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Designing for availability:

Modelling approaches based on industrial best-practices and experience from the operational facilities based on practical examples

APEC Workshop – Reliability and Availability of Particle Accelerator

10-12 December 2018, Fleming's Hotel, Frankfurt am Main

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Jussi-Pekka Penttinen

Outline

1) Introduction
   – Ramentor, ELMAS, RAMS, Risk assessment process
2) Practical examples of industrial use cases
   a) Availability and radiation safety of nuclear waste encapsulation plant
   b) Life Cycle Profit Management (LCPM) – Process critical molding cranes
   c) Analysis of alternative bypass lines of mineral processing line
   d) Infrastructure availability – Design-phase data center
   e) Nuclear Power Plant (NPP) – Safety, availability and performance

Ramentor Oy

- Solutions for RAMS engineering and Risk management
- Founded in 2006 and based in Tampere, Finland
  - Personnel ~10 (Reliability/maintenance management, applied mathematics/software dev.)
  - Privately owned and independent software and expertise company
- Background: From research to practical applications
  - Finnish Technology Agency (TEKES) supported research programs: 1996-2012
  - Tampere University of Technology (TUT) research projects: 2001-2012
  - Ramentor-TUT-CERN research project for FCC RAMS methods/tools 2014-2018

Please visit for more information: http://www.ramentor.com

Jussi-Pekka Penttinen

- Tampere University of Technology (TUT)
  - Researcher (2004 – 2008): Reliability analysis, applied mathematics
  - Doctoral researcher (2016 – 2018): Thesis now in pre-examination
  - Thesis title: An Object-Oriented Modelling Framework for Probabilistic Risk and Performance Assessment of Complex Systems
- CERN FCC RAMS methods R&D project (2015 – 2018)
- Ramentor Oy
  - Chief architect (2006 – Present): ELMAS software

ELMAS – An Acronym

Event

- Time to Failure: Distribution/MTTF
- Time to Repair: Distribution/MTTR
- Maintenance: Service actions
- Costs: Break, downtime, repair
- Hazards
- Usage/stress profile
- External events

Logic

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

Modeling

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

Analysis

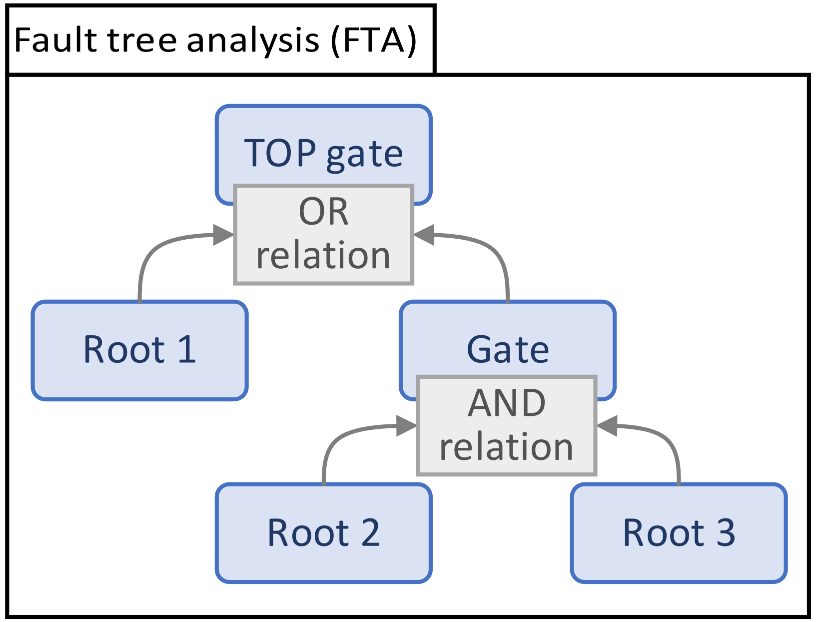
- Simulation
- Reliability, Availability
- Risk Analysis
- Importance measures
- Conditional probabilities
- Spare part consumption
- Resources
- FMEA, RCM

Software

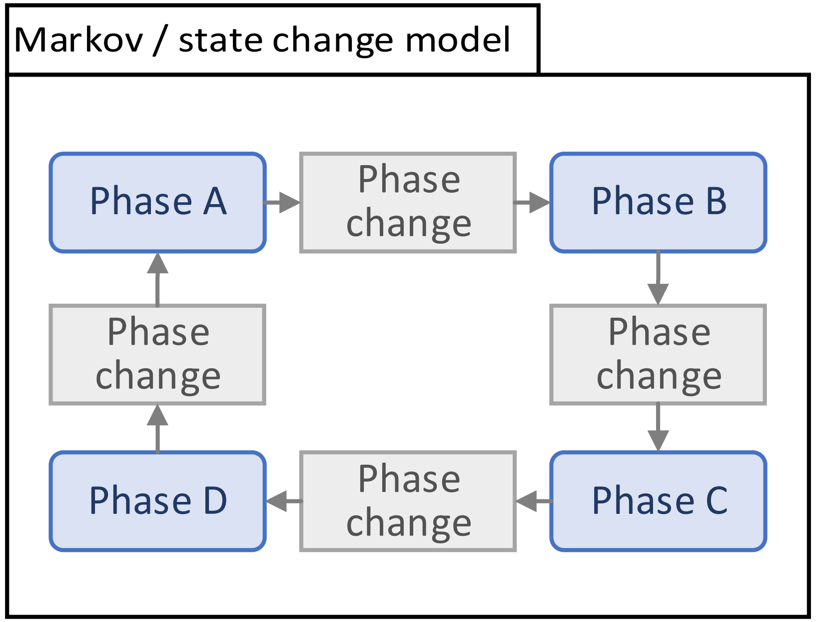
- Graphical user interface
- Excel export and import
- HTML report
- Table summary
- ERP interface
- Project versioning
- Template library
- Search
- Web start

ELMAS – Modelling Techniques

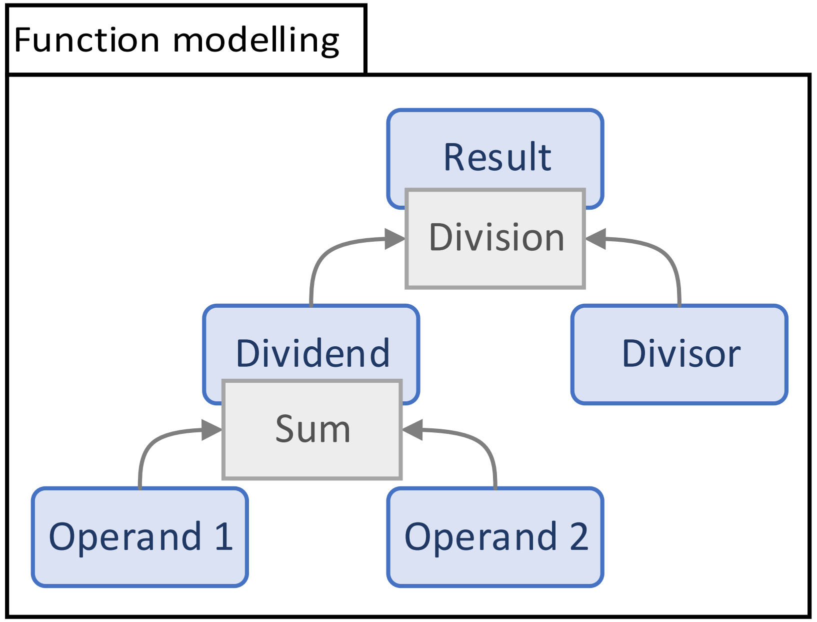
- Several modelling techniques are included in ELMAS



