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Probabilistic Risk and Performance Assessment

AFRY RELIABILITY TOOLS / AFRY X
JUSSI-PEKKA PENTTINEN

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Jussi-Pekka Penttinen

- Tampere University of Technology: M.Sc. (2005)
  - Thesis: Analysis of failure logic using simulation
- Ramentor Oy: Chief Architect (2004-2020)
  - Development of ELMAS tool
  - Research of reliability and risk analysis methods
- Tampere University: D.Sc. (2020)
  - Dissertation: An Object-Oriented Modelling Framework for Probabilistic Risk and Performance Assessment of Complex Systems
- AFRY: Senior Adviser, Product owner (2020-)
  - Reliability analysis and risk assessment: Research, development and application to various targets
- Comments and questions:
  - jussi-pekka.penttinen@afry.com, 040-8222629

Background – AFRY

- AFRY is a European leader in engineering, design, and advisory services, with a global reach
  - 17 000 employees globally (2 800 employees in Finland)
  - Offices in >40 countries (28 offices in Finland)
- In February 2019 ÅF and Pöyry joined forces
  - In November 2019 ÅF Pöyry launched a new common brand, AFRY
- Mission: We accelerate the transition towards a sustainable society
- We are devoted experts in infrastructure, industry, energy and digitalisation, creating sustainable solutions for generations to come

Providing leading solutions for generations to come – Making Future

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Background – AFRY’s offering in six divisions

Infrastructure

- Transportation
- Buildings
- Project Management
- Water
- Environment
- Architecture & Design

Industrial & Digital Solutions

- Advanced Automation
- Connected Products
- Automotive Design & Engineering
- Food & Pharma
- Specialised Technical Services
- Systems Management

Process Industries

- Bioindustries
- Chemicals
- Pulp, board, paper & tissue
- Mining & Metals
- Smart solutions: Health & Safety, Sustainability, AFRY Smart Site & digitalisation

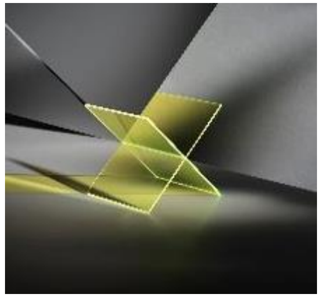
Energy

- Renewable Energy & Thermal Power
- Hydro
- Transmission & Distribution
- Nuclear
- Contracting

Management Consulting

- Energy Sector
- Bioindustry Sector
- Market Analysis
- Strategic Advice
- Operational Excellence
- M&A and Transactions

AFRY X



- Digital Products
- Digital Advisory
- Digital Services: Analytics, AI & Big data, Cyber Security, Design, Software dev’t & integration, Digital Quality

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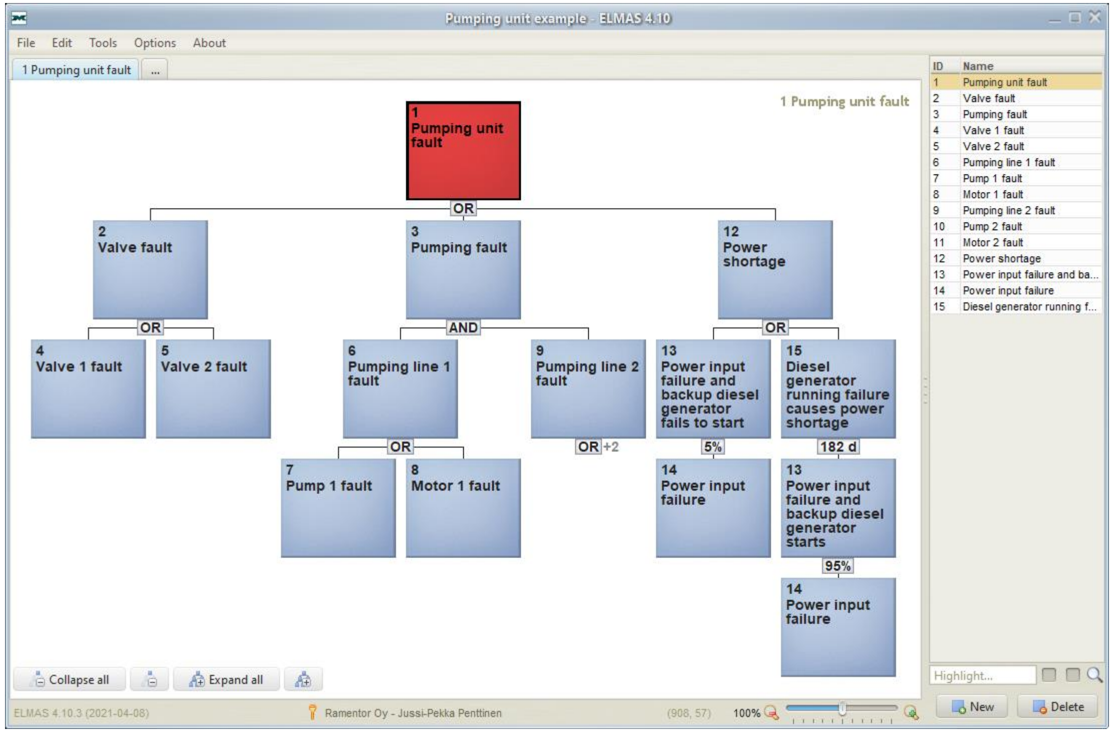
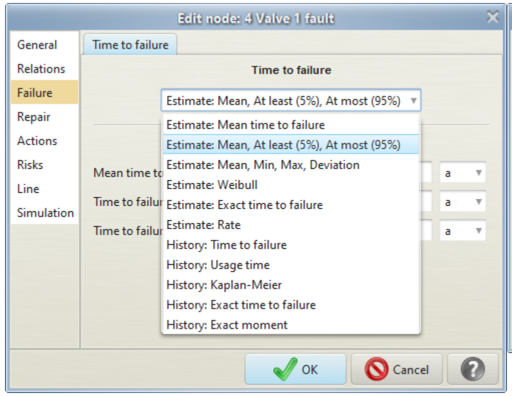
Background – AFRY X

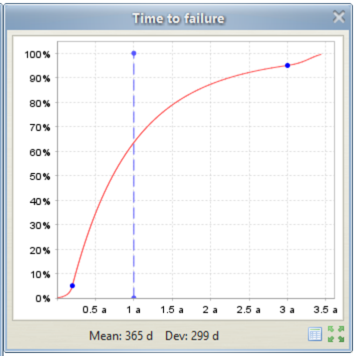
- AFRY X was set up as a new division as of 2022
  - AFRY X is a digital powerhouse that aims to be a digital leader in industrial IoT, AI, design and cyber security
  - More than 800 digital experts (100 in Finland)
  - Net sales about 100 million euros
- With basis in AFRY's deep sectoral expertise, AFRY X will develop and sell software in a SaaS business as well as offer cutting-edge digital services
- AFRY acquired Ramentor Oy in October 2020
  - The development of Ramentor's reliability and risk management software continues in AFRY X division

Background – ELMAS Fault Tree Analysis

- Graphical presentation of logical tree diagram
  - Efficient handling of large trees (>10 000 faults)
- Advanced failure logic and time distribution definitions
  - Standard logic gates, probabilities and delays included
  - Create failure and repair distributions based on experts' best estimates or by importing history data (distribution fitting)
- Stochastic discrete event simulation (DES)
  - Various risk and reliability analysis results based on simulation
- Include qualitative analysis for risk prioritization
  - Failure modes and effects and criticality analysis (FMECA), PSK 6800, or customized domain specific criticality classification
- Include dynamic process modelling
  - Process phase/mode changes, buffers/other delays, etc.
- Automatized fault tree creation / criticality classification







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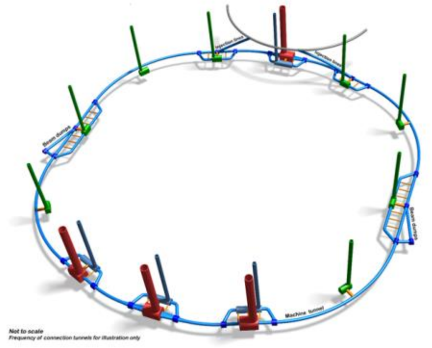
Probabilistic modelling

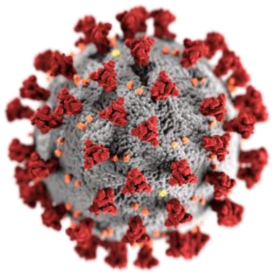


CERN particle accelerator that delivers collisions for scientific research

Availability goal for a future circular collider (FCC-ee) is 80%

Production line that makes donuts

In average 100 000 donuts are produced per day



Spreading of the Coronavirus

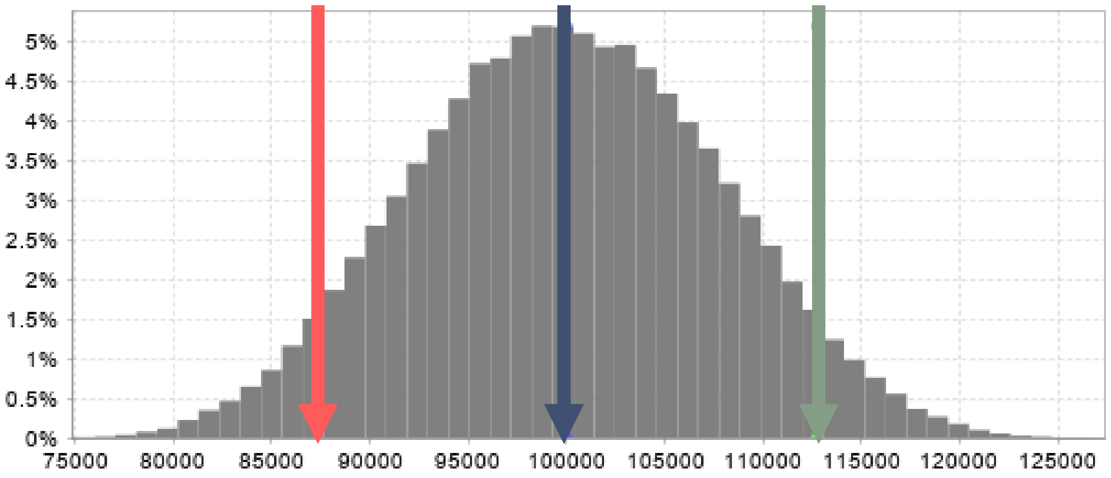
The value of the basic reproduction number (R0) in Finland was 2.4

Lotto, in which 7 numbers are drawn from a pool of 40 numbers

In average 18 million lines are needed to match 7 numbers

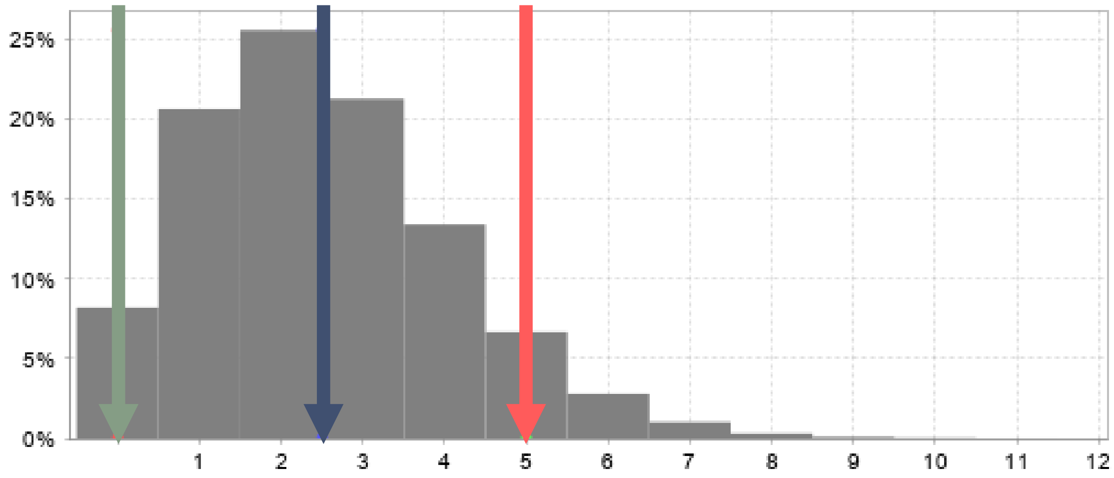
Probability distribution

Number of donuts produced



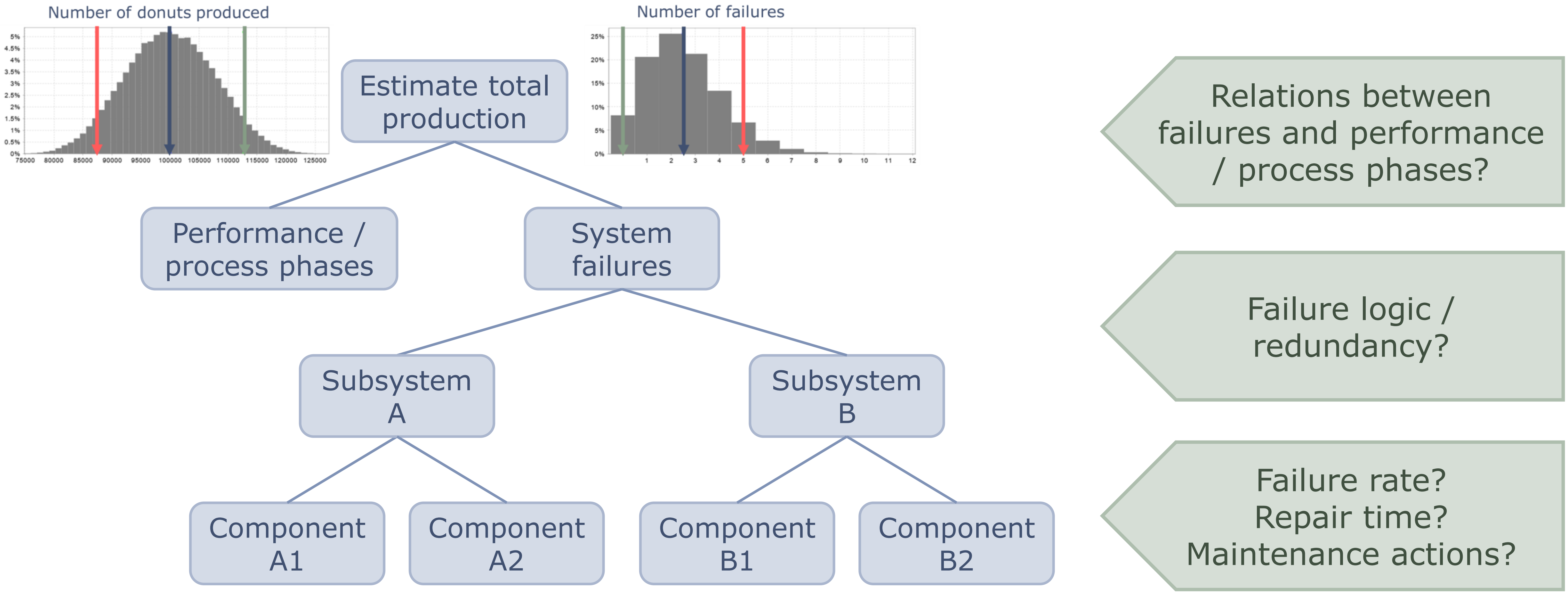
Bad case (5%)	Mean	Good case (95%)
87 000 donuts produced	100 000 donuts produced	113 000 donuts produced

Number of failures



Good case (5%)	Mean	Bad case (95%)
No failures	2.5 failures	5 failures

Reliability and performance model



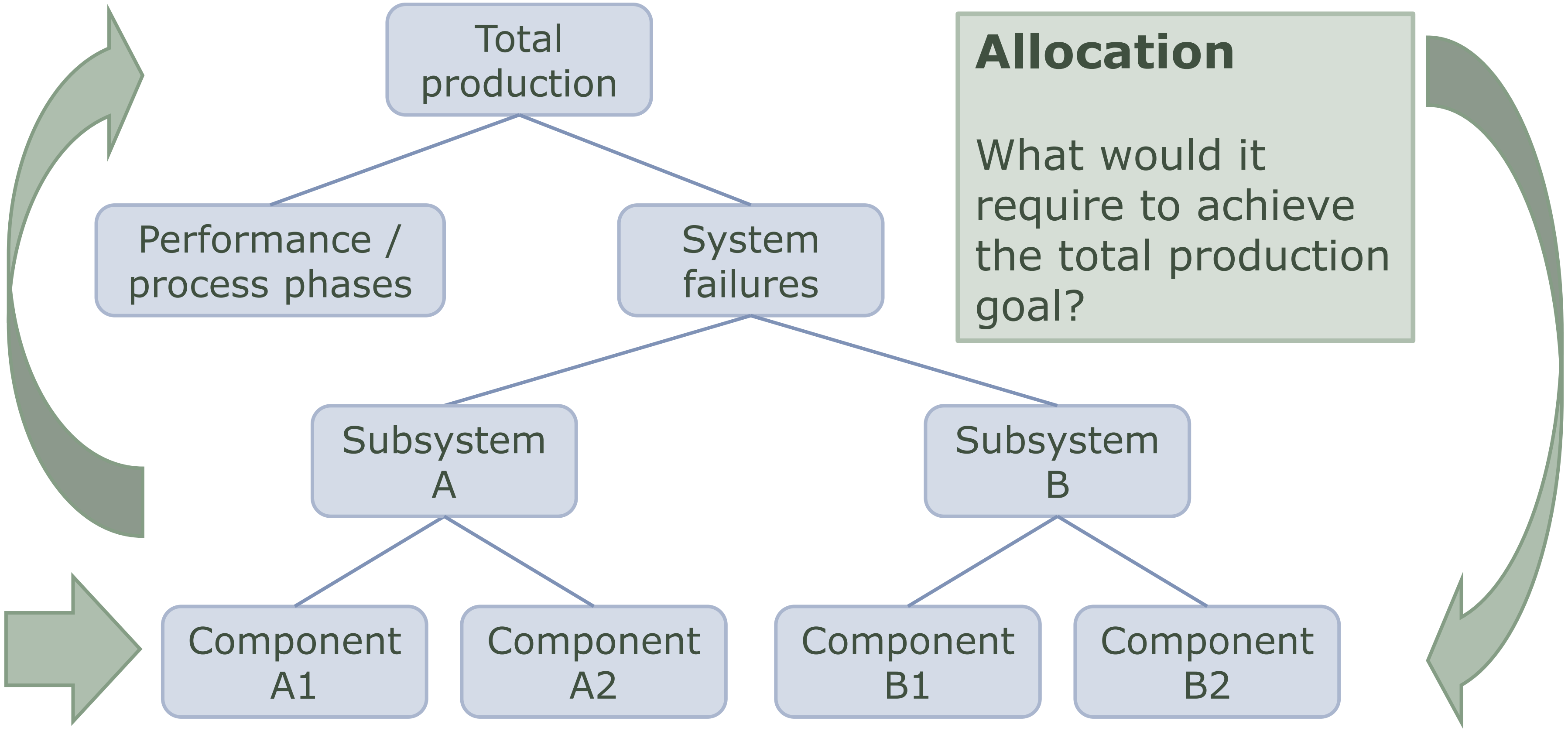
Model → Understanding → Decisions

Scenario analysis

How much would improving a component affect to the total production?

