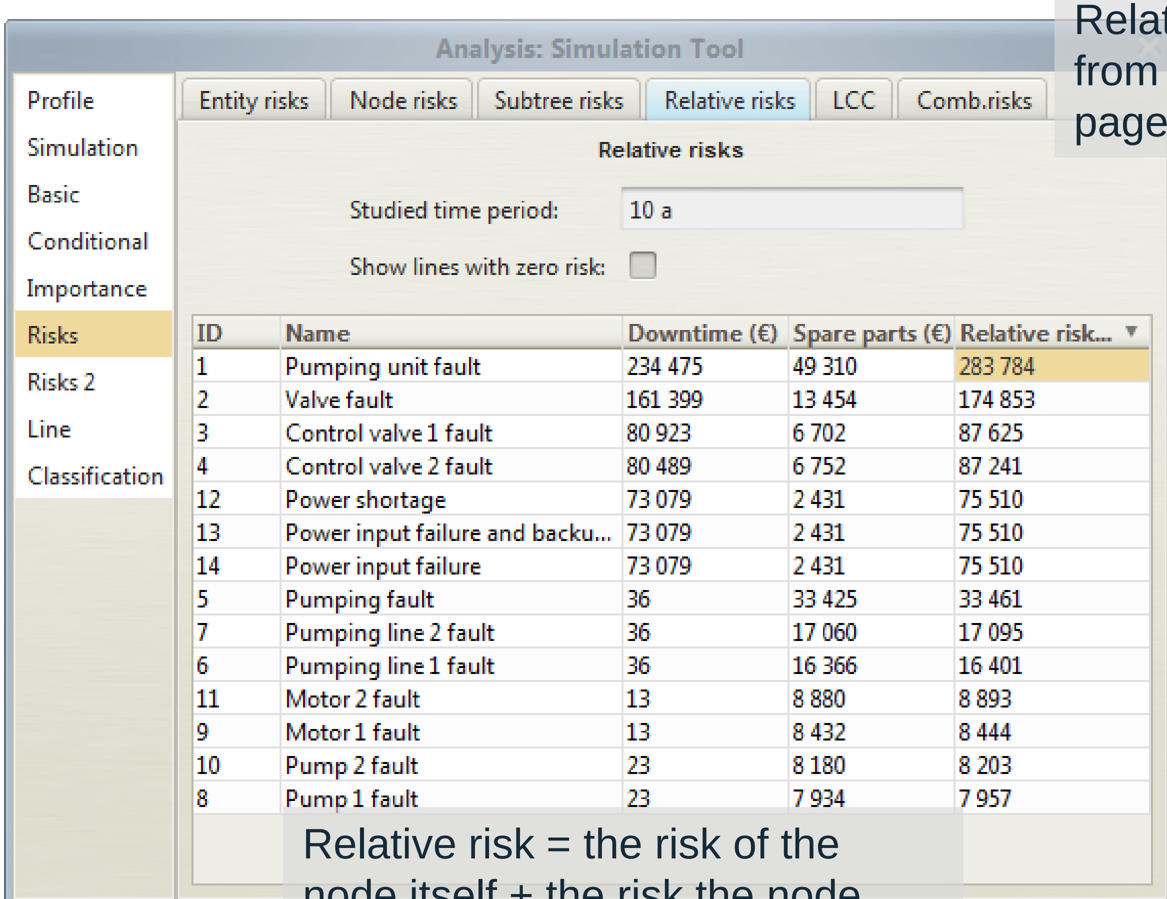
Results for each simulated node shown in table

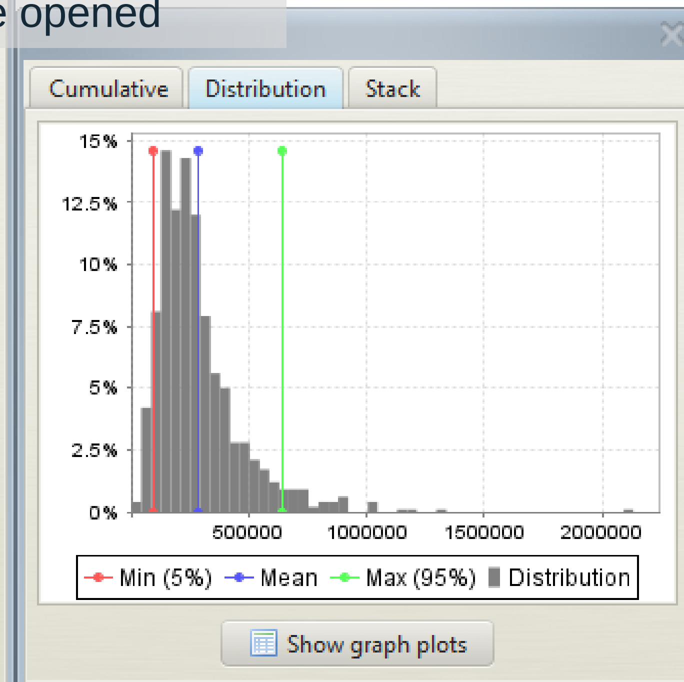


Number of failures distribution shown for selected node

Risk analysis

Relative risks tab from Risk results page opened





Relative risk = the risk of the node itself + the risk the node causes through other nodes