Causes and consequences

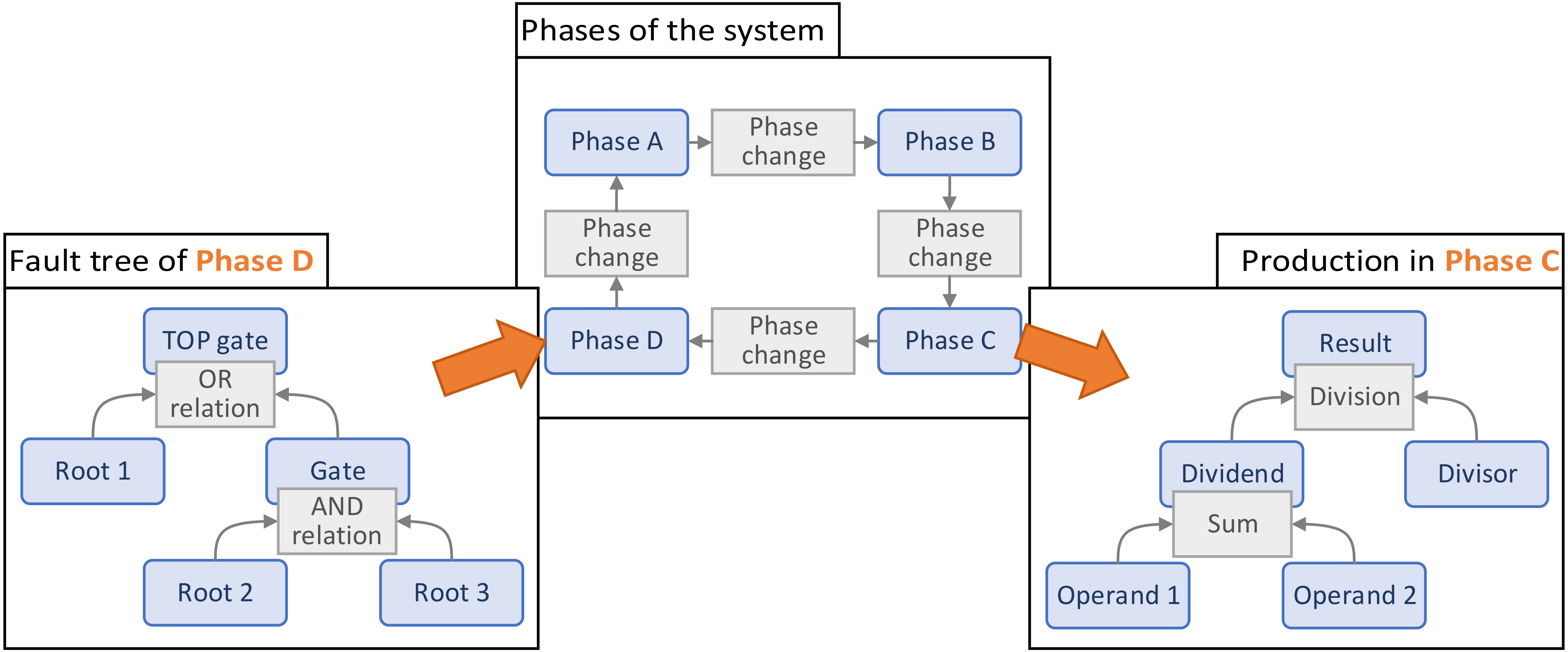


Dynamic operation phases



Key performance indicator

ELMAS – Comprehensive System Model



ELMAS 4.9

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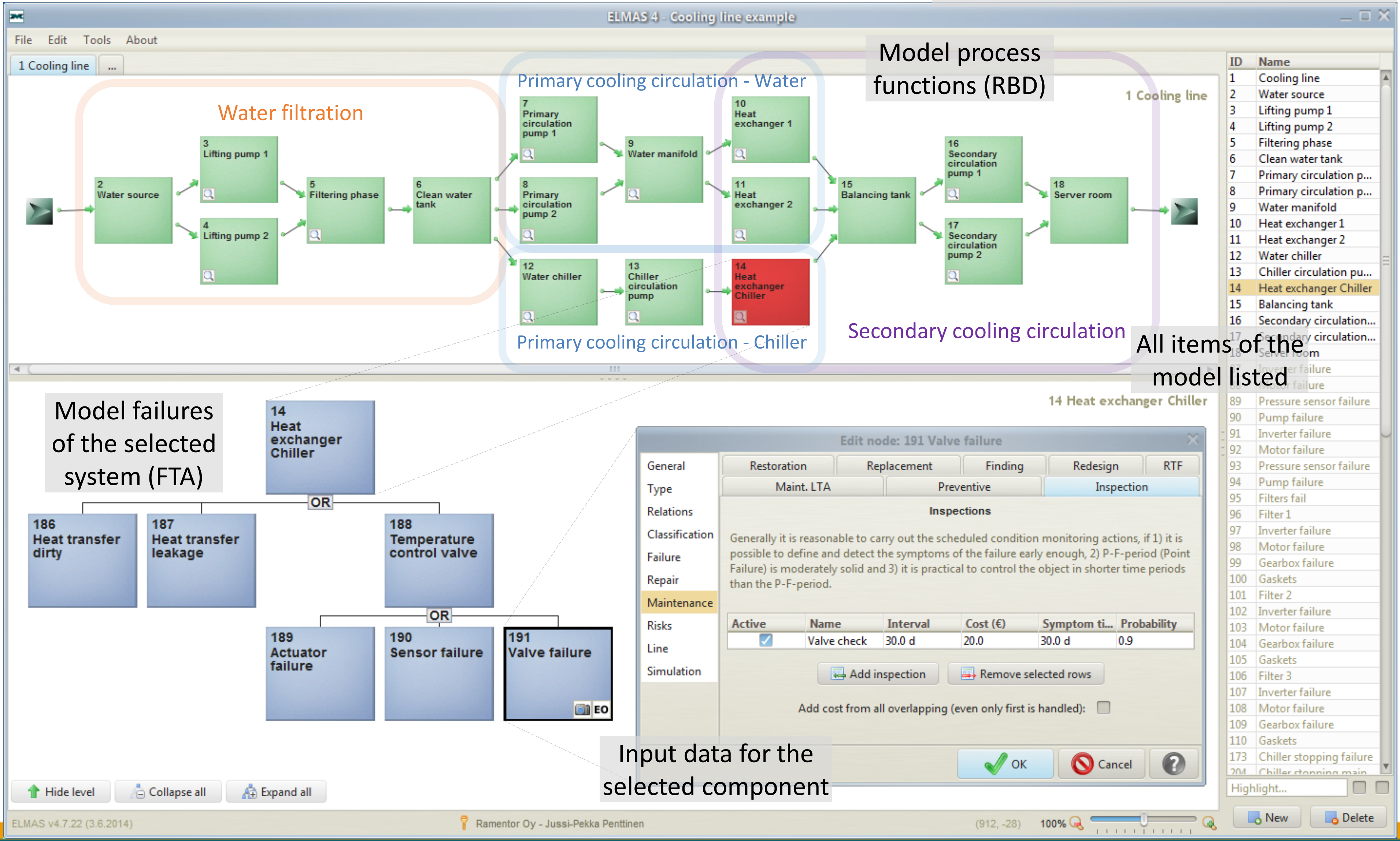