Criticality

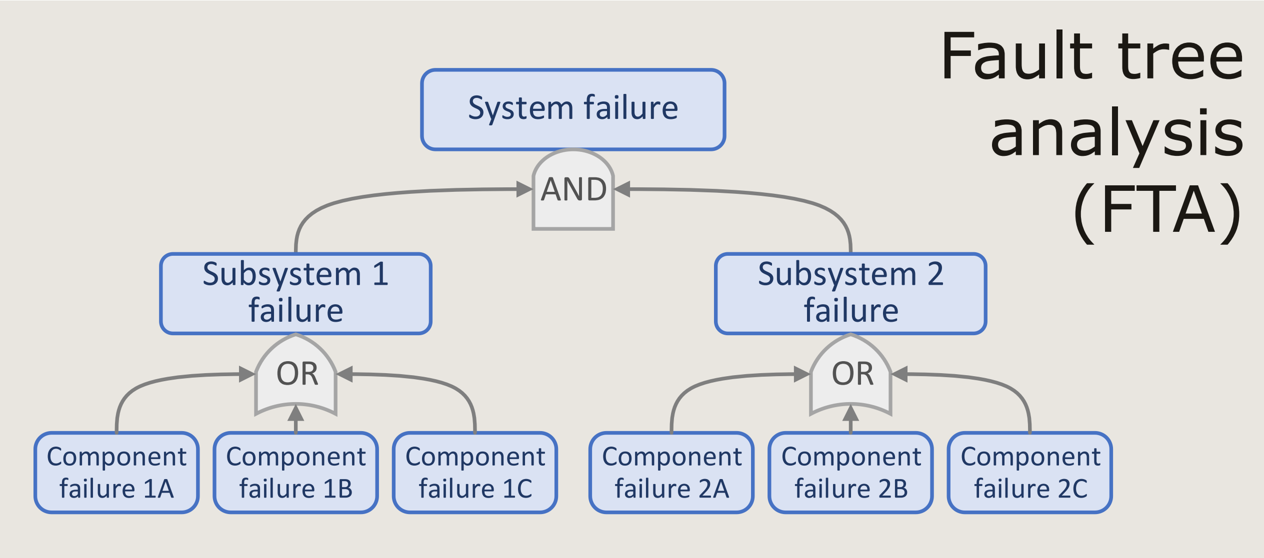
What are the most important components?

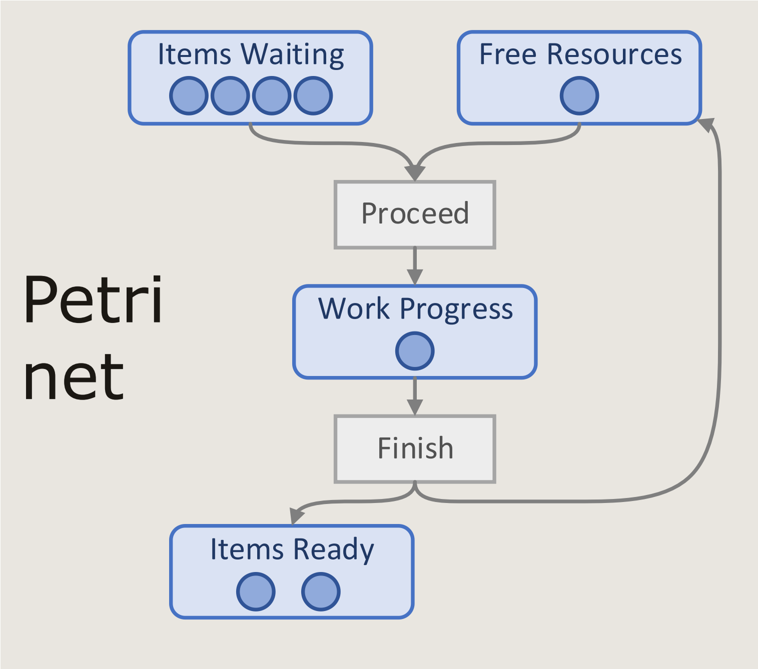


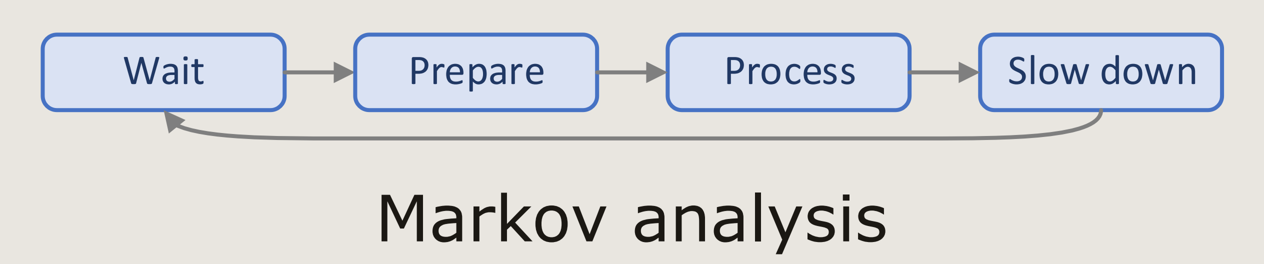
Allocation

What would it require to achieve the total production goal?

Traditional risk assessment techniques







Event Tree Analysis (ETA), Failure Mode and Effect and Criticality Analysis (FMECA), etc.

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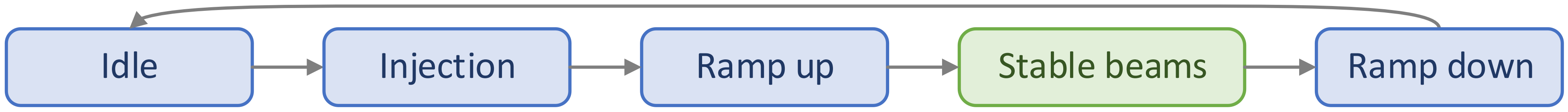
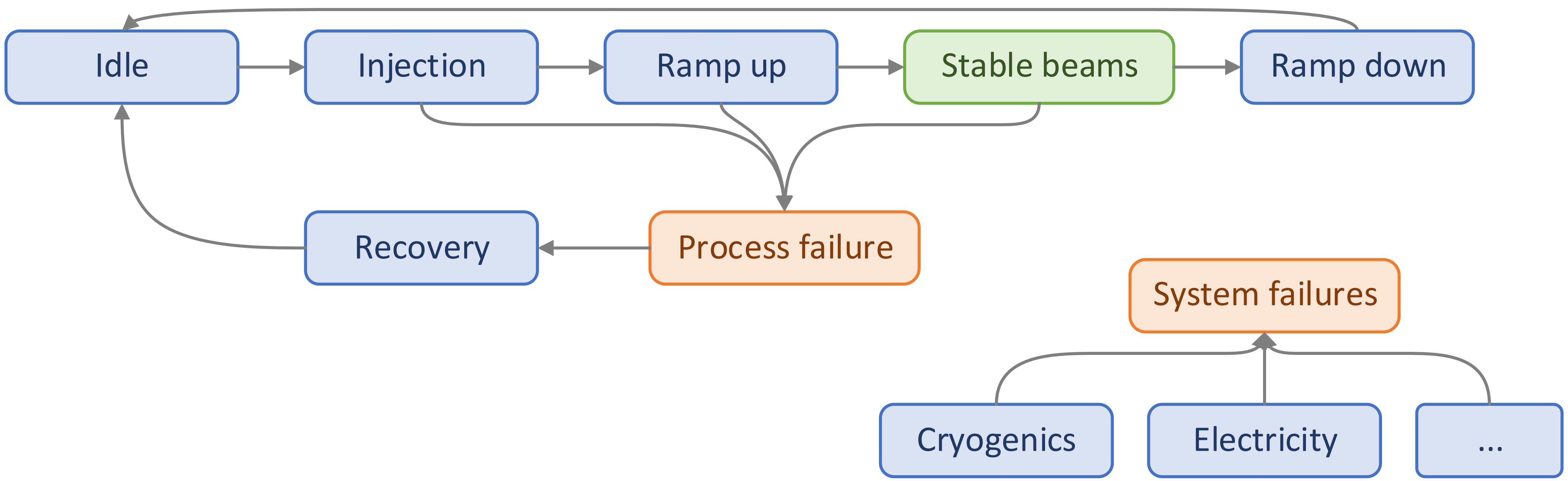
Process modelling – Case: CERN



Process modelling – Case: CERN



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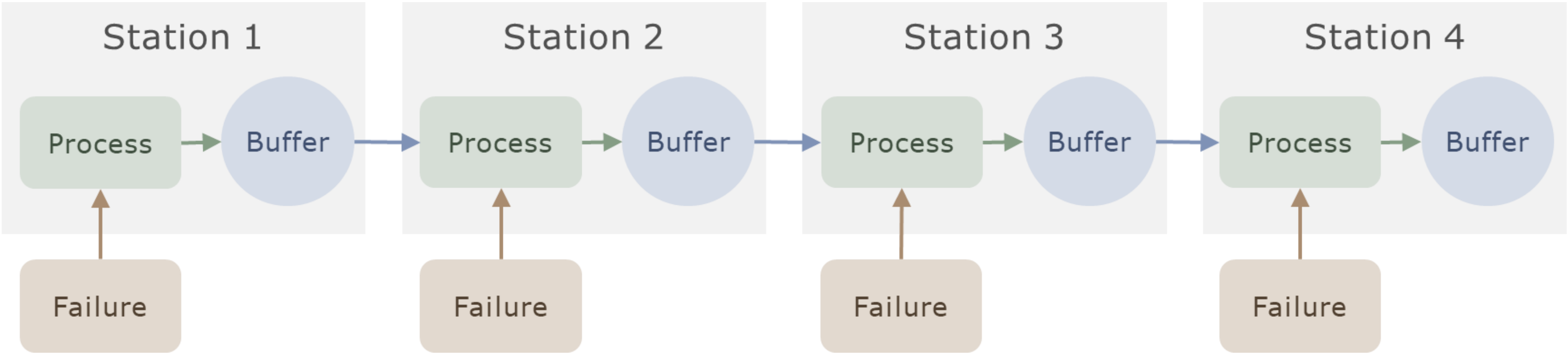
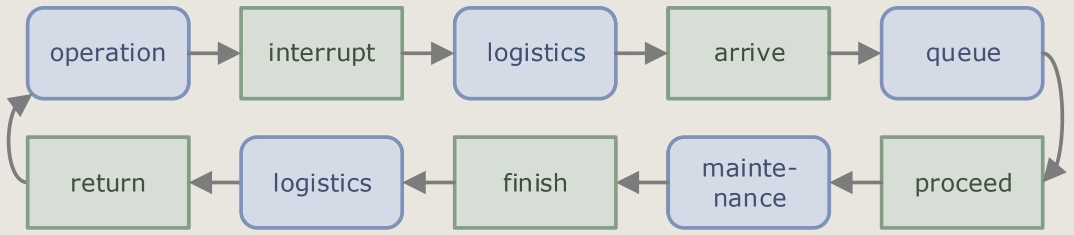
Process modelling – Case: Manufacturing

- Demo case: Four stations in a sequence
  - Each station has a process unit and a buffer
  - Failures can stop the process
  - Maximum number of items is defined for a buffer
- Results
  - Total number of items manufactured
  - Buffer level progress of each station
  - Delays because of empty/full buffer

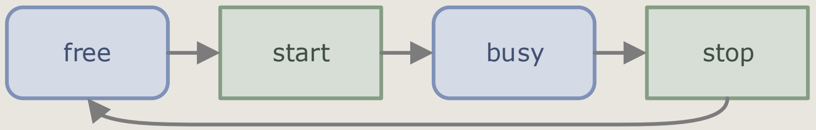


Fleet maintenance modelling

- State model for each system of the fleet:
  - Interrupts caused by failures/preventive maintenance
  - Logistics delays to and from maintenance
  - Queueing if maintenance resources not available
  - Duration of maintenance operations
- State model for each maintenance resource:
  - Model start and stop of maintenance operations
  - Different model for each resource type: workshops, critical tools, human resources, spare parts...
  - Different resource needs of maintenance operations



Several system models

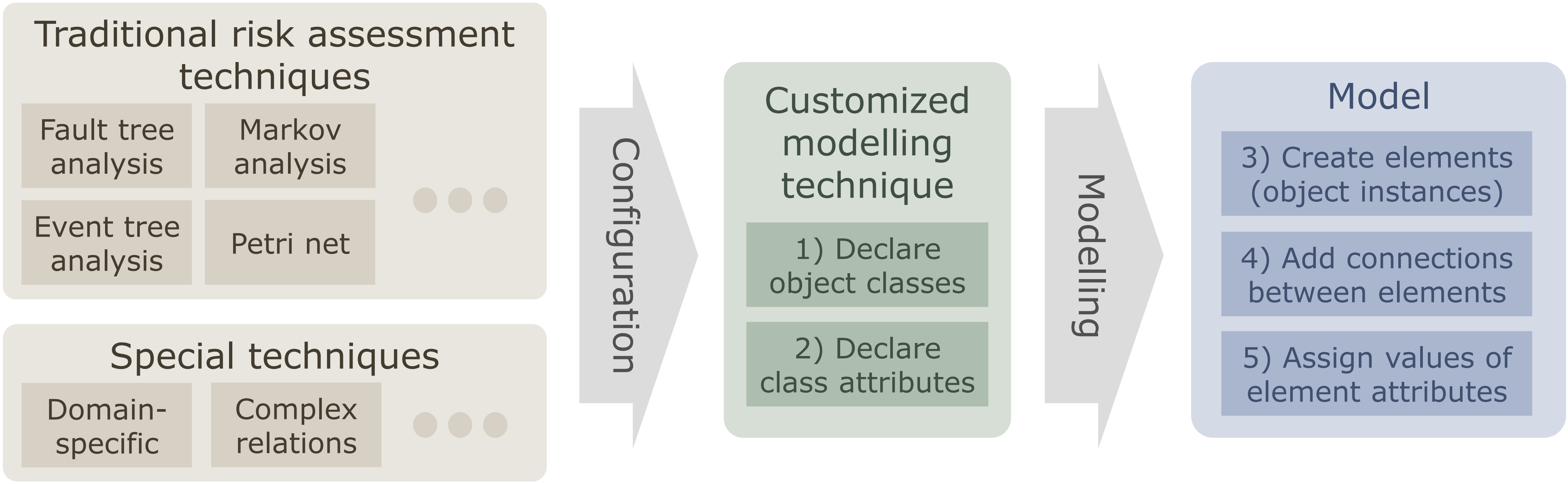


Several resource models

Fleet model that combines several systems and resources

The framework is named as Analysis of Things (AoT) to emphasize its universal nature and wide application possibilities.

AoT – Object-oriented modelling framework



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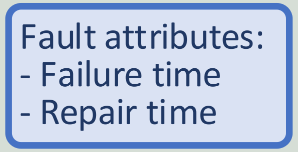
AoT – Object-oriented model (FTA)

The framework is named as Analysis of Things (AoT) to emphasize its universal nature and wide application possibilities.

Configuration

1) Model object classes

2) Model class attributes

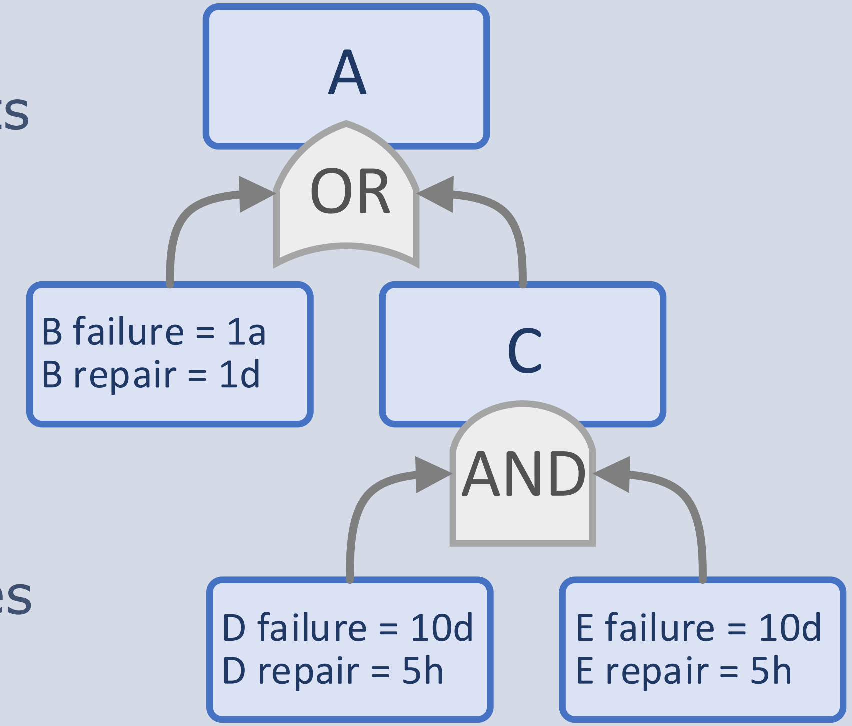


Model

3) Model elements

4) Connections

5) Attribute values



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The framework is named as Analysis of Things (AoT) to emphasize its universal nature and wide application possibilities.