Distribution of risks with min and max estimate shown for selected node

Other properties

- Import data through Excel tables
- Export HTML or Excel reports
- FMEA, RCM and RCA tools
- Combined Block diagrams, Fault trees and Event trees
- Usage, stress and production profile in simulation
- Conditional and importance results from simulation
- History report simulation
- Show only needed tools and hide unused tools
- Change terms and texts used in the software for each case

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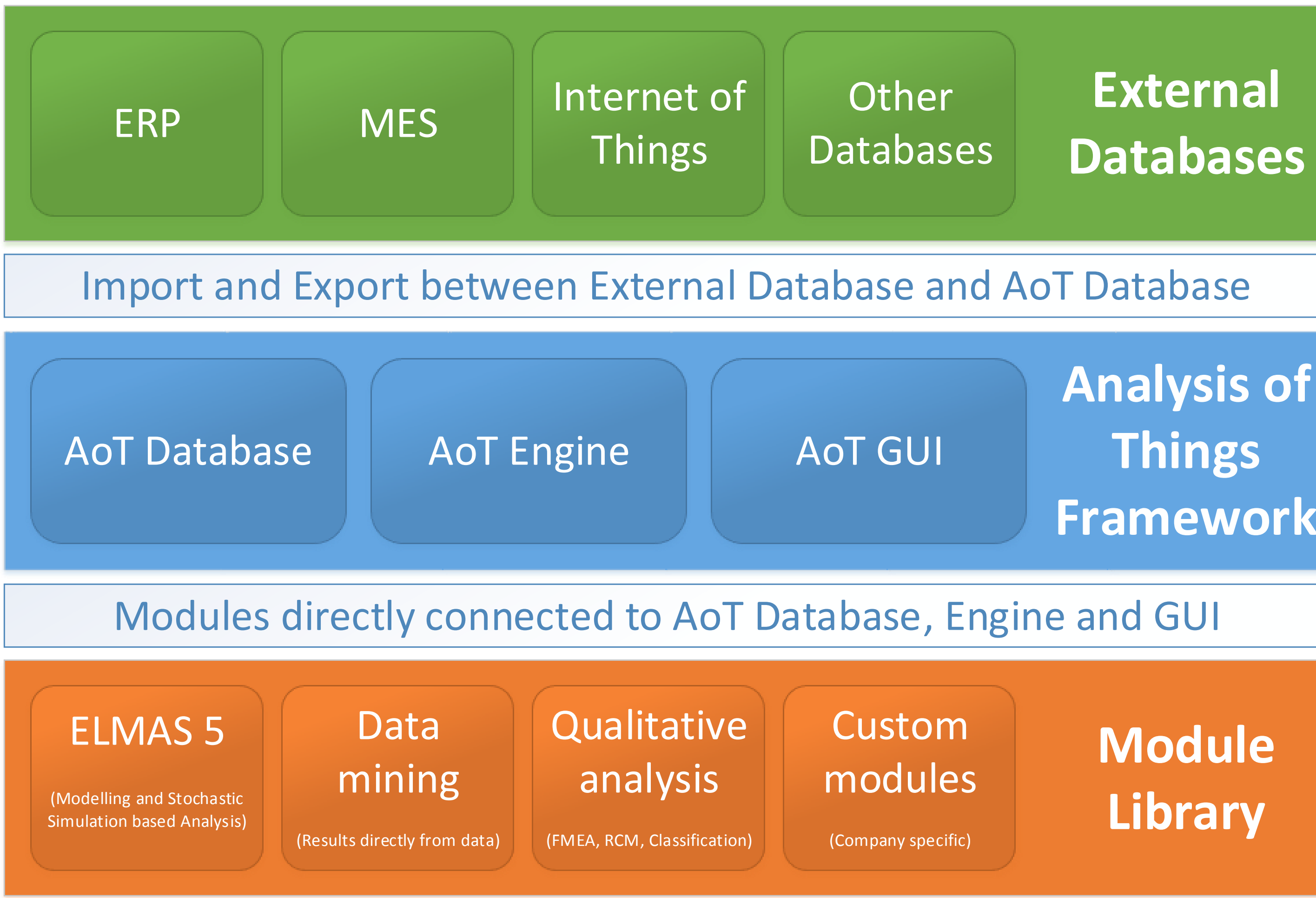
Some future plans