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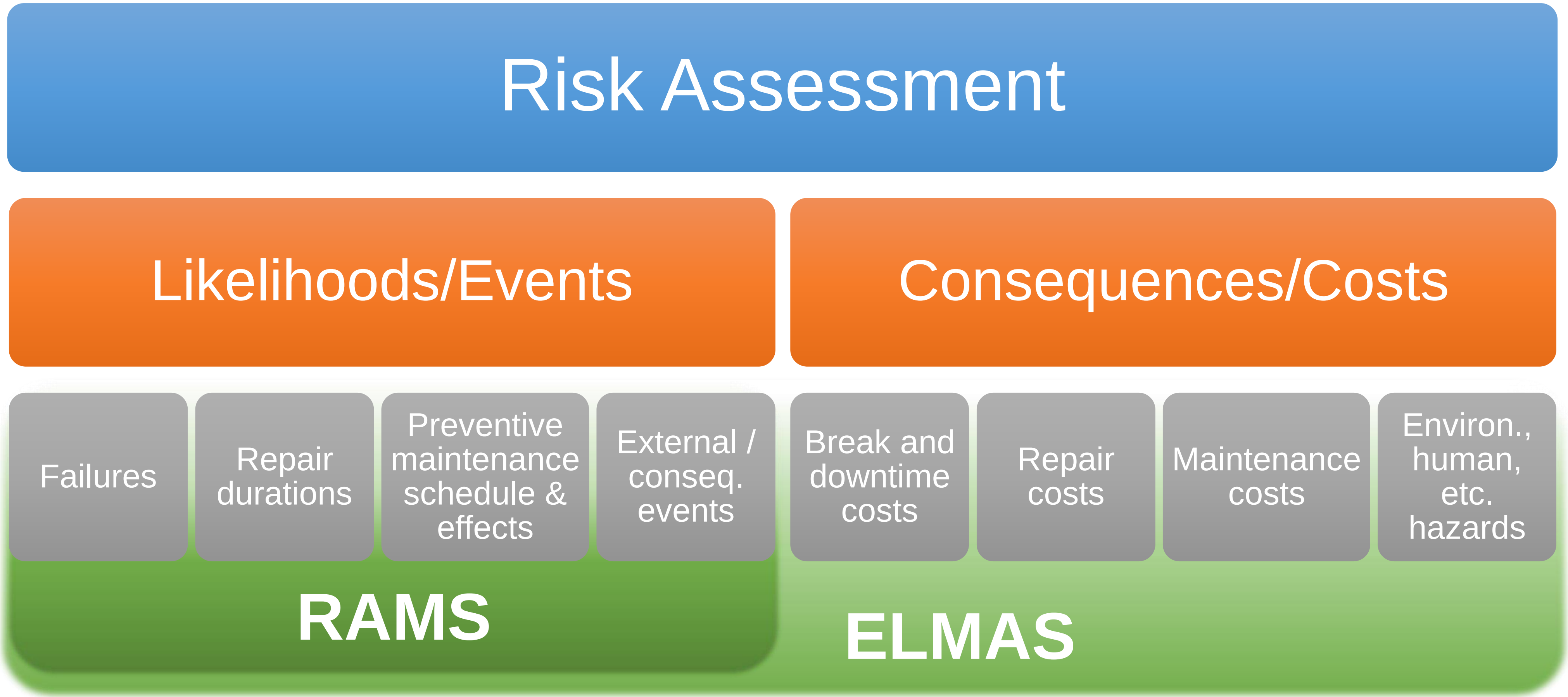
Design for RAMS (Greenfield)

- At early design state: Find out any **possible design flaws**
- Design for Reliability
  - Needs for **redundancy**? Change or improve components?
- Design for Availability
  - Compare **production scenarios**, manage overall **lifecycle**
- Design for Maintainability
  - Optimize **maintenance strategies**, understand **resource needs**

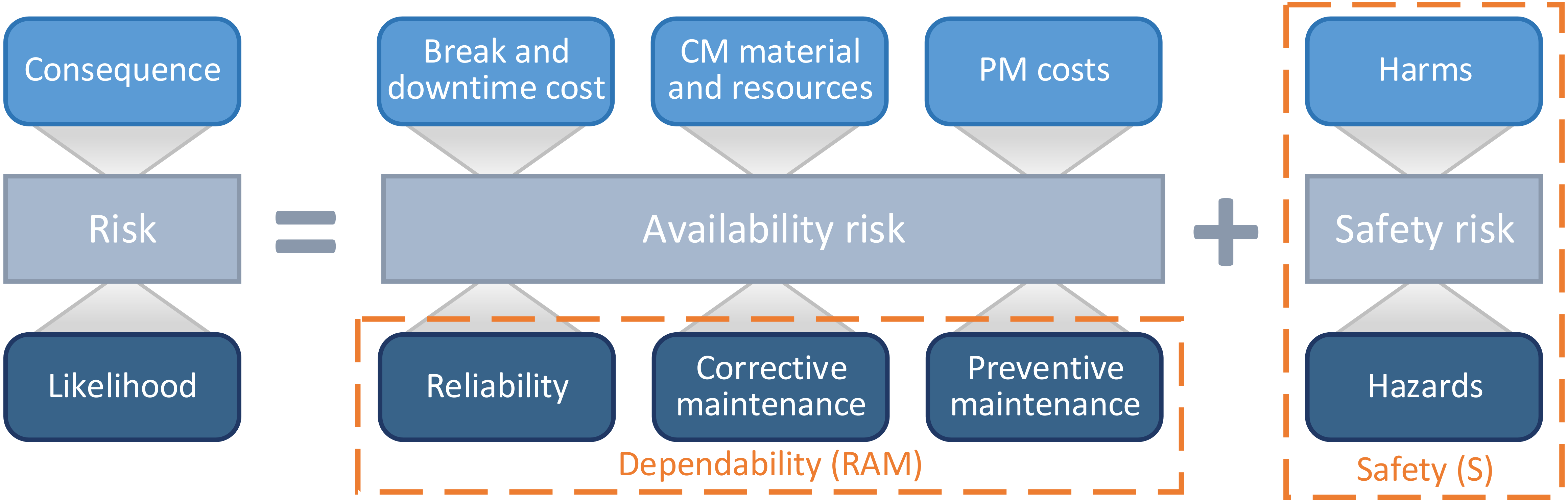
Continuous RAMS development (Brownfield)

- Identify improvement potential/targets
  - Calculate the effect of improvement actions
- Justification of investments based on cost calculations
  - Compare alternative investments
- Maintenance optimization
  - Improve dependability or reduce maintenance costs
- Use all available history data and improve its quality

ELMAS – Risk Assessment and RAMS



ELMAS – RAMS and Risk



Risk Assessment Process (ISO GUIDE 73)

1) Risk identification (Find, recognize and describe risks)

2) Risk analysis (Comprehend the nature and determine the level of risk)

3) Risk evaluation (Compare analysis results with risk criteria to determine whether the risk and its magnitude is acceptable or tolerable)

Risk Assessment Process (ISO GUIDE 73)