AoT – Tabular model definition format

A reliability analysis expert configures the modelling approach
- 1) Declare classes
- 2) Declare attributes

User creates a model with a software tool or by using automatized import
- 3) Create model elements
- 4) Add connections
- 5) Assign attribute values

A	B	C
Fault	class	Element
OR	class	Element
AND	class	Element
Fault/failure	attribute	Duration
Fault/repair	attribute	Duration
A,B,C,D,E	instance	Fault
A/child	connect	OR
OR/child	connect	B,C
B/failure	=	1a
B/repair	=	1d

Application of the created model
- Store the model to a database
- Share the model with other analysis tools/users
- Simulate analysis results

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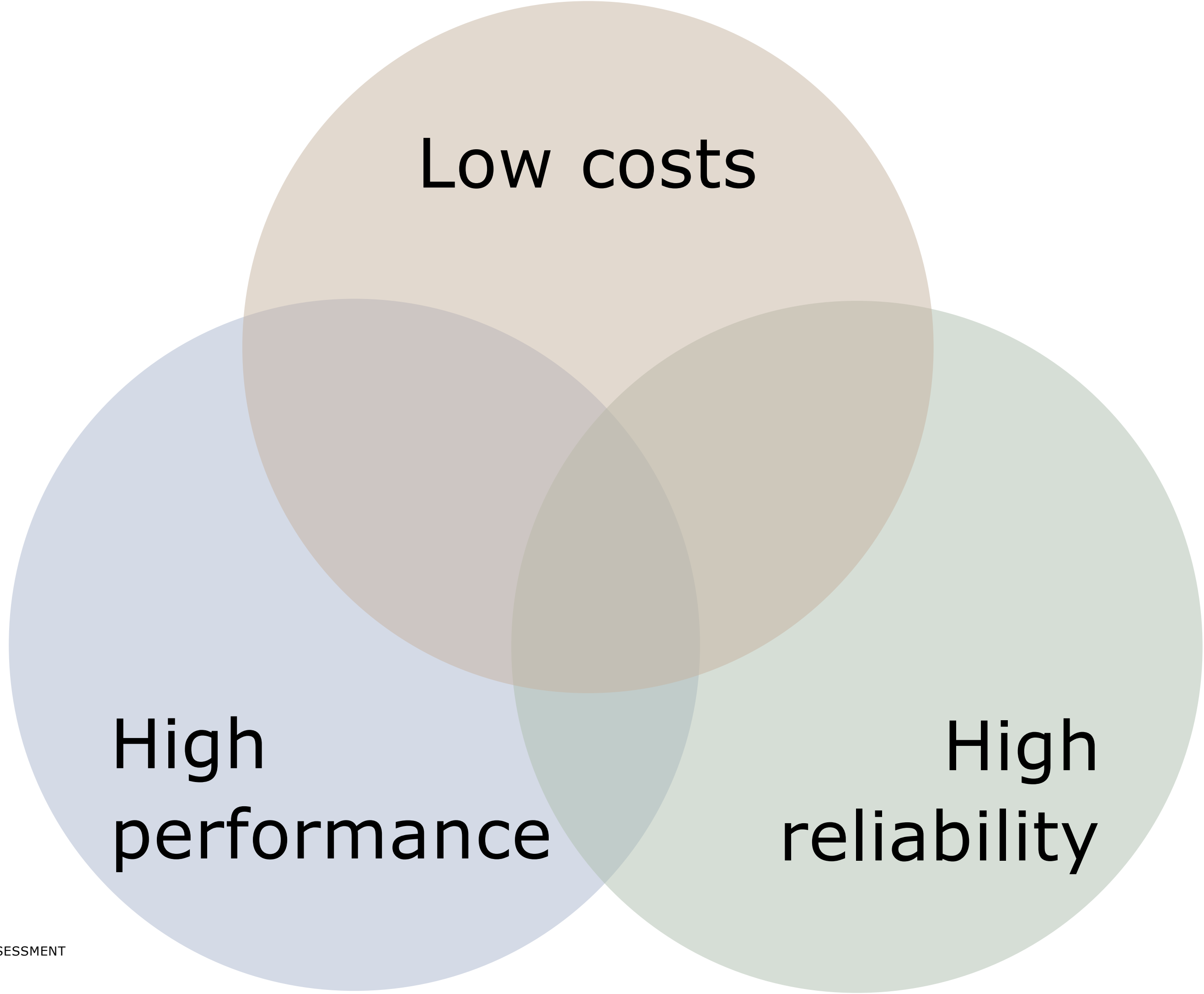
Risk/reliability management



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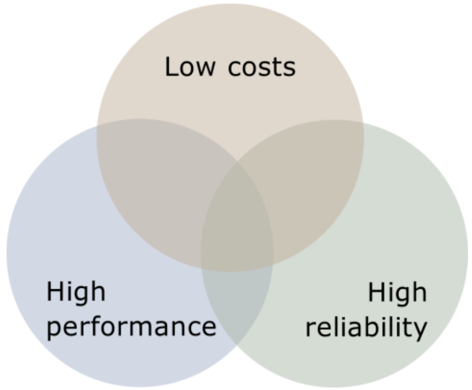
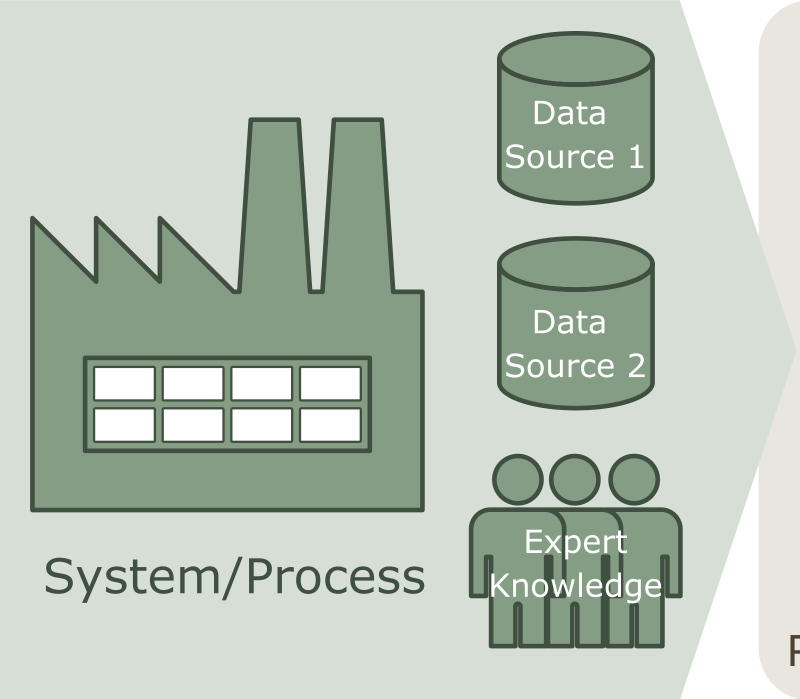
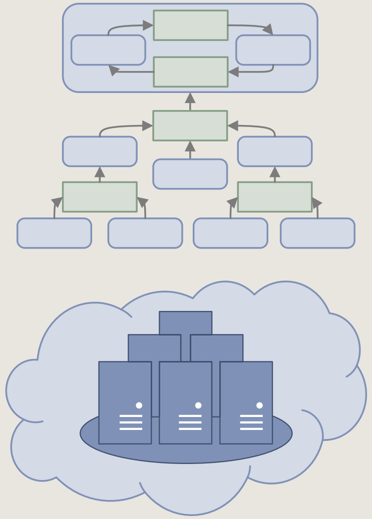
Risk/reliability assessment process





Reliability/Operation Model



Risk/Performance Simulation

- ▶ Is the **required reliability/availability** achieved? Is the risk tolerable?
- ▶ What is the **overall effect** of failures on system key performance indicators?
- ▶ Which are the most critical (**TOP 10**) components and how to improve them?
- ▶ Where to add **monitoring** or apply **AI**?
- ▶ What are the overall effects of proposed **improvements or scenarios**?
- ▶ What is the **return of investment** time?

System → Model → Analysis → Results

Questions or comments?

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AoT Framework

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AoT Framework

The framework is named as Analysis of Things (AoT) to emphasize its universal nature and wide application possibilities.

Model definition with graphical user interfaces (expert tools)

Failure/maintenance/other databases (automatic import)

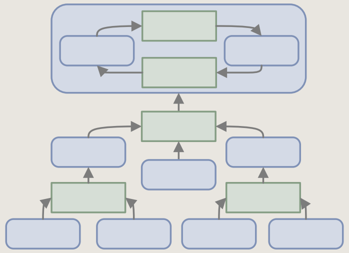
Condition monitoring, Real time data, IoT (automatic import)

Analysis with graphical user interface (executive tools)

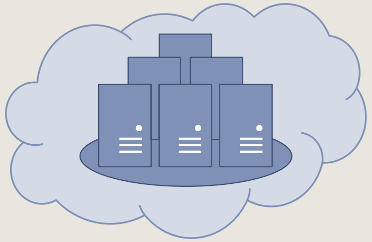
Model definition interface

Application Programming Interface (API)

Reliability/operation modeling



AoT Framework



Risk/performance simulation

Analysis results interface

Overall availability/performance, The most critical components/failures (TOP 10)

Maintenance scheduling/optimization, Action planning, Resource allocation

Dashboards and guidance for system operators and maintenance personnel

Risk assessment, Scenario analyses, Return of investment times

Data → API → Model → Analysis → API → Results

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AFRY Reliability Tools Platform

Stand-alone modelling and simulation tools (Java)

Integrated calculation engines (customer’s APM/other systems)

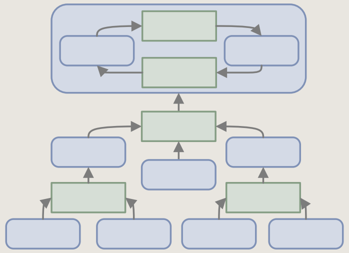
Cloud-based modelling and simulation tools (web browser)

Customized analysis tools and user interfaces for special cases

Model definition interface

Application Programming Interface (API)

Reliability/operation modeling



AFRY Reliability Tools

Risk/performance simulation

Analysis results interface

ELMAS, Fault tree analysis (FTA), FMECA, RCM and other risk assessment techniques

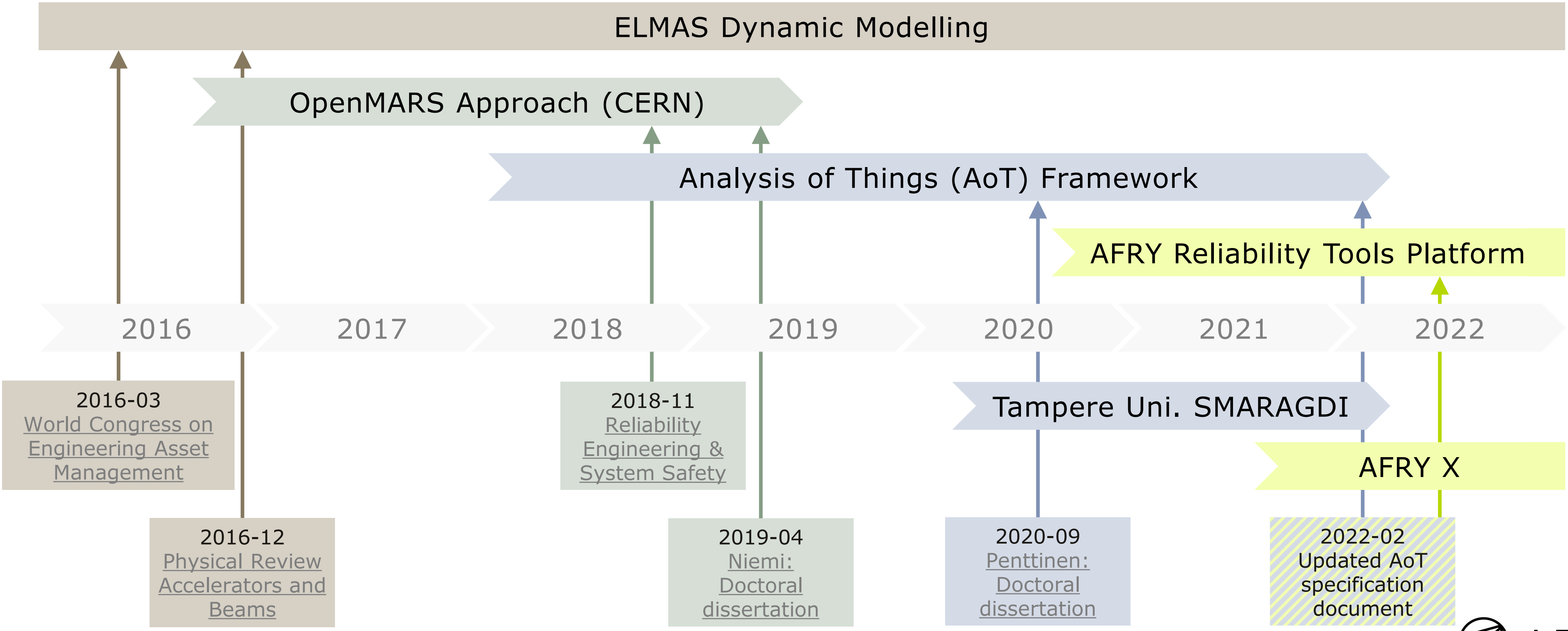
Production/performance optimization, Availability/safety/overall risk management

Fleet maintenance/operation planning, Spare part storage optimization, etc.

Customized analysis results and domain specific visualizations

Tool → API → Model → Analysis → API → Solution

Timeline – Publications



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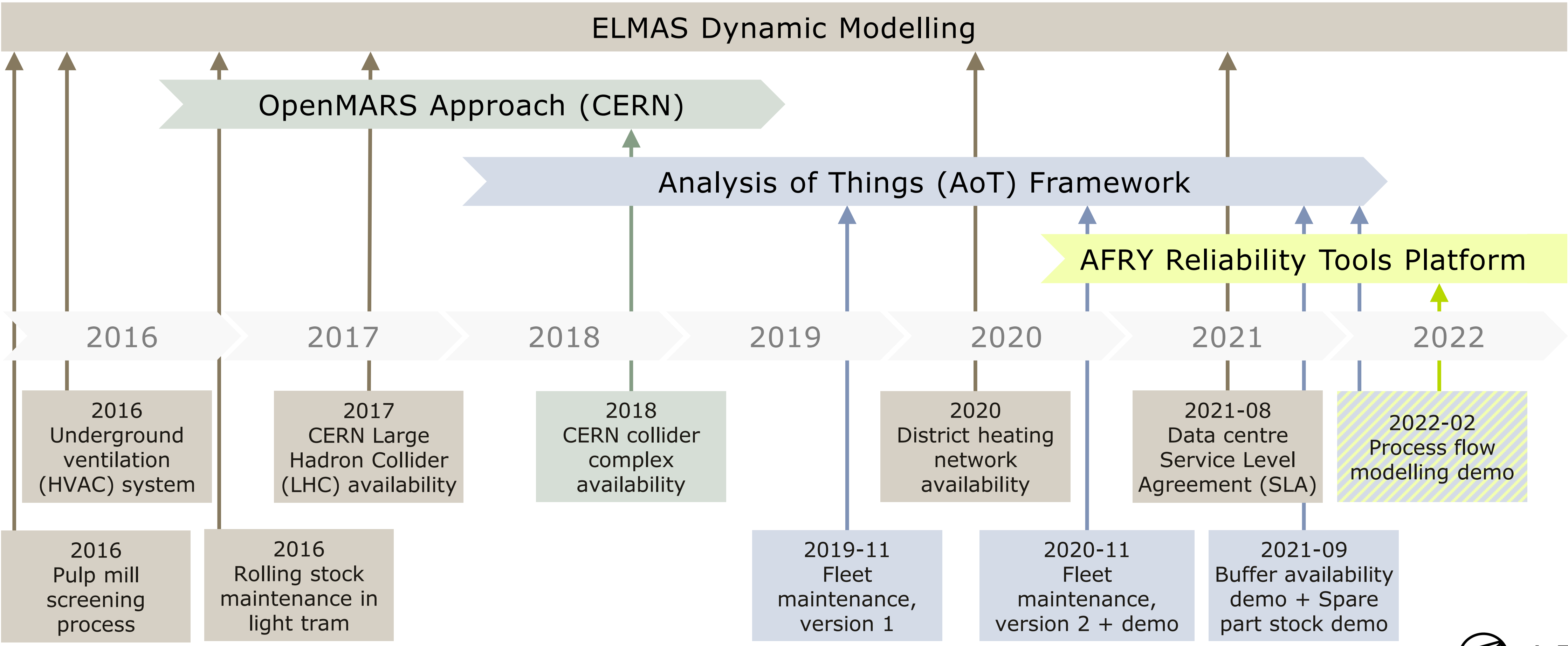
Timeline – Applications



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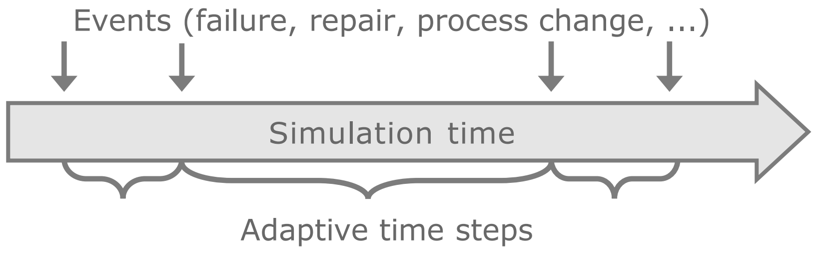
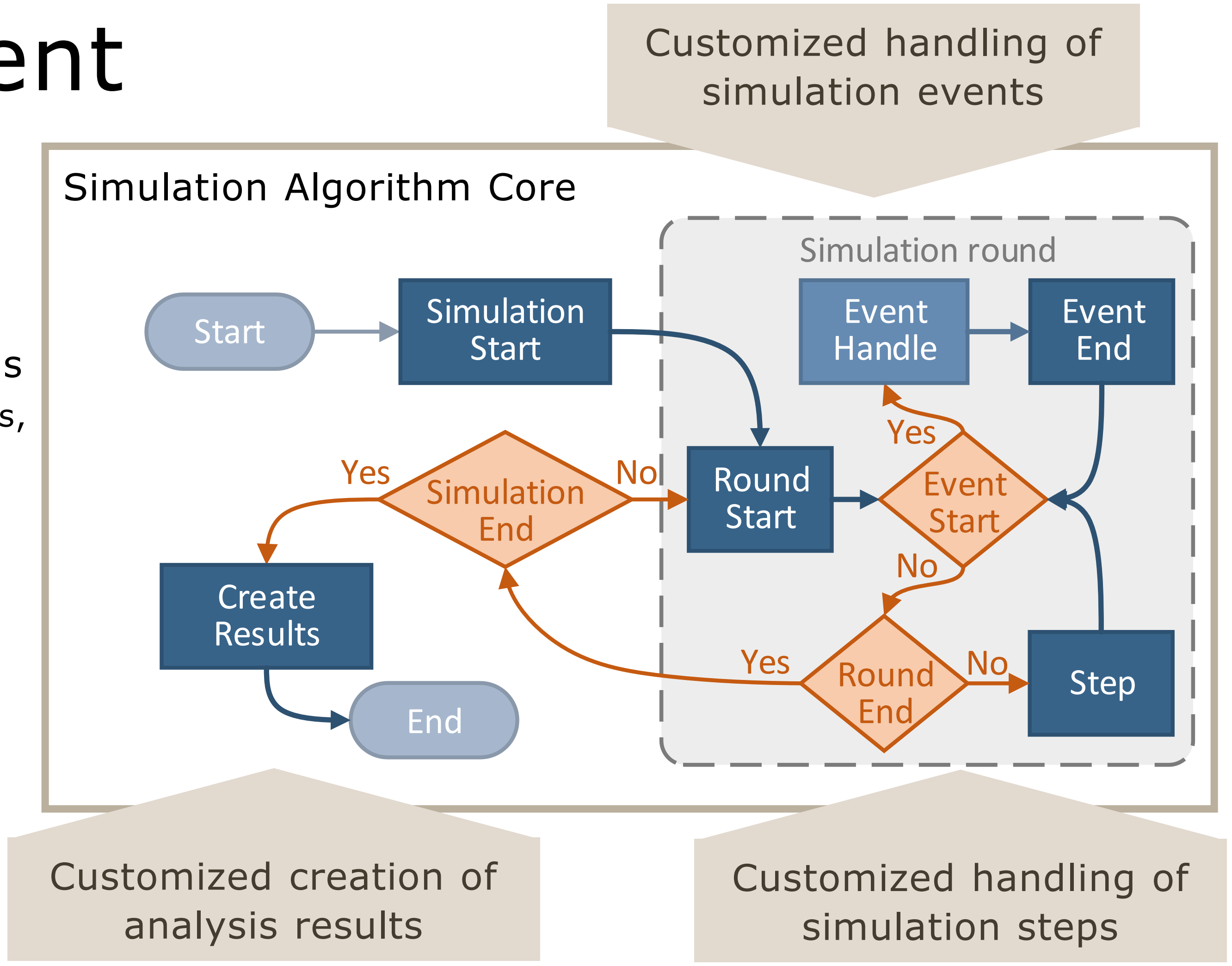
AoT – Flexible simulation algorithm development