- Analysis of Things (AoT) framework with modules for different usages:
  - ELMAS 5, Data mining, Qualitative analyses, Company specific…
- Direct data import/export with external databases
  - ERP, MES, Internet of Things, Company database…
- More possibilities (than change of terms and hide analyses) to tailor GUI and simulation for each case
  - Efficiency for large and complex model simulations (Nuclear)
  - Straightforward simple analyses (PERT, basic fault tree)
- Online module library for different usages/analyses

Analysis of Things (AoT) Framework



Levels with Fleet Model included

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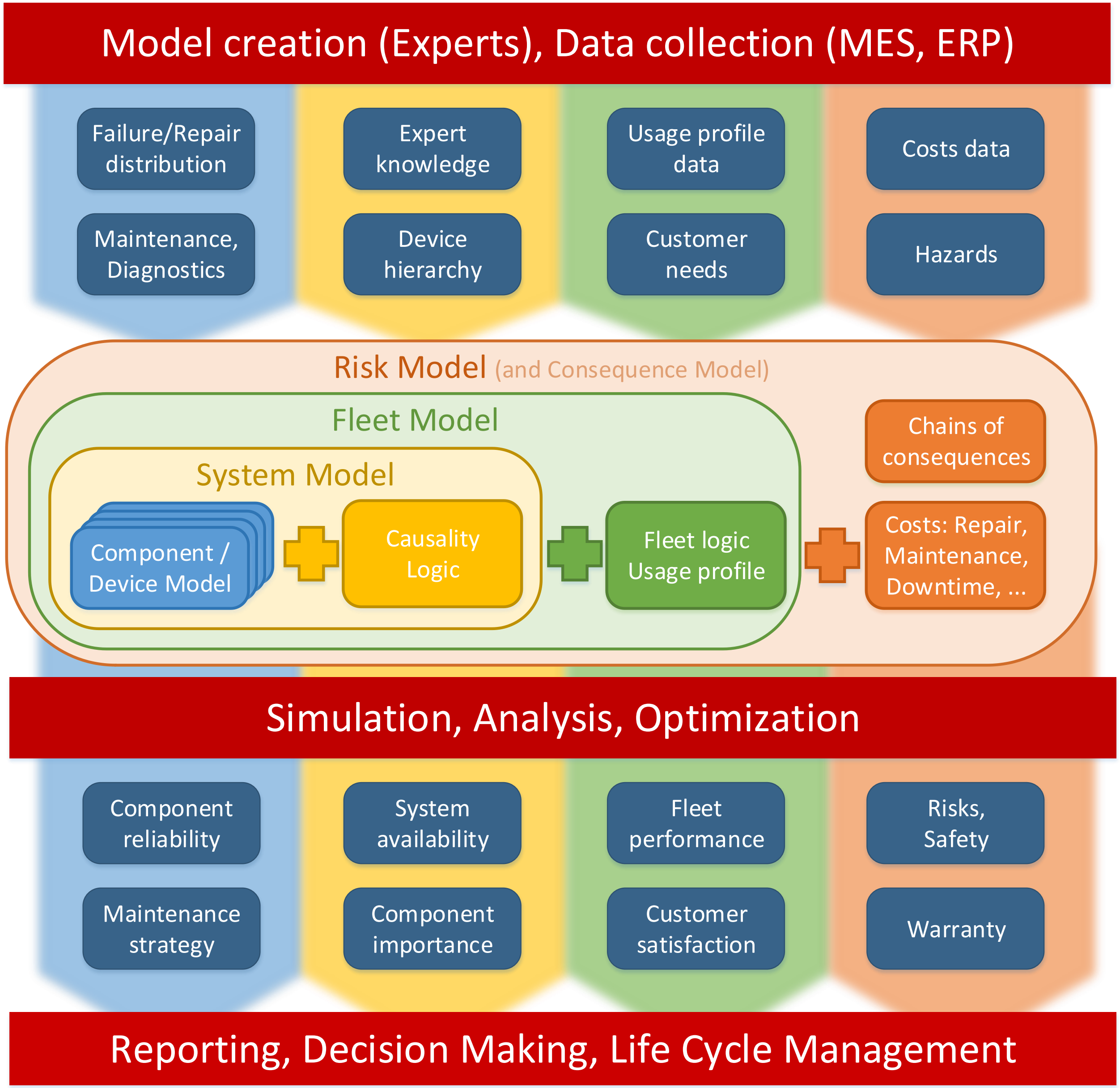

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