– ELMAS: Modeling and Simulation of Explicit Results

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, …**

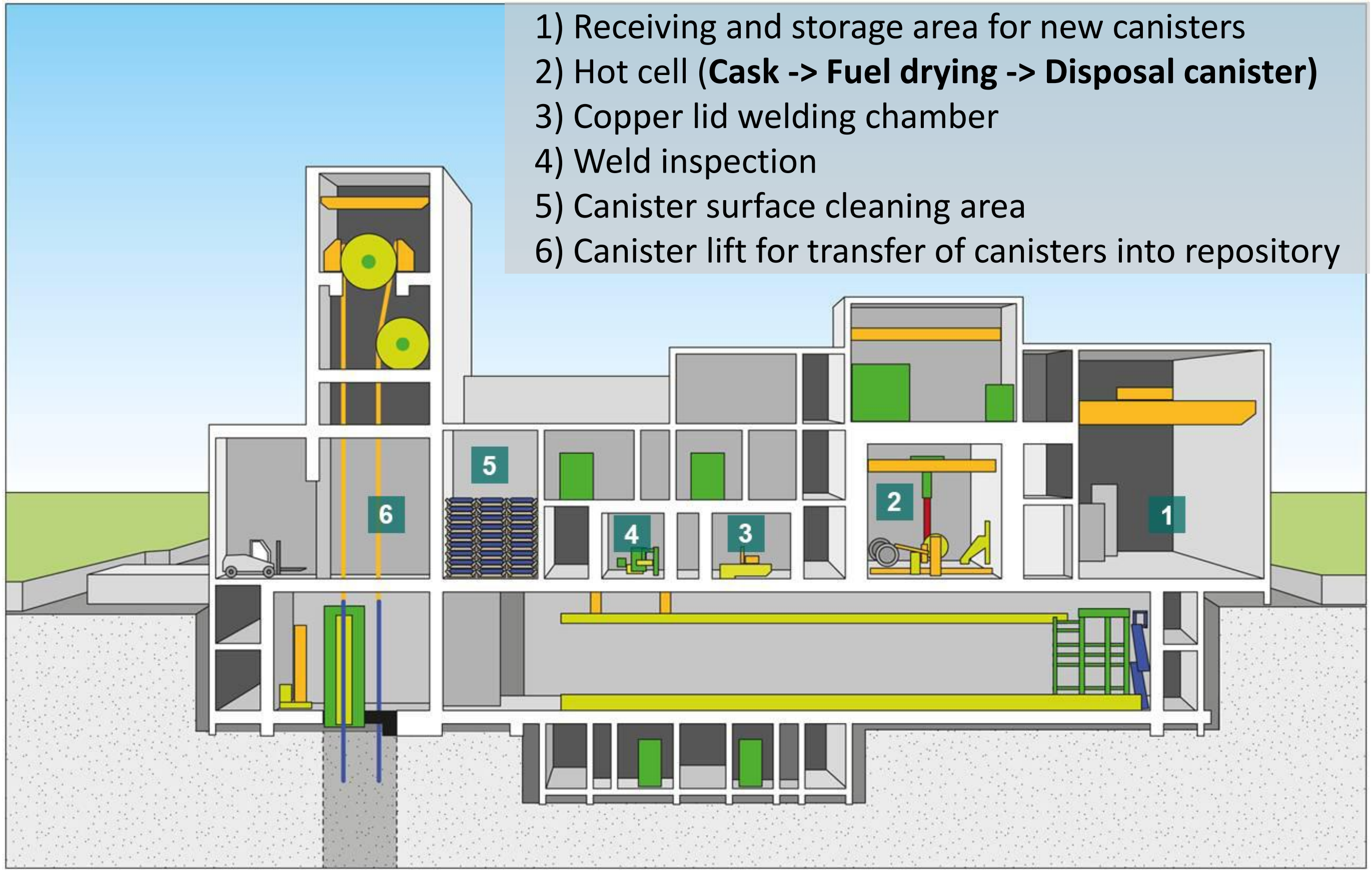
Case examples

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 disposal canisters
- Repository (ONKALO)
  - Tunnels are located deep inside the bedrock, where the encapsulated spent nuclear fuel is disposed of

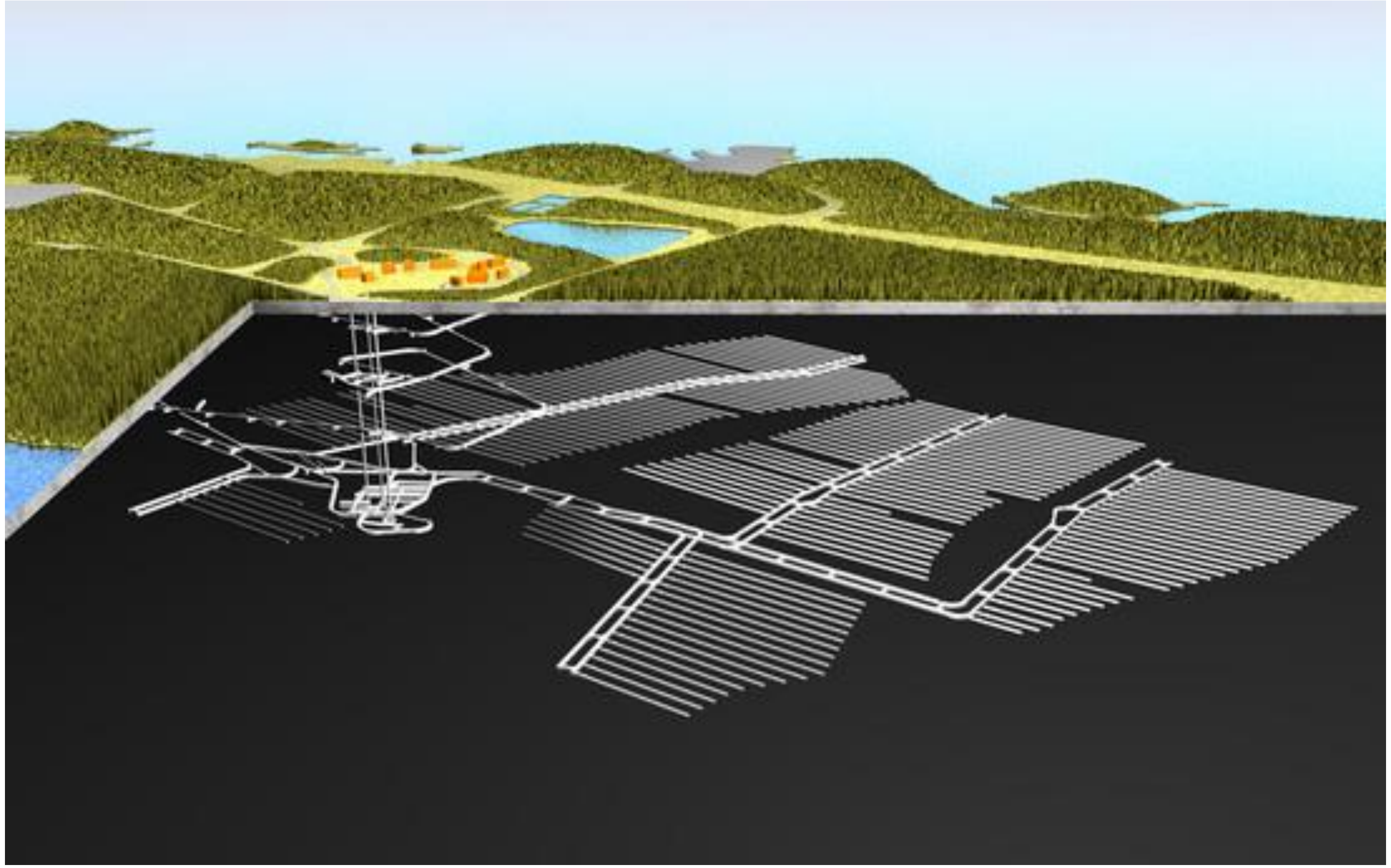
Case A) – Final Disposal Facility (FDF):

Aboveground Encapsulation Plant



Case A) – Final Disposal Facility (FDF):