- Customized simulation algorithms are formed by applying template method pattern
- The algorithm core contains template methods
  - The core includes also handling of simulation rounds, event queue and result data collection
- Customized content fills the core algorithm
  - Customized event handling
  - Customized simulation time step handling
  - Customized creation of analysis results

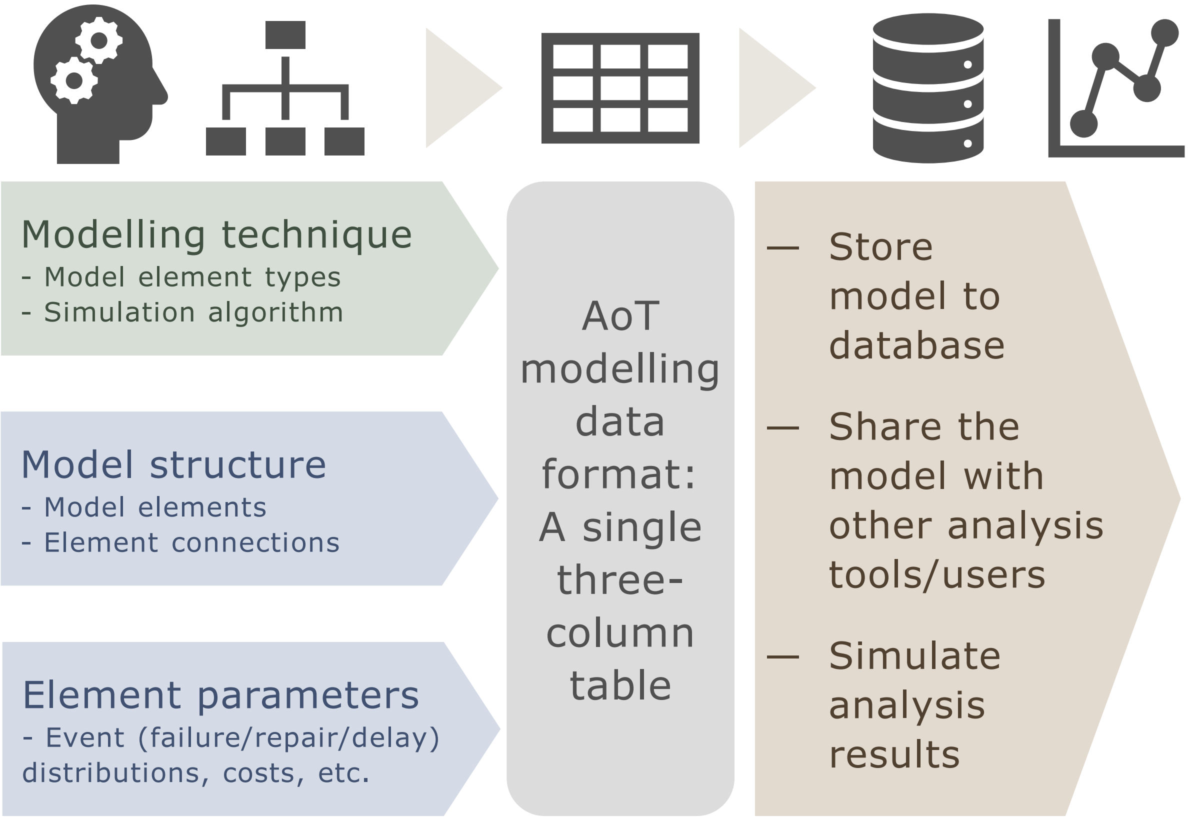




The framework is named as Analysis of Things (AoT) to emphasize its universal nature and wide application possibilities.

AoT – Flexible modelling data format

- A single table combines the model information
  - Includes modelling technique definition
  - Includes model element/structure definition
  - Includes model parameter definition
- Tabular definition of object-oriented models
  - Plain, compact and platform-independent format
  - Simple and efficient storing of models to database
  - Enables manual model editing (Excel)
- The three-column table lists definition rows
  - Column A: The object of the definition
  - Column B: Keyword indicates the type of the definition
  - Column C: The value defined for the object
- Special keywords for analysis tool UI definition
  - Localisation/translations, input fields, result charts, ...



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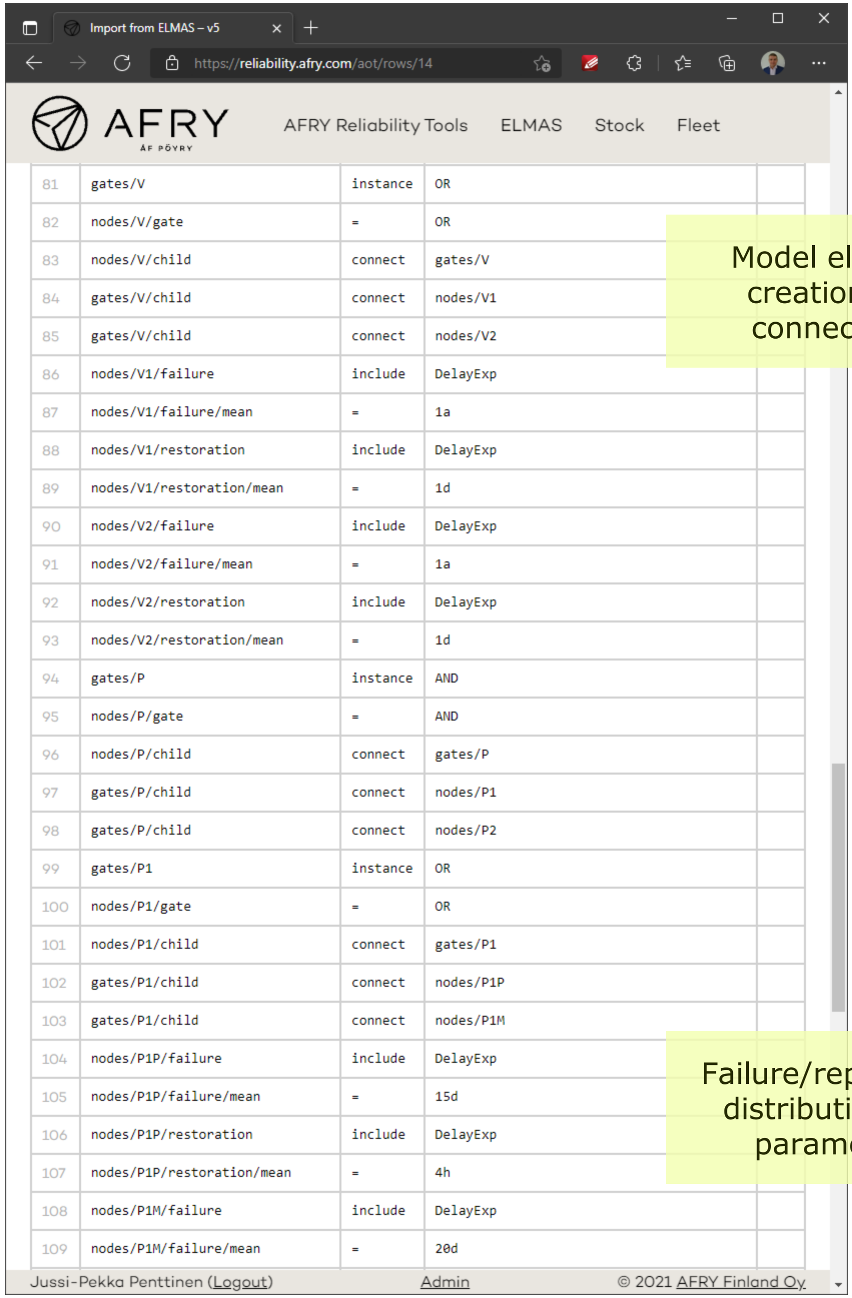
Tabular format for model definition

- Modelling technique definition keywords
  - `class`: Create an element class
  - `container`: Class elements can contain other elements
  - `attribute`: Class elements have an attribute
  - `prototype`: Create a sub element for class elements
- Model element structure definition keywords
  - `instance`: Create an element of a class
  - `include`: Include features to an element
  - `connect`: Connection to another element
- Element attribute value definition keywords
  - `share`: Share an attribute value with another element
  - `add`: Add a value to an attribute
  - `assignment(=)`: Assign an attribute value



81	gates/V	instance	OR
82	nodes/V/gate	=	OR
83	nodes/V/child	connect	gates/V
84	gates/V/child	connect	nodes/V1
85	gates/V/child	connect	nodes/V2
86	nodes/V1/failure	include	DelayExp
87	nodes/V1/failure/mean	=	1a
88	nodes/V1/restoration	include	DelayExp
89	nodes/V1/restoration/mean	=	1d
90	nodes/V2/failure	include	DelayExp
91	nodes/V2/failure/mean	=	1a
92	nodes/V2/restoration	include	DelayExp
93	nodes/V2/restoration/mean	=	1d
94	gates/P	instance	AND
95	nodes/P/gate	=	AND
96	nodes/P/child	connect	gates/P
97	gates/P/child	connect	nodes/P1
98	gates/P/child	connect	nodes/P2
99	gates/P1	instance	OR
100	nodes/P1/gate	=	OR
101	nodes/P1/child	connect	gates/P1
102	gates/P1/child	connect	nodes/P1P
103	gates/P1/child	connect	nodes/P1M
104	nodes/P1P/failure	include	DelayExp
105	nodes/P1P/failure/mean	=	15d
106	nodes/P1P/restoration	include	DelayExp
107	nodes/P1P/restoration/mean	=	4h
108	nodes/P1M/failure	include	DelayExp
109	nodes/P1M/failure/mean	=	20d

Model element creation and connections

Failure/repair time distribution and parameters

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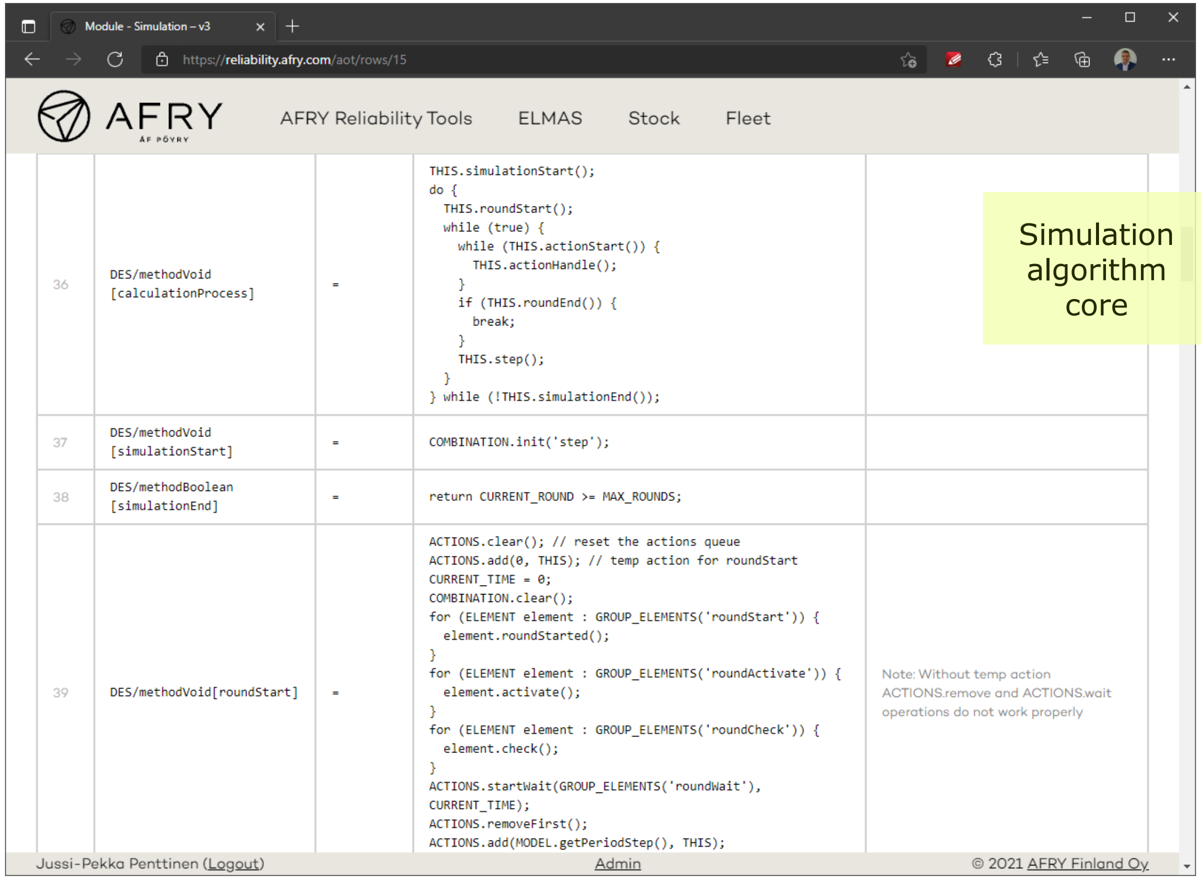
Tabular format for simulation algorithm



Module - Simulation – v3

https://reliability.afry.com/aot/rows/15

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36	DES/methodVoid [calculationProcess]	=	THIS.simulationStart();
			do {
			THIS.roundStart();
			while (true) {
			while (THIS.actionStart()) {
			THIS.actionHandle();
			}
			if (THIS.roundEnd()) {
			break;
			}
			THIS.step();
			}
			} while (!THIS.simulationEnd());	

37	DES/methodVoid [simulationStart]	=	COMBINATION.init('step');	
38	DES/methodBoolean [simulationEnd]	=	return CURRENT_ROUND >= MAX_ROUNDS;	

39	DES/methodVoid[roundStart]	=	ACTIONS.clear(); // reset the actions queue
			ACTIONS.add(0, THIS); // temp action for roundStart
			CURRENT_TIME = 0;
			COMBINATION.clear();
			for (ELEMENT element : GROUP_ELEMENTS('roundStart')) {
			element.roundStarted();
			}
			for (ELEMENT element : GROUP_ELEMENTS('roundActivate')) {
			element.activate();
			}
			for (ELEMENT element : GROUP_ELEMENTS('roundCheck')) {
			element.check();
			}
			ACTIONS.startWait(GROUP_ELEMENTS('roundWait'),
			CURRENT_TIME);
			ACTIONS.removeFirst();
			ACTIONS.add(MODEL.getPeriodStep(), THIS);
				Note: Without temp action ACTIONS.remove and ACTIONS.wait operations do not work properly

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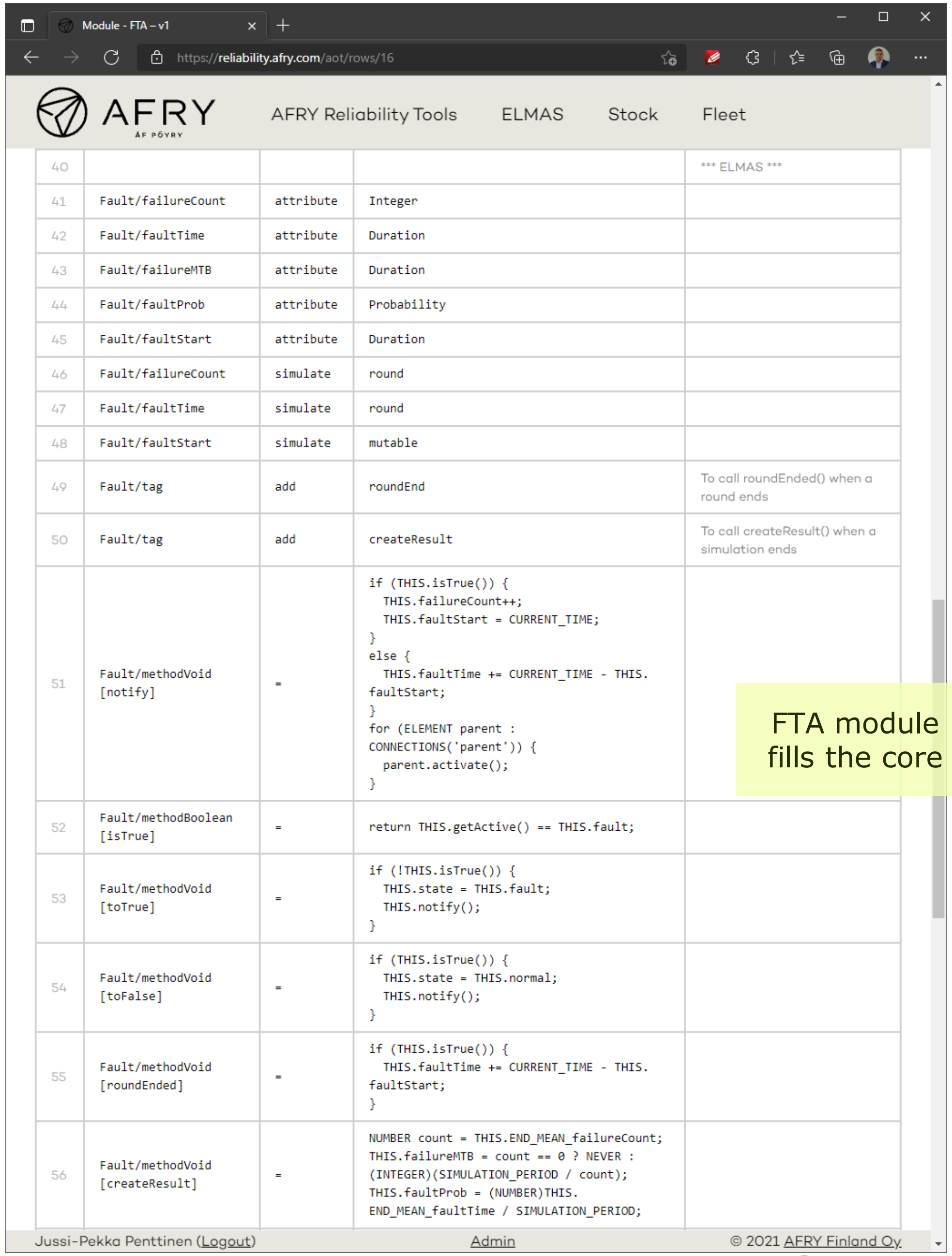
Simulation algorithm core



Module - FTA – v1

https://reliability.afry.com/aot/rows/16

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40				*** ELMAS ***
41	Fault/failureCount	attribute	Integer	
42	Fault/faultTime	attribute	Duration	
43	Fault/failureMTB	attribute	Duration	
44	Fault/faultProb	attribute	Probability	
45	Fault/faultStart	attribute	Duration	
46	Fault/failureCount	simulate	round	
47	Fault/faultTime	simulate	round	
48	Fault/faultStart	simulate	mutable	
49	Fault/tag	add	roundEnd	To call roundEnded() when a round ends
50	Fault/tag	add	createResult	To call createResult() when a simulation ends

51	Fault/methodVoid [notify]	=	if (THIS.isTrue()) {
			THIS.failureCount++;
			THIS.faultStart = CURRENT_TIME;
			}
			else {
			THIS.faultTime += CURRENT_TIME - THIS.
			faultStart;
			}
			for (ELEMENT parent :
			CONNECTIONS('parent')) {
			parent.activate();
			}	

52	Fault/methodBoolean [isTrue]	=	return THIS.getActive() == THIS.fault;	

53	Fault/methodVoid [toTrue]	=	if (!THIS.isTrue()) {
			THIS.state = THIS.fault;
			THIS.notify();
			}	

54	Fault/methodVoid [toFalse]	=	if (THIS.isTrue()) {
			THIS.state = THIS.normal;
			THIS.notify();
			}	

55	Fault/methodVoid [roundEnded]	=	if (THIS.isTrue()) {
			THIS.faultTime += CURRENT_TIME - THIS.
			faultStart;
			}	

56	Fault/methodVoid [createResult]	=	NUMBER count = THIS.END_MEAN_failureCount; THIS.failureMTB = count == 0 ? NEVER : (INTEGER)(SIMULATION_PERIOD / count); THIS.faultProb = (NUMBER)THIS. END_MEAN_faultTime / SIMULATION_PERIOD;	

Jussi-Pekka Penttinen (Logout) Admin © 2021 AFRY Finland Oy

FTA module fills the core

Publications and Specifications

- An Object-Oriented Modelling Framework for Probabilistic Risk and Performance Assessment of Complex Systems
  - The doctoral dissertation describes how the OpenMARS approach is developed further to be a generic framework for development of reliability analysis and risk/performance assessment tools
  - http://urn.fi/URN:ISBN:978-952-03-1635-8
- Modeling Future Hadron Colliders' Availability for Physics
  - The doctoral dissertation presents how ELMAS was applied in CERN to model the Large Hadron Collider (LHC) and how the development of the OpenMARS approach was started
  - http://urn.fi/URN:ISBN:978-952-03-1057-8
- An open modelling approach for availability and reliability of systems
  - The peer-reviewed journal article presents the OpenMARS approach
  - https://researchportal.tuni.fi/en/publications/an-open-modelling-approach-for-availability-and-reliability-of-sy-2
- An Open Modelling Approach for Availability and Reliability of Systems – OpenMARS
  - The OpenMARS specification in CERN document server
  - https://cds.cern.ch/record/2302387

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Questions or comments?

Reliability Tools

AFRY RELIABILITY TOOLS / AFRY X
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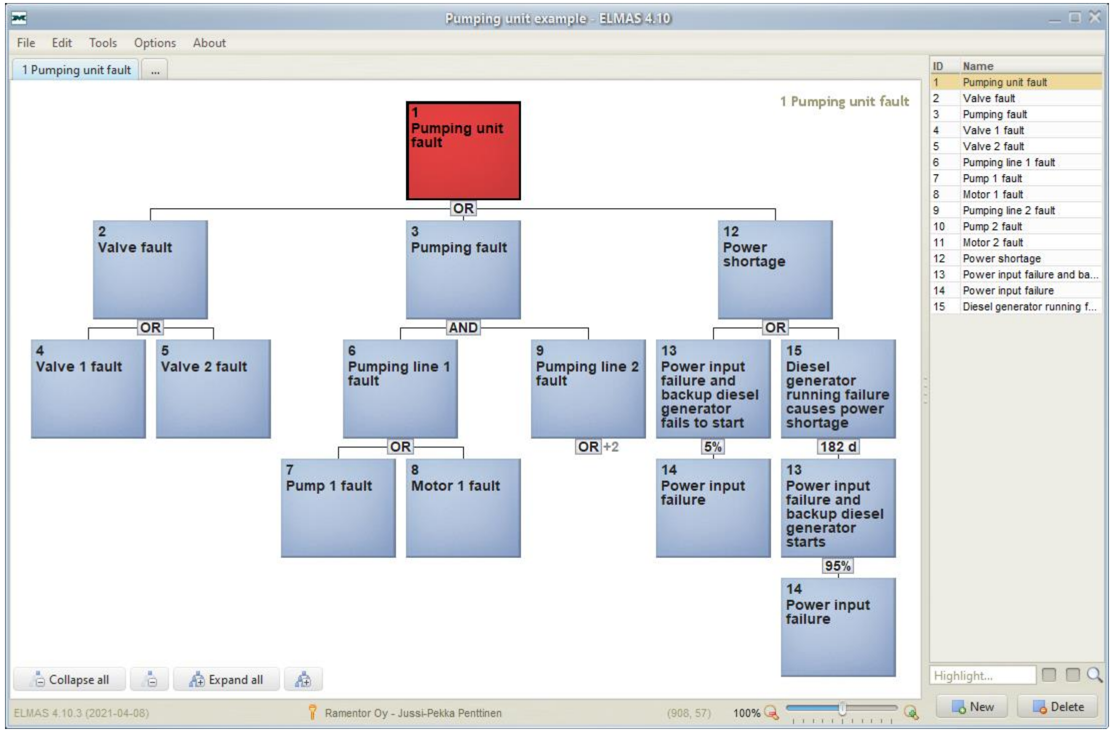
ELMAS FTA



— Graphical presentation of logical tree diagram
  — Efficient handling of large trees (>10 000 faults)

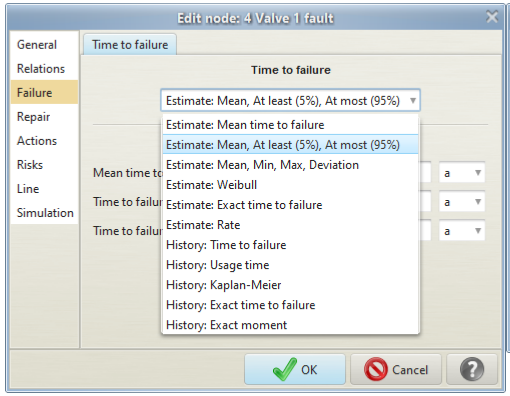
— Advanced failure logic and time distribution definitions
  — Standard logic gates, probabilities and delays included
  — Create failure and repair distributions based on experts' best estimates or by importing history data (distribution fitting)

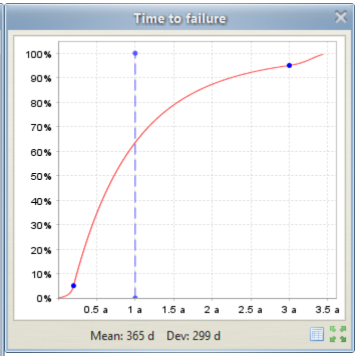
— Stochastic discrete event simulation (DES)
  — Various risk and reliability analysis results based on simulation

— Include qualitative analysis for risk prioritization
  — Failure modes and effects and criticality analysis (FMECA), PSK 6800, or customized domain specific criticality classification

— Include dynamic process modelling
  — Process phase/mode changes, buffers/other delays, etc.

— Automatized fault tree creation / criticality classification





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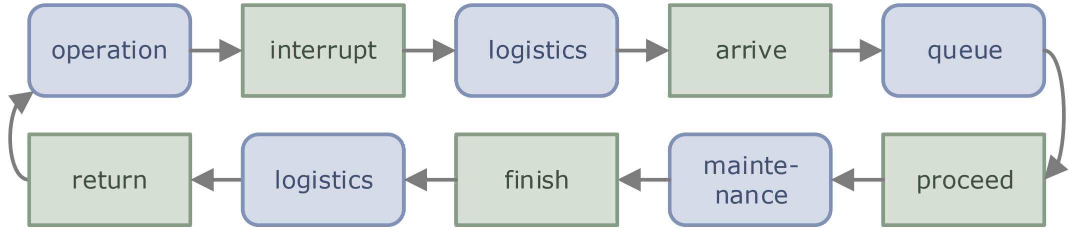
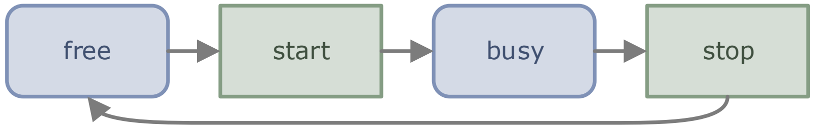
Demo tool: A fleet of similar systems (1/2)

- A system can be a vehicle or any other item that has failures and requires maintenance
- Reliability and maintainability simulation:
  - Failure modes of each system?
  - MTTF / failure distribution of each failure mode?
  - MTTR / repair distribution of each failure mode?
  - Preventive maintenance schedule?
- Maintenance resource simulation:
  - Number of maintenance persons/workshops available?
  - Logistics delays to and from maintenance?
  - Priority order of operations if queueing required?
- Availability simulation:
  - How many systems are available?
- A Fleet demo tool was created at 2020-Q4

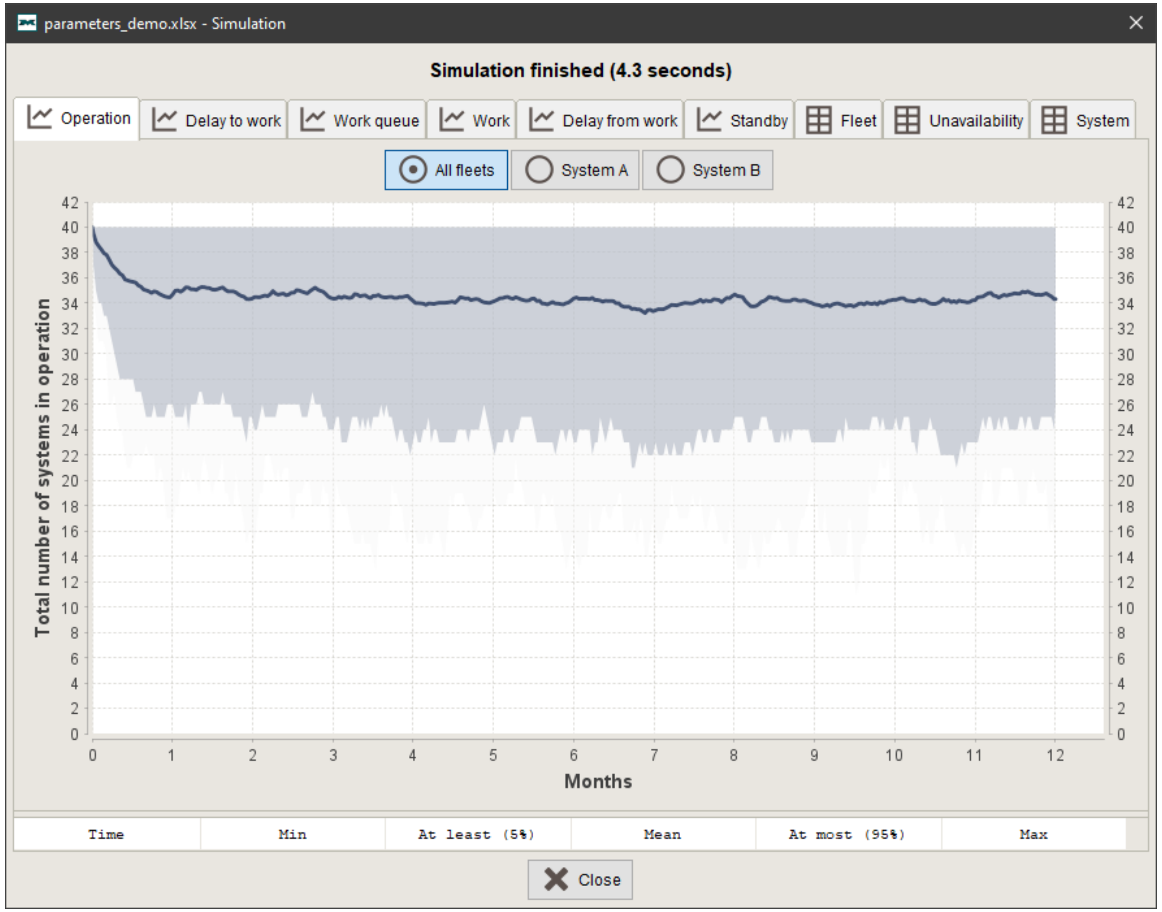


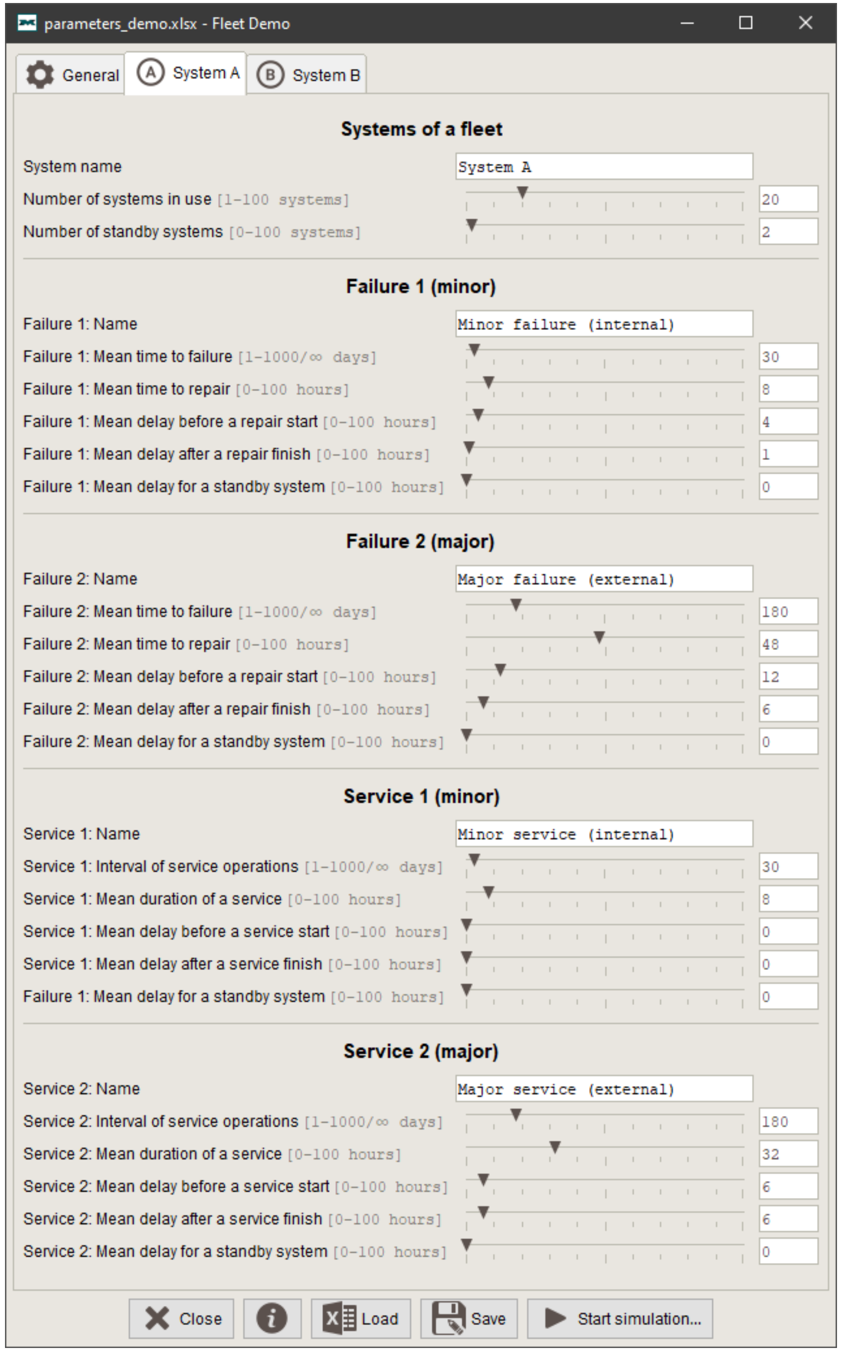
State model for each system:
- Interrupts caused by failures and preventive maintenance
- Logistics delays to and from maintenance
- Queueing if maintenance resources not available
- Duration of maintenance operations



State model for each maintenance resource:
- Start and stop of maintenance operations

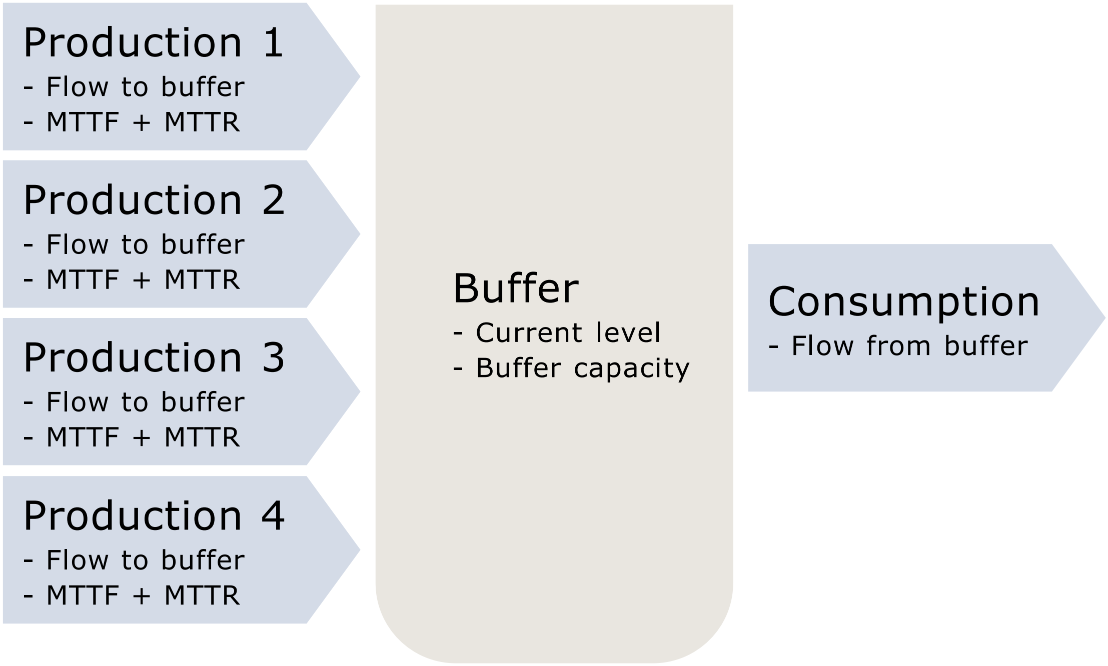
Demo tool: A fleet of similar systems (2/2)