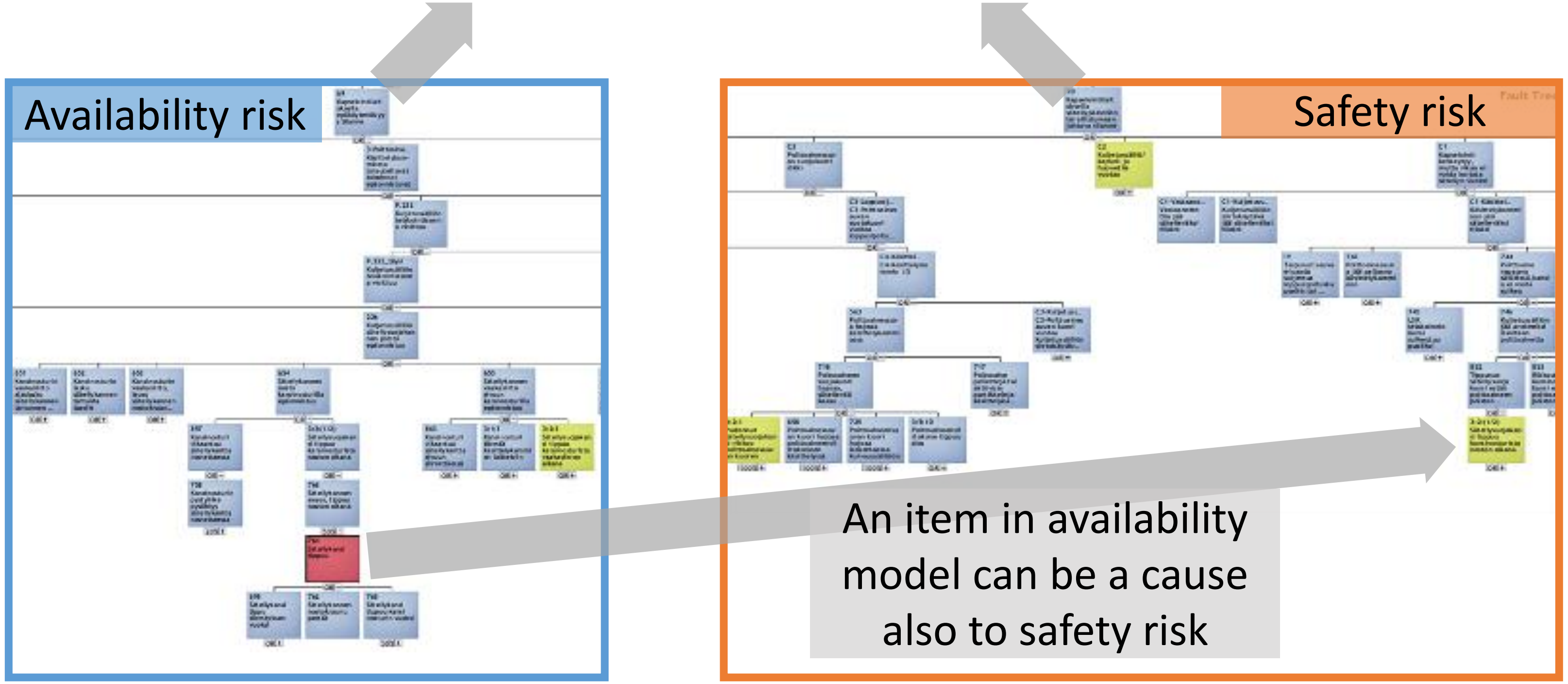
Repository (ONKALO)



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):

Key Findings and Improvements

- Comprehensive availability and safety model created
- Several changes were made based on design reviews
  - Improved identification of unexpected impacts of design changes
  - 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
  - STUK 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

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

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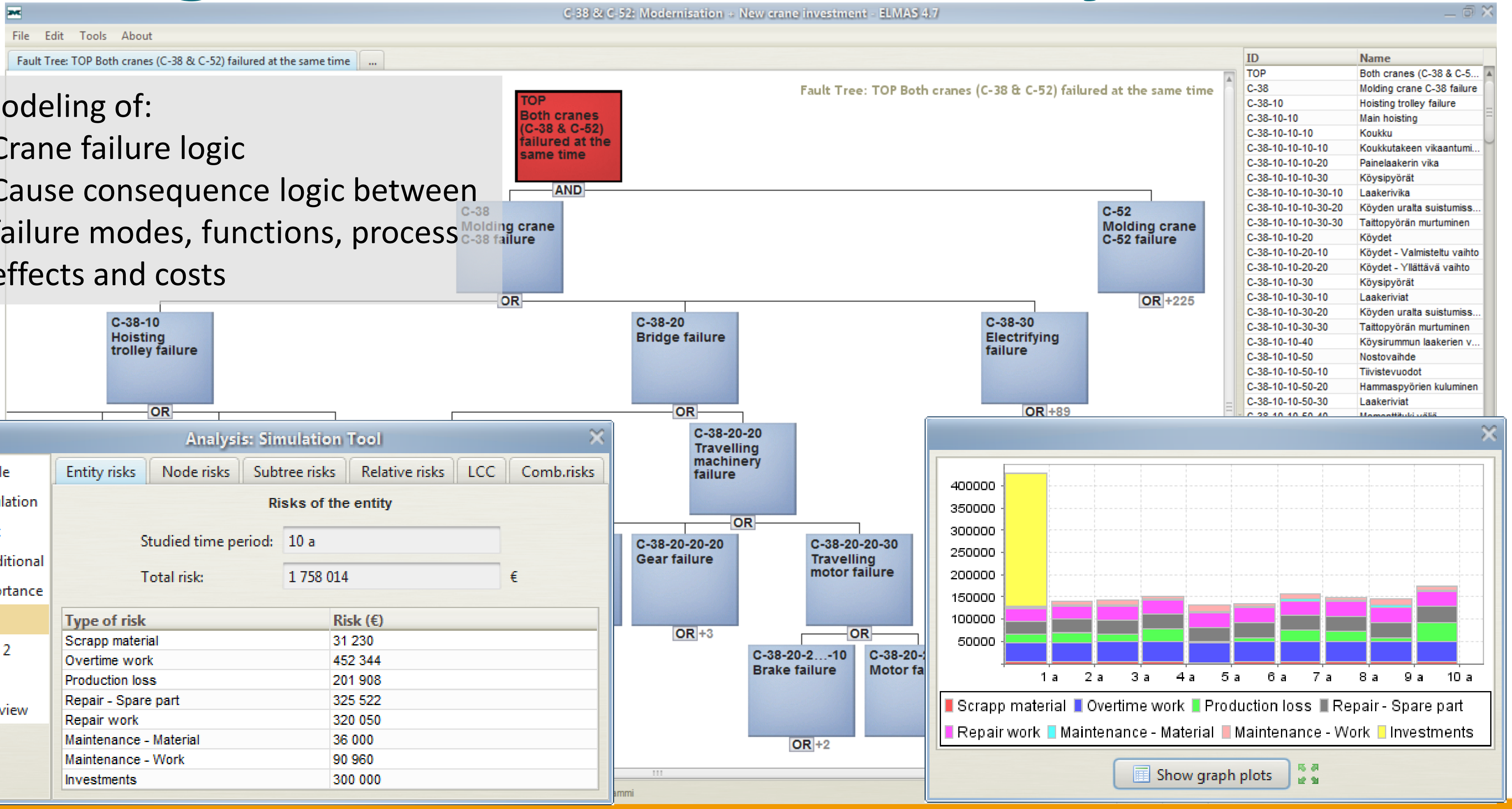
Case B) – Life Cycle Profit Management (LCPM):

Modeling, Simulation and Analysis

Figures are fictional

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



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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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

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

Key Findings and Improvements

Figures are fictional

- Based on LCPM analysis, the modernisation of auxiliary hoisting & renewal of older crane (Scenario 3), 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

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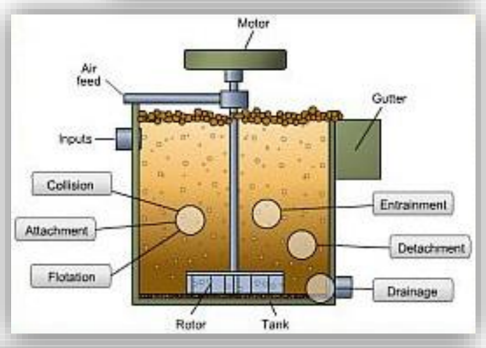
Case C) – Mineral Processing Line

- 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):