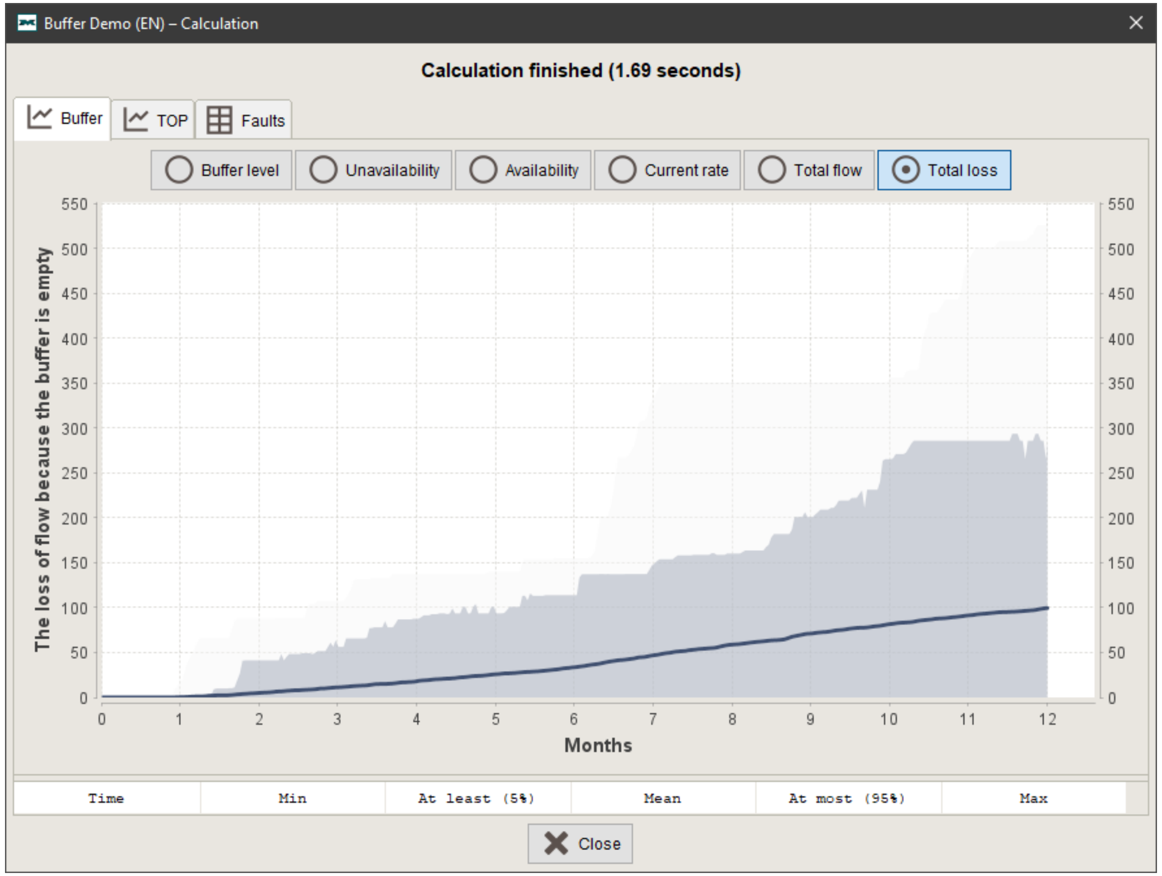


Demo tool: Buffer level simulation (1/2)

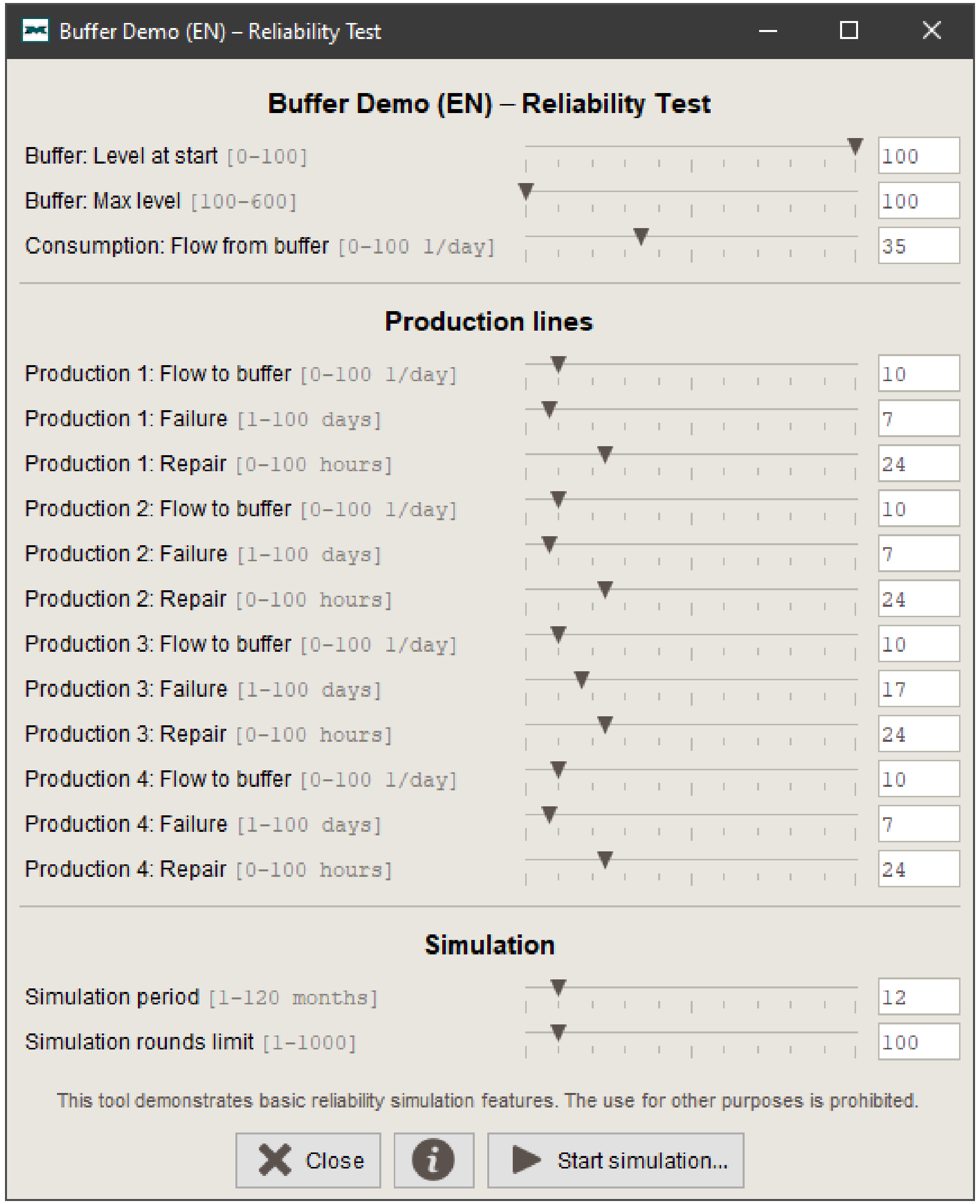
- Several production lines, which each have:
  - Flow to the buffer (1/day)
  - Mean time to failure/restoration (MTTF + MTTR)
- A buffer unit, which has:
  - A current buffer level
  - Buffer capacity (maximum buffer level)
- A consumption element, which has:
  - Flow from the buffer (1/day)
- Stochastic simulation + Analysis results:
  - Mean buffer level
  - Availability/Unavailability (% of time the buffer is empty)
  - Total flow through the buffer
  - The loss of flow because the buffer is empty
- Buffer level simulation demo tool was created at 2021-Q3



Demo tool: Buffer level simulation (2/2)

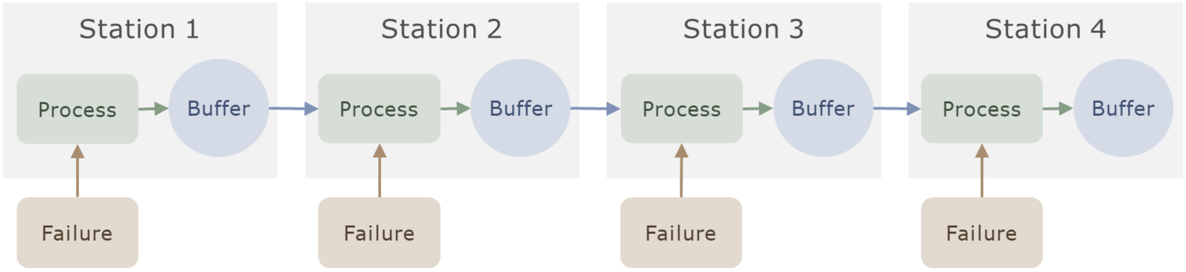


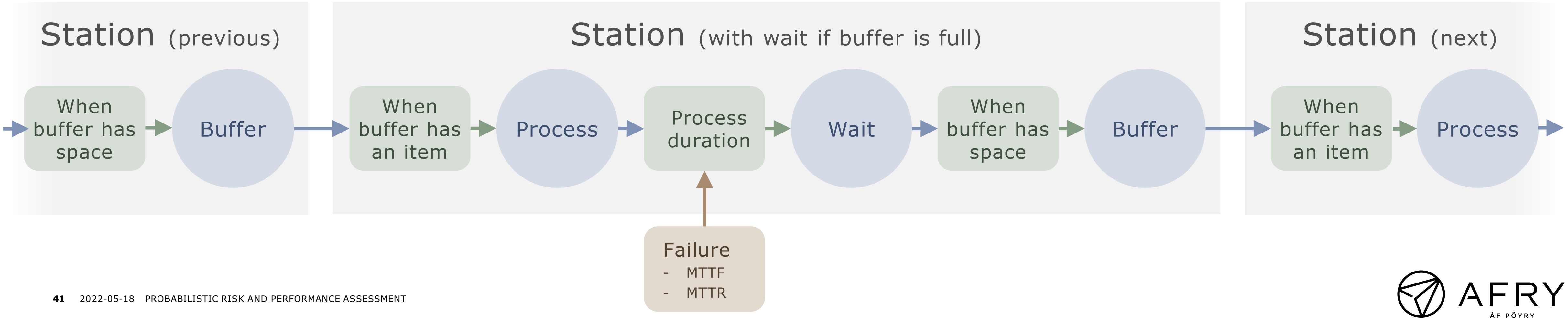
Simulation



Demo tool: Process flow simulation (1/3)

- Demo case: Four stations in a sequence
  - Each station has a process unit and a buffer
  - Failures can stop the process
  - Maximum number of items is defined for a buffer
- The last buffer (Station 4) describes how many items have been processed





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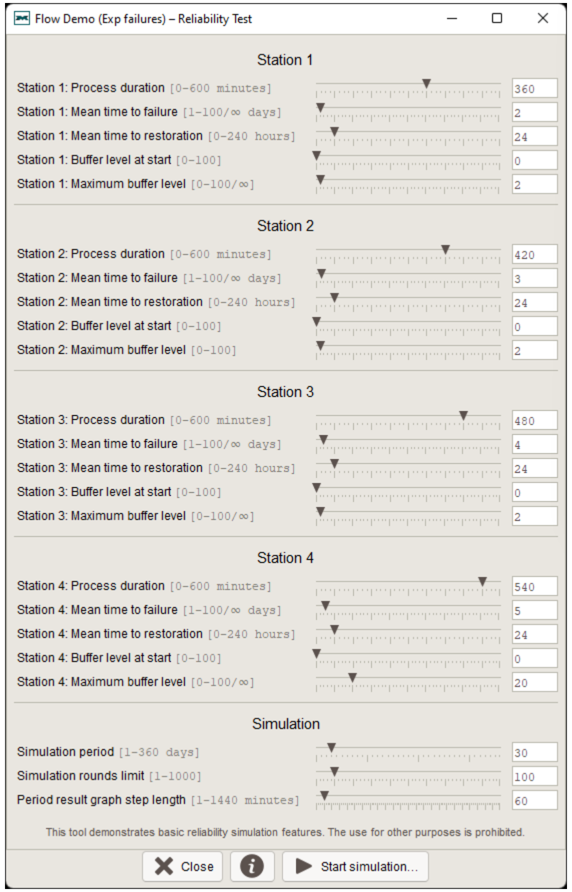
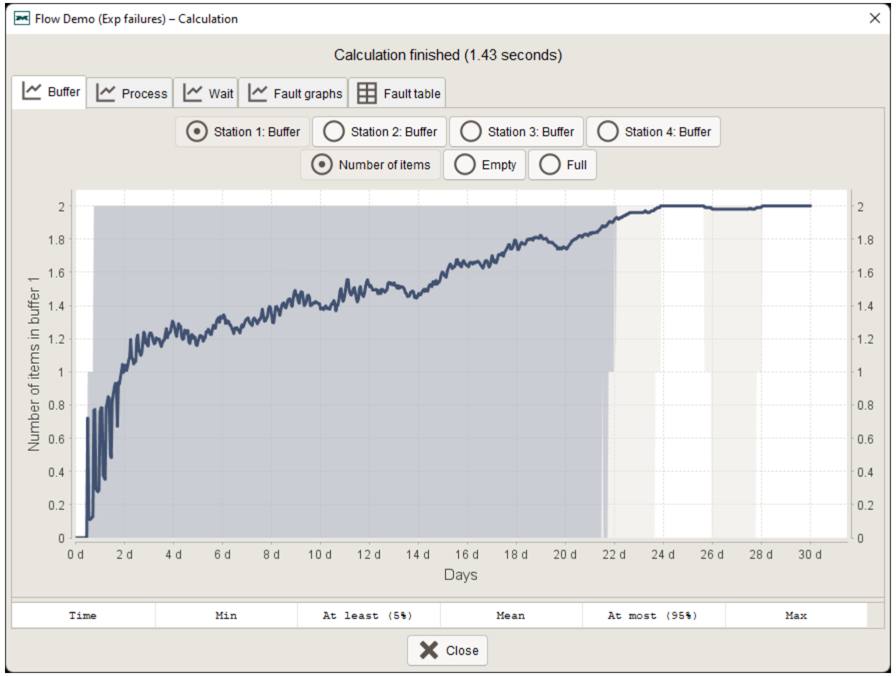
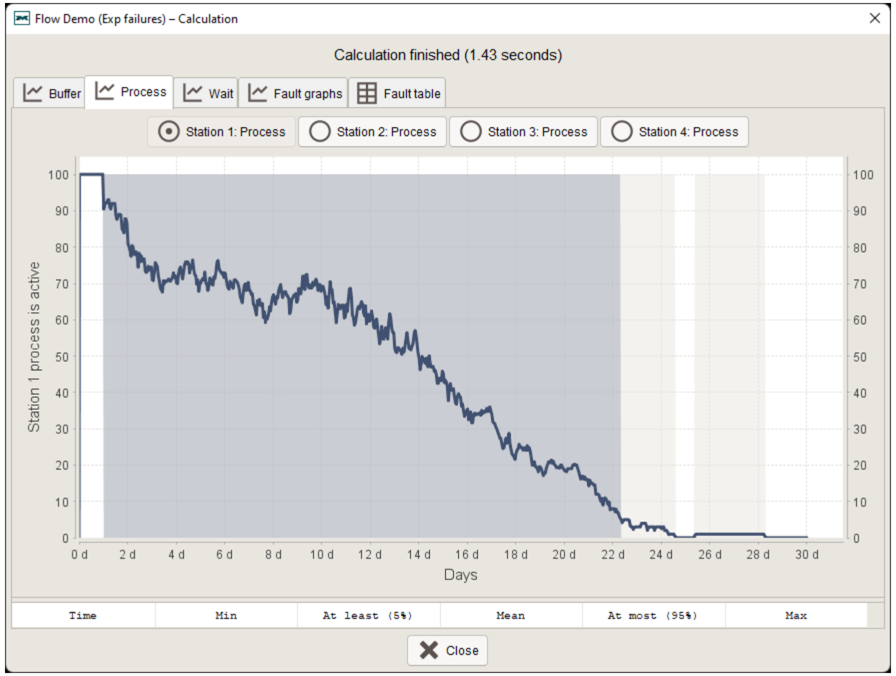
Demo tool: Process flow simulation (2/3)







Demo case:
How long it takes to produce 20 items
when failures can stop the process?

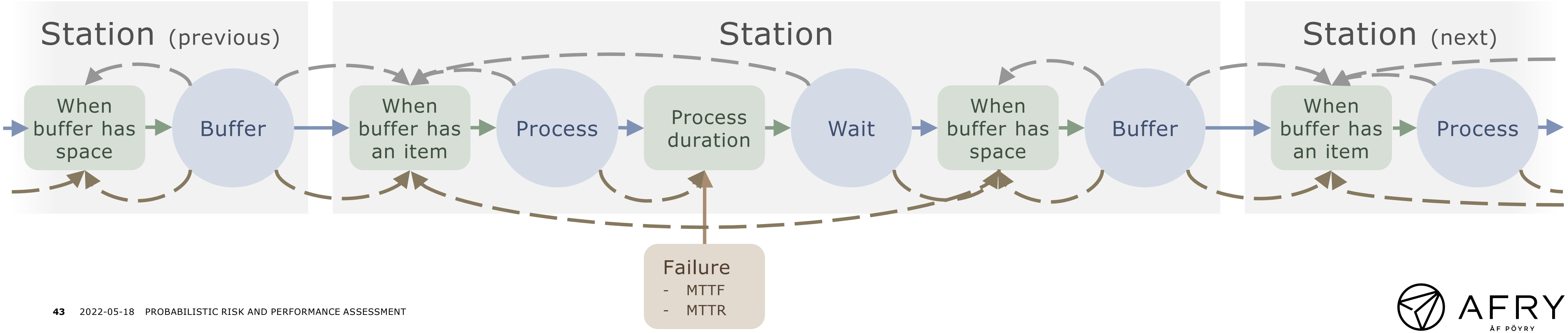
Demo tool: Process flow simulation (3/3)

Triggers

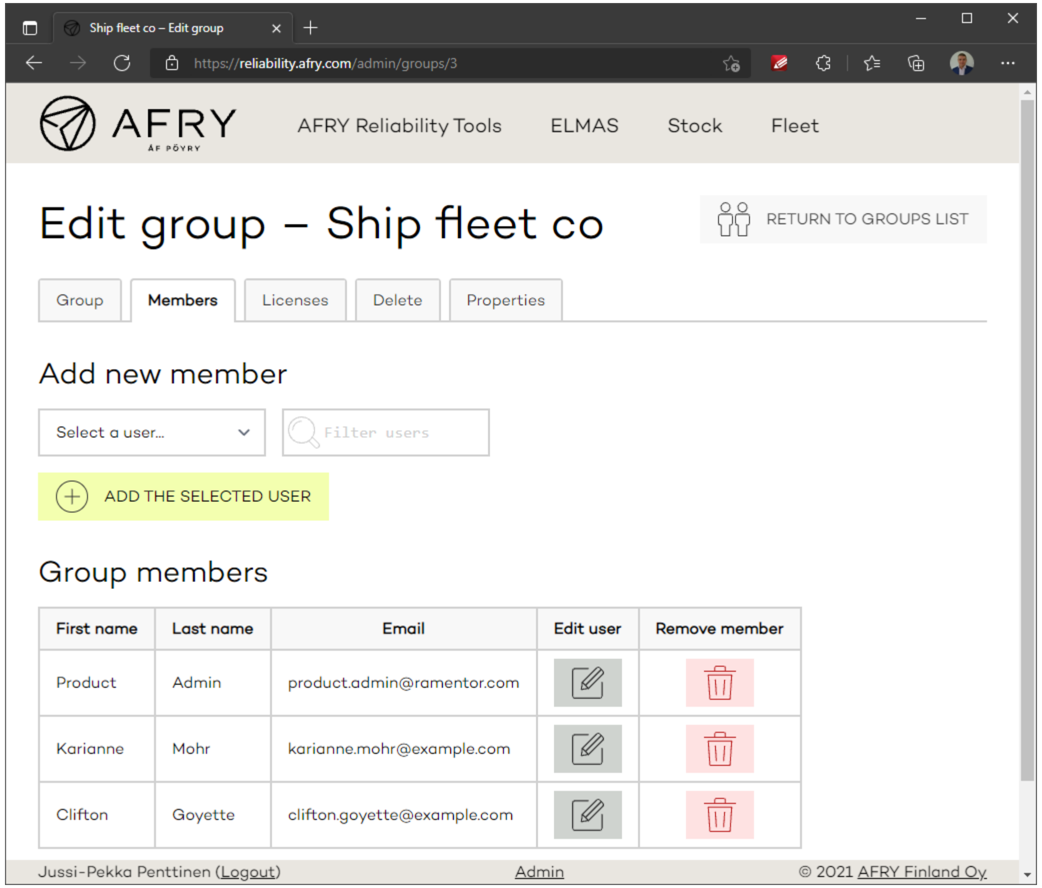
1) Check next transition when a place gets an item
2) Check process restart when wait ends
3) Check wait end when buffer is not full anymore

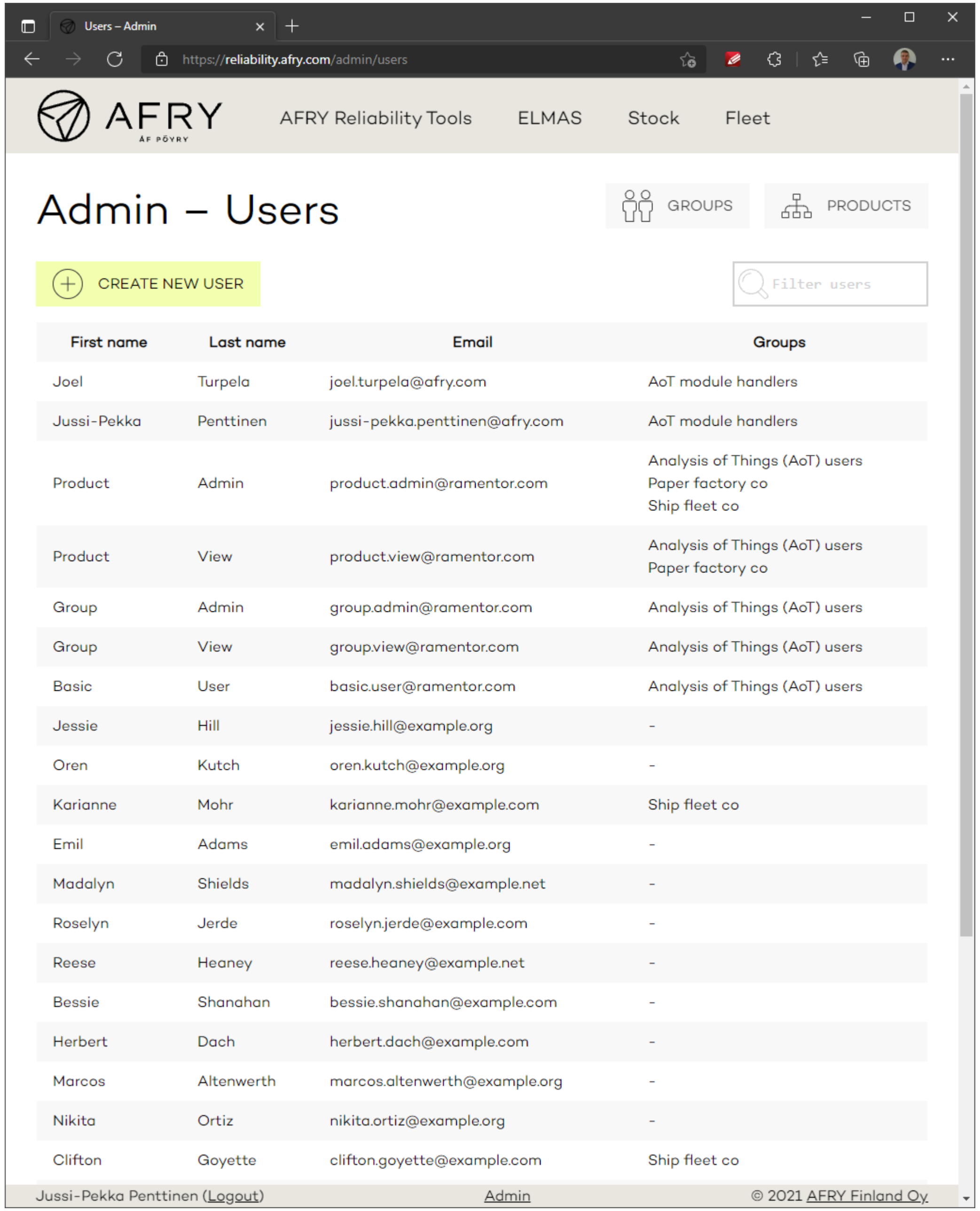
Conditions

4) Wait can end if buffer has space (=is not full)
5) Process can start when previous buffer has an item, process is not already ongoing, and an item is not waiting for next buffer



Demo tool: User license handling





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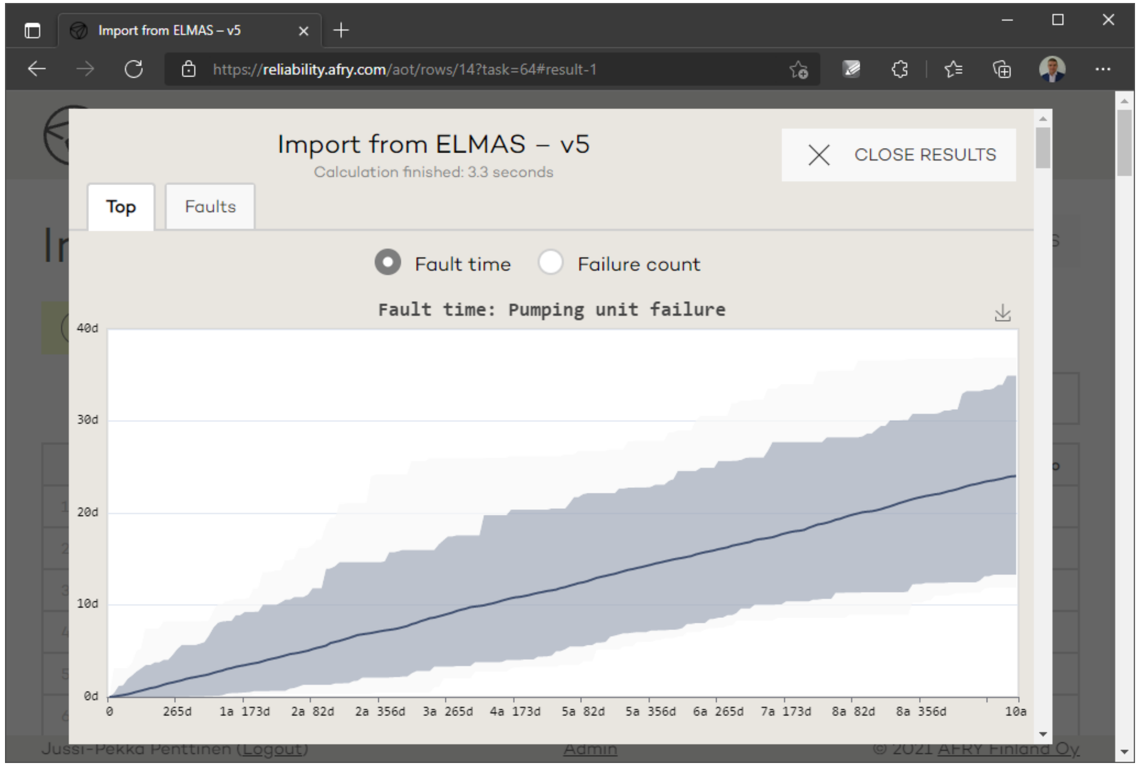
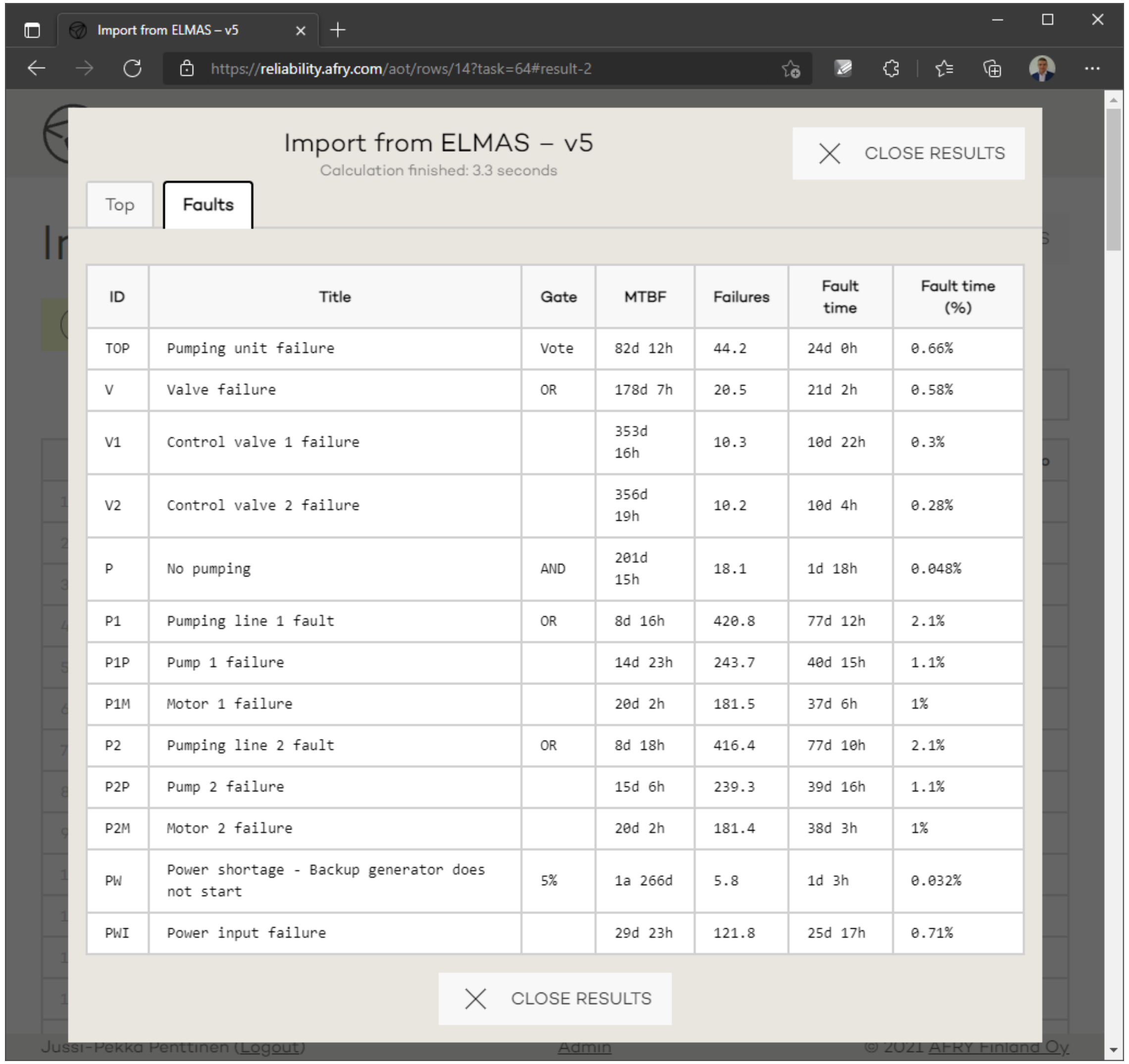
Demo tool: Web portal for cloud simulation





ID	Title	Gate	MTBF	Failures	Fault time	Fault time (%)
TOP	Pumping unit failure	Vote	82d 12h	44.2	24d 0h	0.66%
V	Valve failure	OR	178d 7h	20.5	21d 2h	0.58%
V1	Control valve 1 failure		353d 16h	10.3	10d 22h	0.3%
V2	Control valve 2 failure		356d 19h	10.2	10d 4h	0.28%
P	No pumping	AND	201d 15h	18.1	1d 18h	0.048%
P1	Pumping line 1 fault	OR	8d 16h	420.8	77d 12h	2.1%
P1P	Pump 1 failure		14d 23h	243.7	40d 15h	1.1%
P1M	Motor 1 failure		20d 2h	181.5	37d 6h	1%
P2	Pumping line 2 fault	OR	8d 18h	416.4	77d 10h	2.1%
P2P	Pump 2 failure		15d 6h	239.3	39d 16h	1.1%
P2M	Motor 2 failure		20d 2h	181.4	38d 3h	1%
PW	Power shortage - Backup generator does not start	5%	1a 266d	5.8	1d 3h	0.032%
PWI	Power input failure		29d 23h	121.8	25d 17h	0.71%

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Questions or comments?

ELMAS

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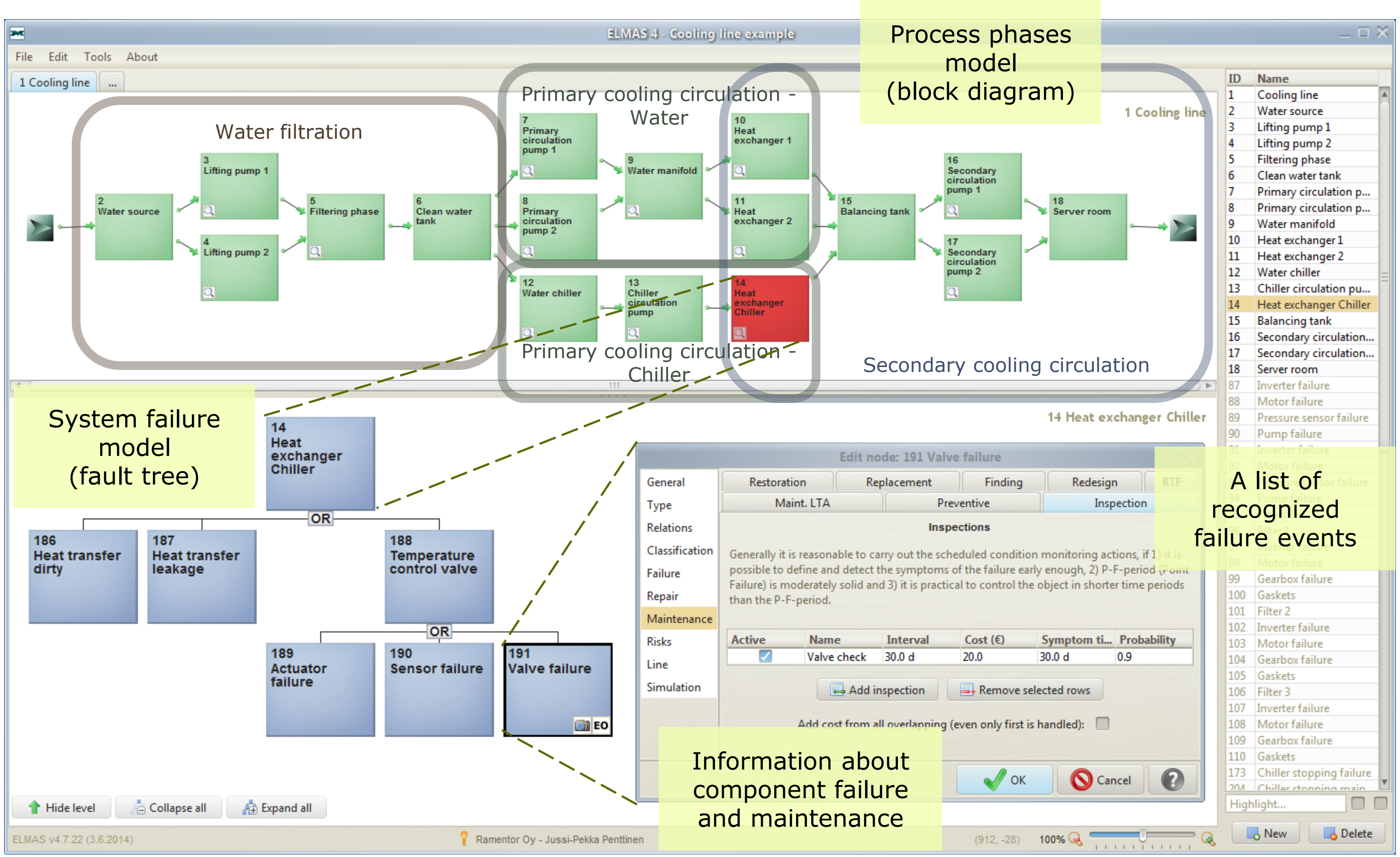
EVENT LOGIC MODELLING AND ANALYSIS SOFTWARE

ELMAS 4.9

- Modelling and simulation of system/component failures
- Analysis combines maintenance data with expert knowledge
- Design, improvement and optimization of reliability and availability
- Risk assessment
- Analysis of Life-cycle-costs (LCC)
- Fault Tree Analysis (FTA)
- Failure Modes, Effects, and Criticality Analysis (FMECA)
- Reliability Centered Maintenance (RCM)



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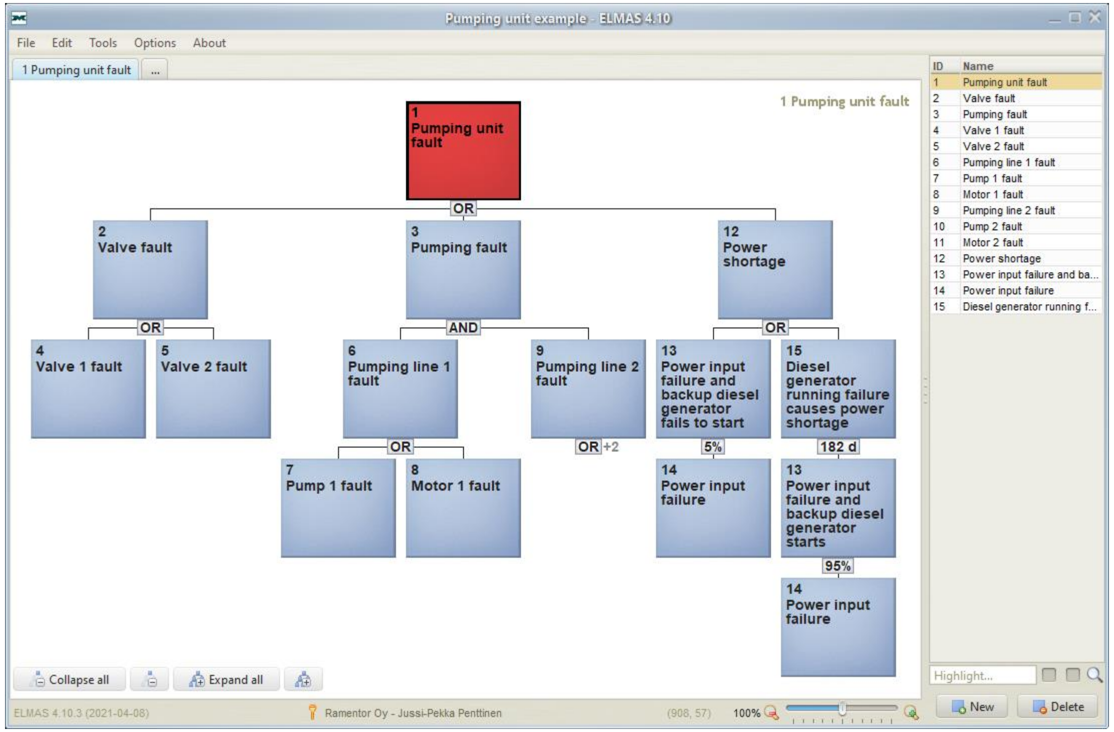
ELMAS 4.9 – Advanced Fault Tree Modeling