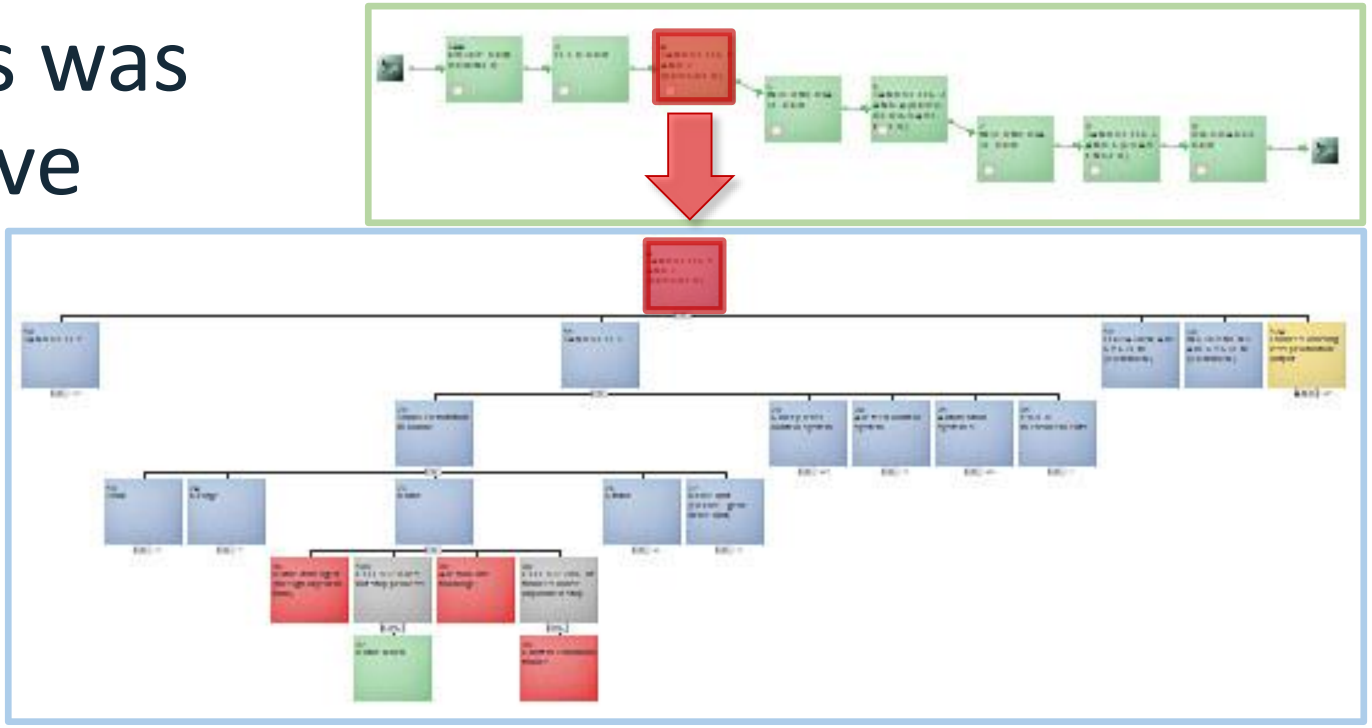
Case Description

- 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 created a model (Experts from Ramentor and client)
  – All mechanical and automation components of processing tanks and supporting systems, and process and user-related faults were included
- Overall equipment effectiveness (OEE)
  – In addition to availability also performance (and quality) included

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



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 impact failure modes**

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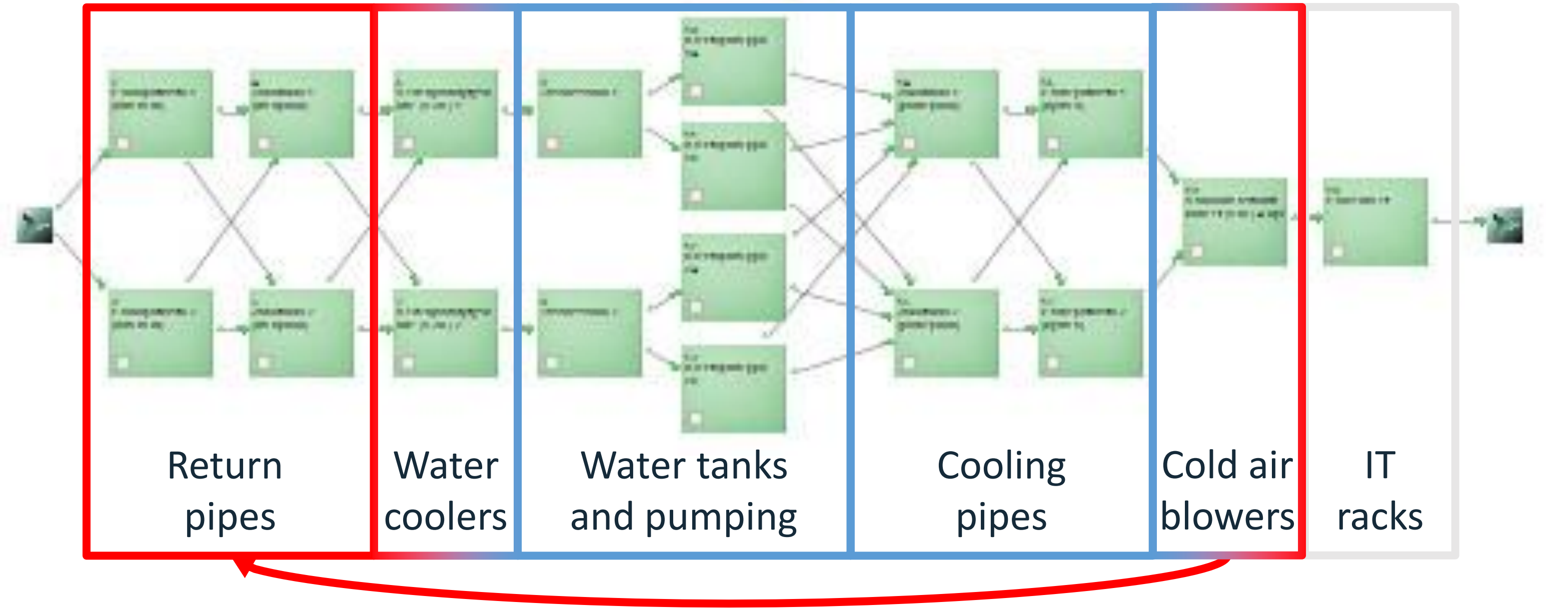
Case D) – Infrastructure Availability:

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

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*

(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%

*) 99.995% availability
= Tier level 4

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%, but repair of any of the 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 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 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, …)
  3) Initial lubrication water system
  4) Cleaning system of condenser tubes

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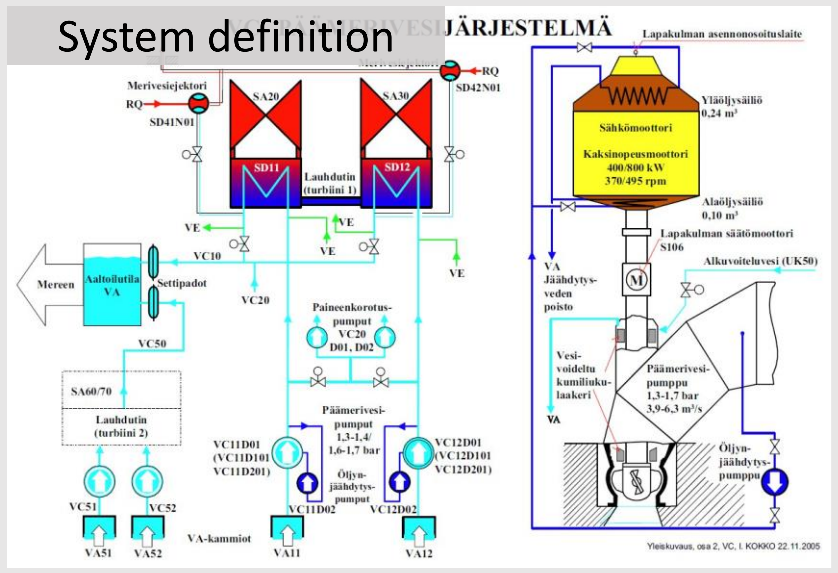
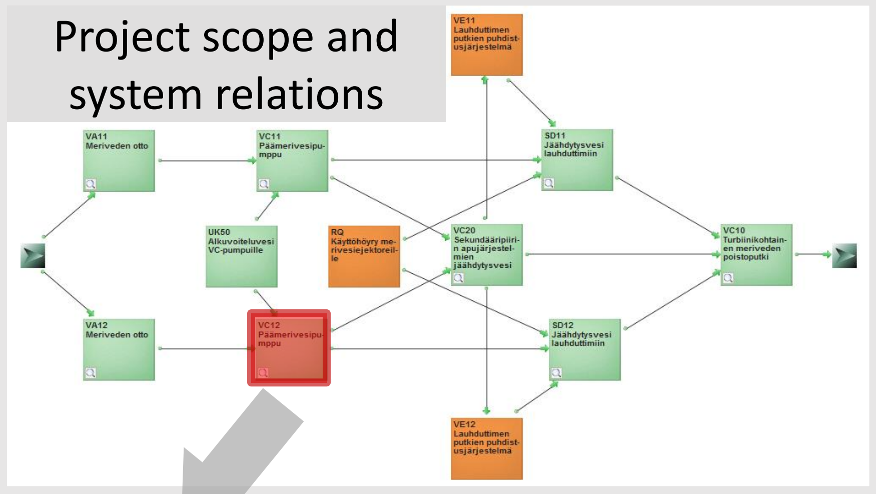
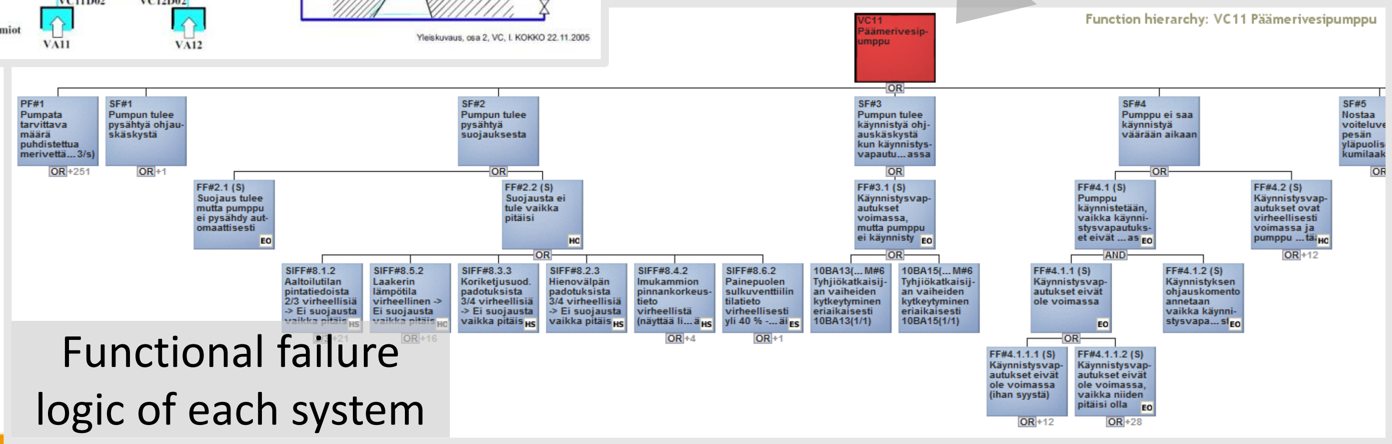
Case E) – Nuclear Power Plant (NPP):

ELMAS Project Model







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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 to improve the use of operative IT-systems
- Scenarios for risks & equipment life cycle management

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)
- Stochastic discrete event simulation made in each case
  - Failure/repair distributions -> Risk/availability analysis results/reports
- Management of improvement tasks of items in one case
  - List tasks -> Prioritize and schedule -> Update model

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OpenMARS –
An Open Modelling approach for Availability and Reliability of Systems

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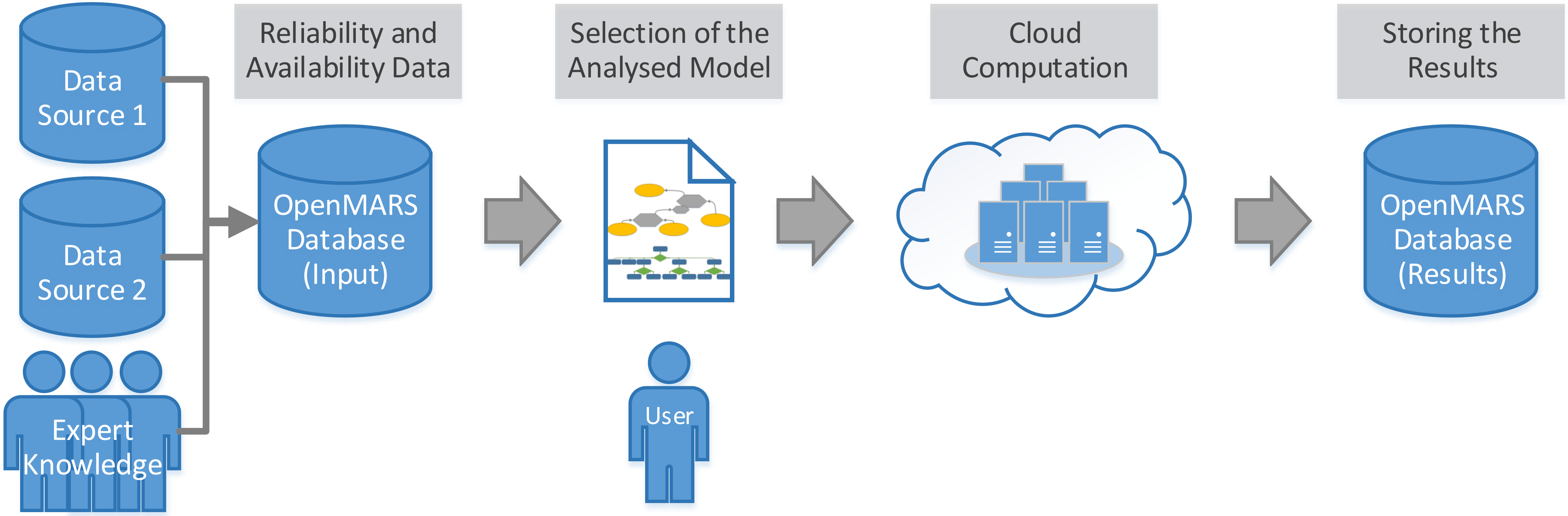
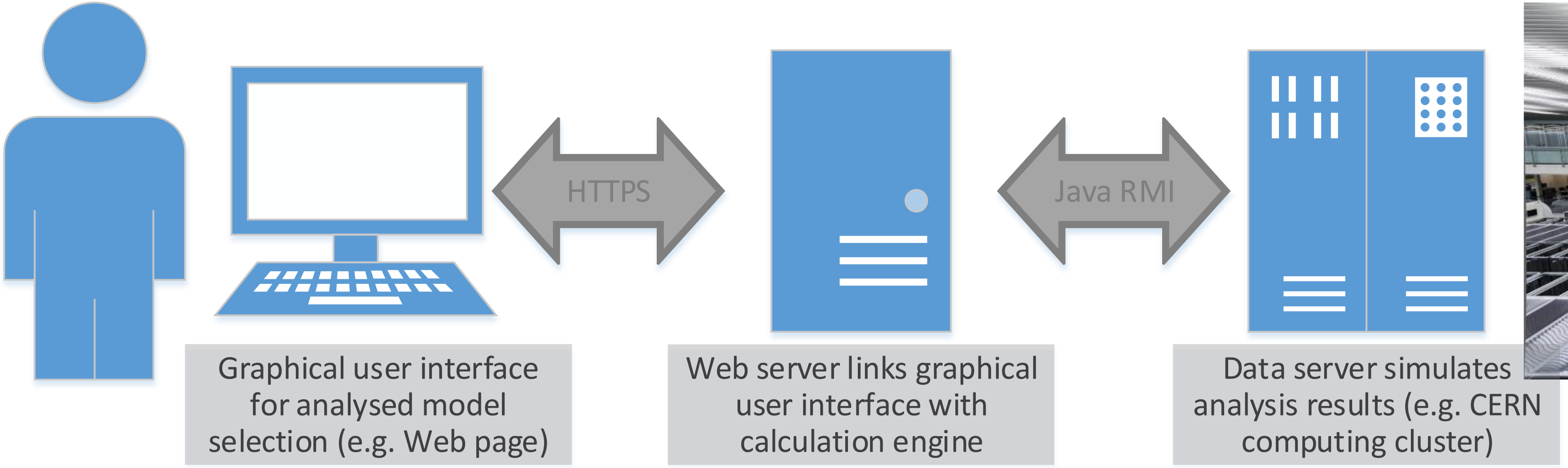
OpenMARS publications

- A new approach for complex systems' risk assessment
  - Co-operation: CERN, Tampere University of Technology & Ramentor
- OpenMARS journal article
  - Reliability Engineering & System Safety: https://authors.elsevier.com/a/1YBC03OQ~fLaeo
- OpenMARS specification
  - CERN Document Server: https://cds.cern.ch/record/2302387

Database and Computing Environment



Remote use of the Computing Cluster



FCC Study Innovation Award

Read more: http://www.ramentor.com/fcc-innovation-award/

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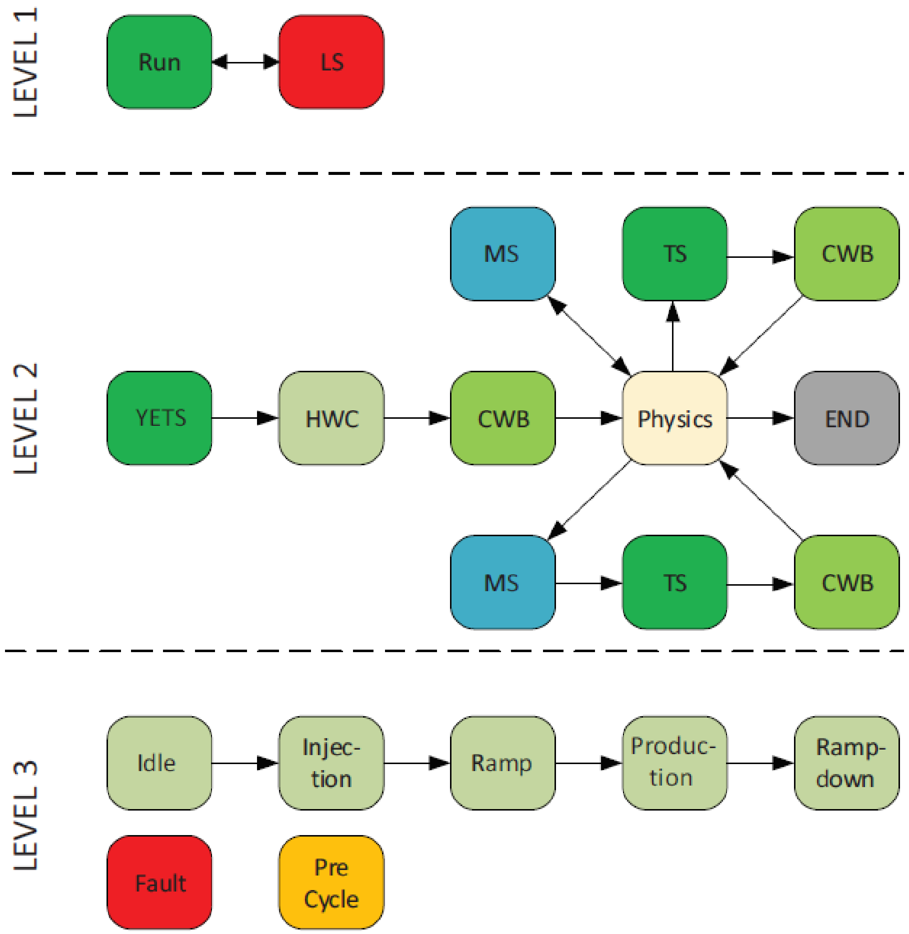
Example: CERN three level state model

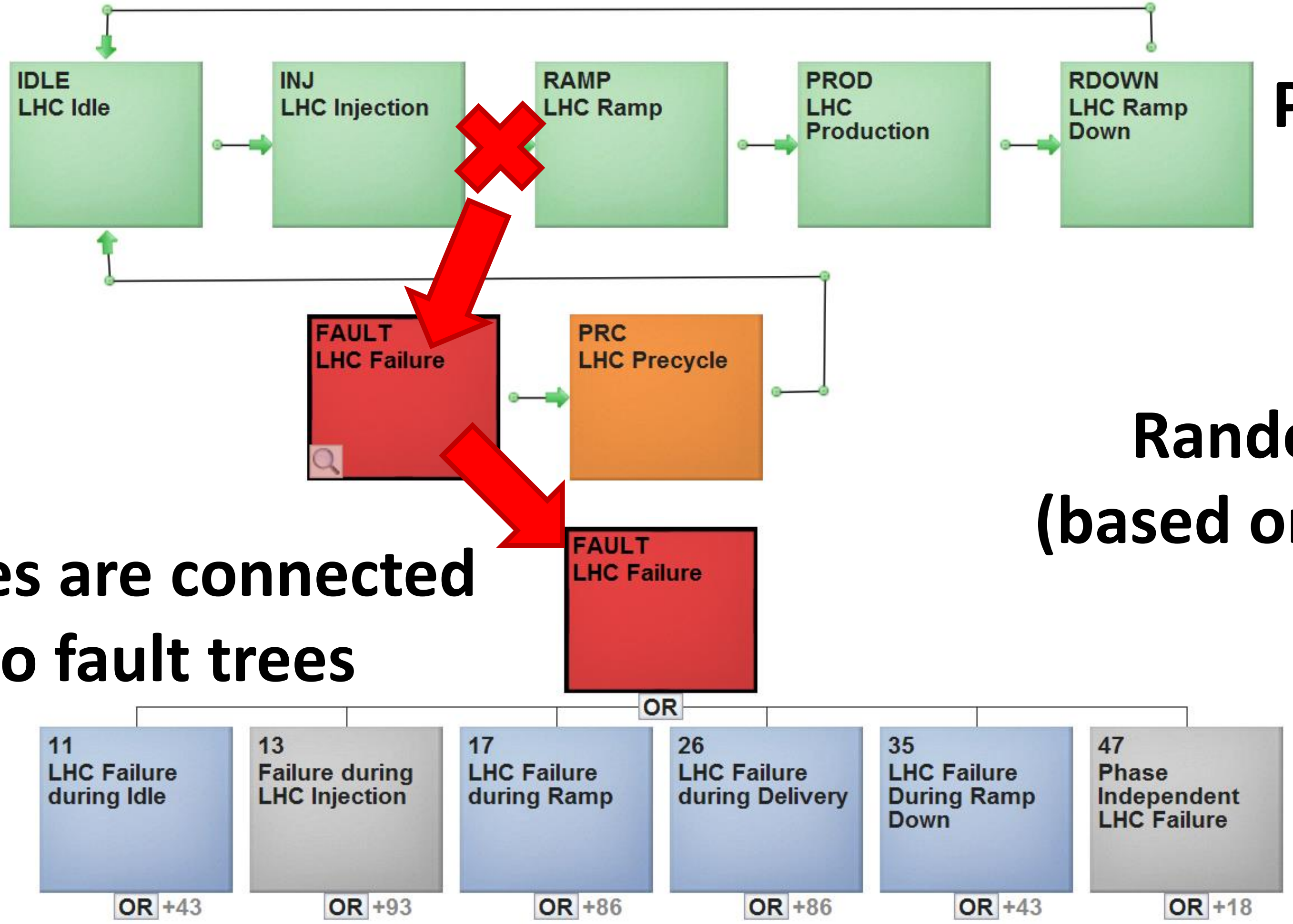


Multi-year operation schedule:
Run, Long Shutdown (LS)

Yearly operation schedule:
Technical stops (TS, YETS),
Hardware commissioning (HWC),
Beam commissioning (CWB),
Machine studies (MS),
Physics production

Beam production mode cycle phases:
Injection, Ramp, Stable beams,
Ramp-down, Idle time between cycles

Example: CERN phase dependent failure



Probabilistic phase transitions (Monte Carlo approach)

Randomly generated failures (based on probability distributions)

Phases are connected to fault trees

All failures are not relevant in all phases