- Graphical presentation of logical tree diagram
  - Efficient handling of large (>1000 faults) trees
- Advanced failure logic and time distribution definitions
  - Standard logic gates, probabilities and delays included
  - Create failure and repair distributions based on experts' best estimates or by importing history data (distribution fitting)
- Stochastic discrete event simulation (DES)
  - For systems that are too complex to be modelled using analytical techniques
- Customizable criticality classification
  - Include qualitative analyses and risk prioritization, such as Failure modes and effects and criticality analysis (FMECA)
- Dynamic modelling
  - Include dynamic process phase/mode changes
  - Include chains of consequences and dynamic delays
  - Include maintenance schedule and special actions



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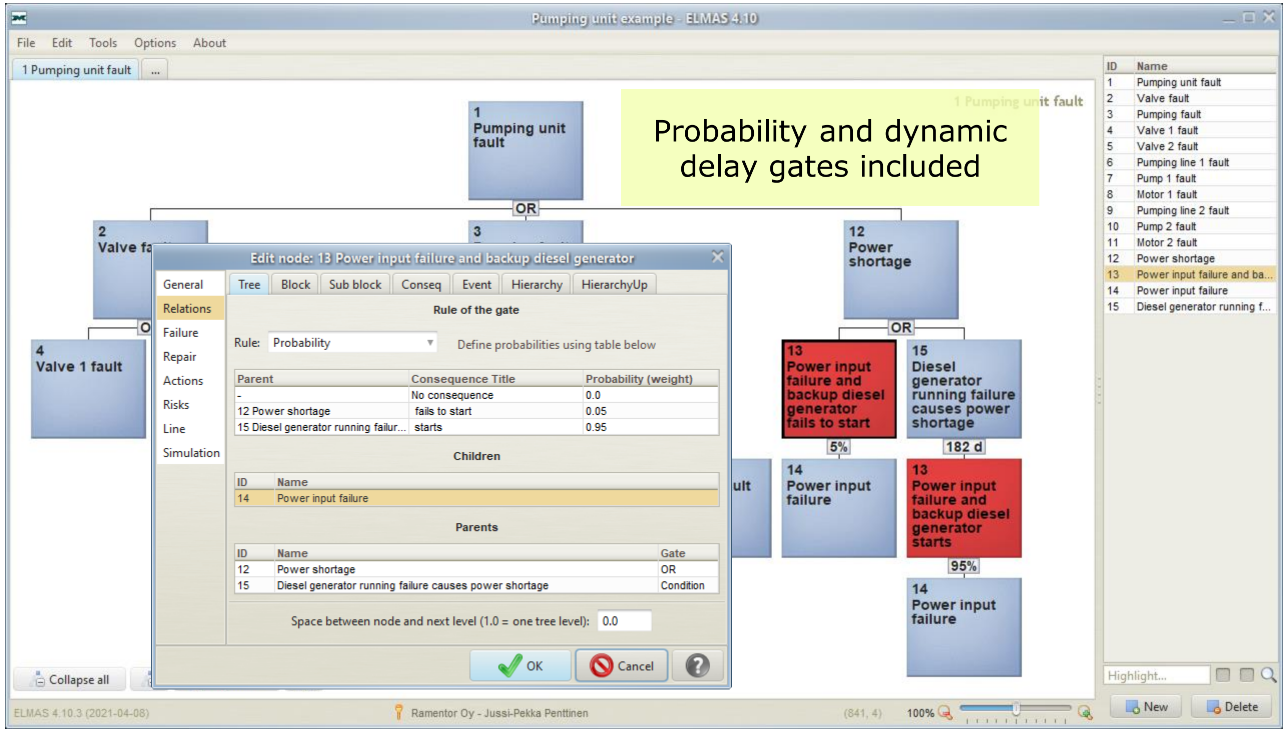
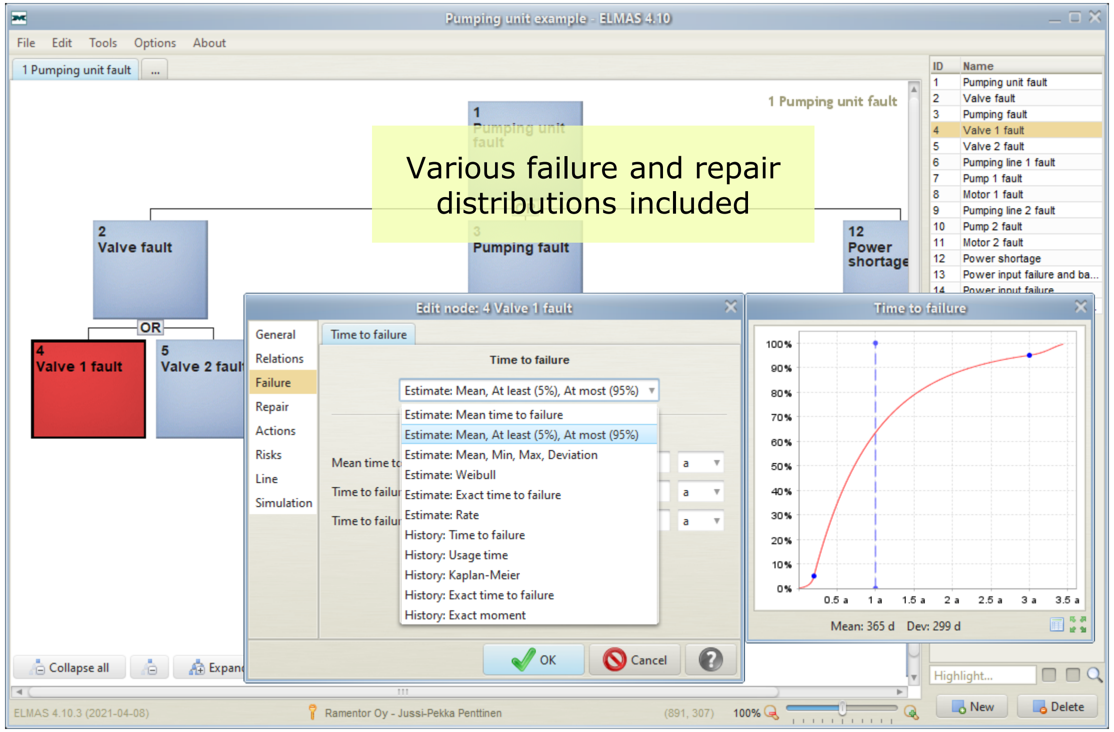
ELMAS 4.9 – Failure logic and distributions





ELMAS includes advanced fault tree modelling features. For comparison with other software packages, see slides 15-17 from PowerPoint Presentation - cern.ch)

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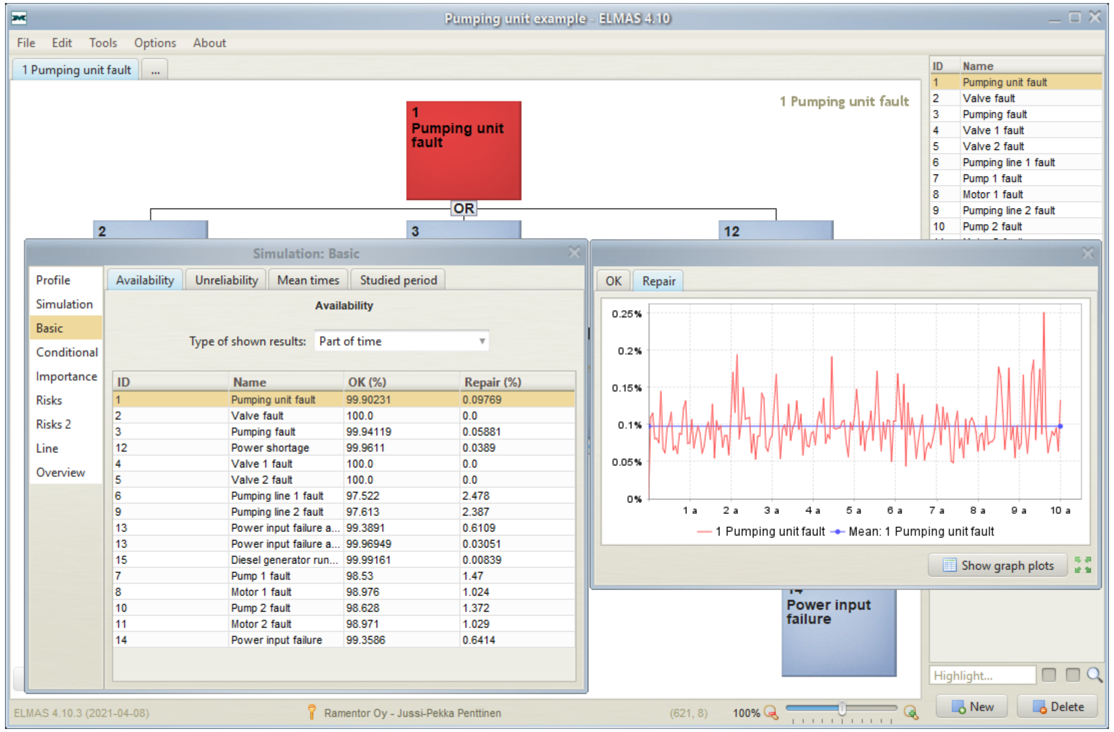
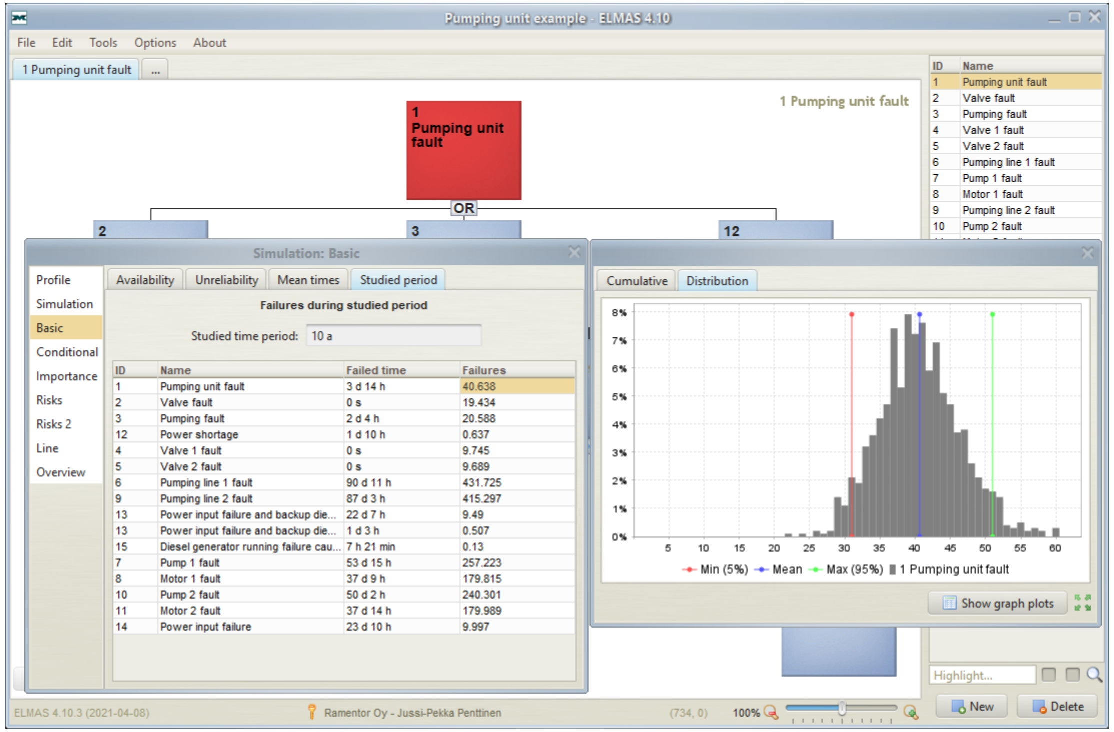
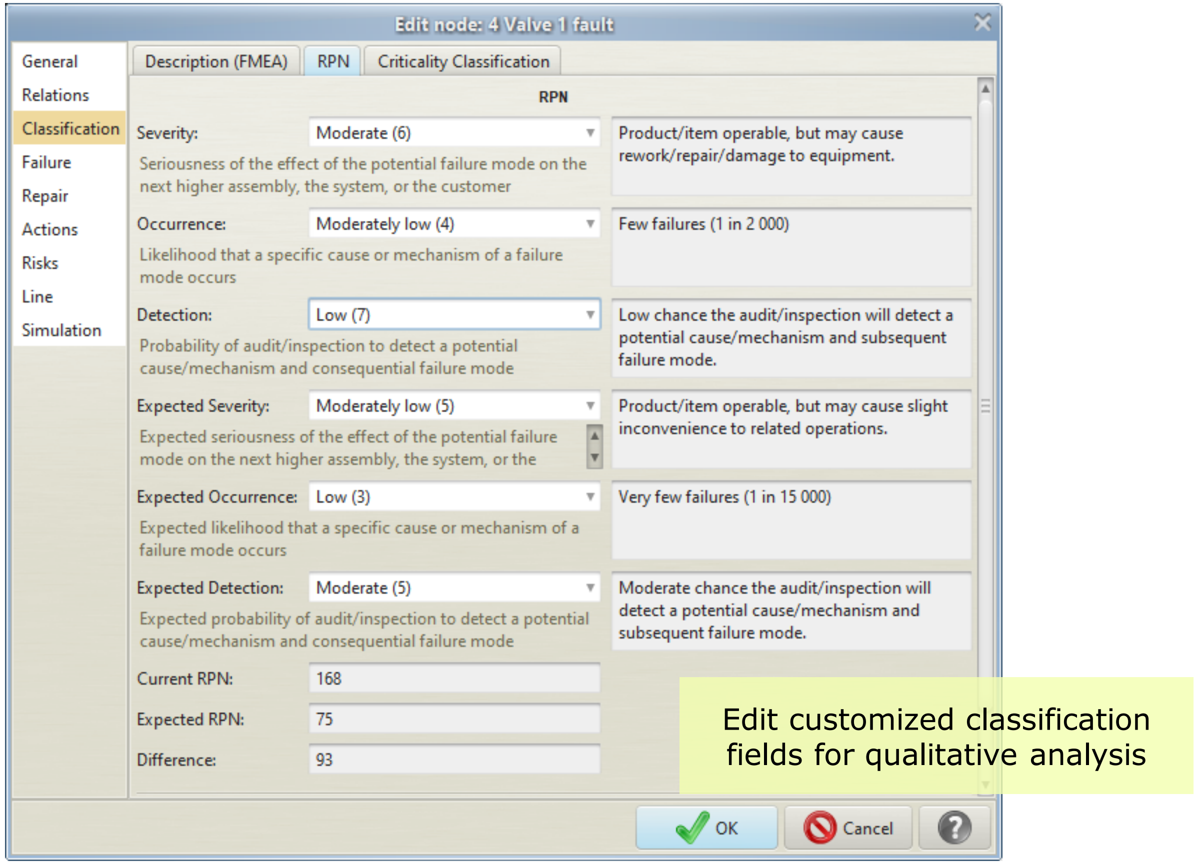
ELMAS 4.9 – Stochastic simulation

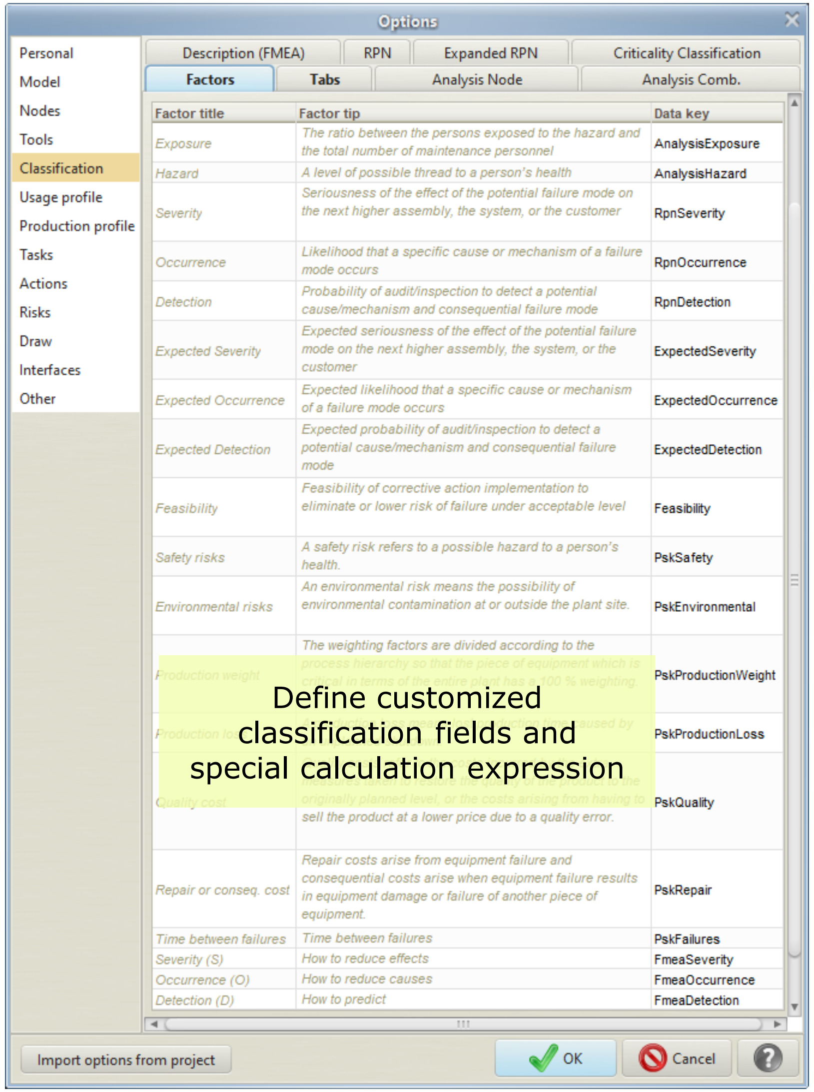




ELMAS includes an efficient simulation algorithm. For example, ELMAS calculation time 2.1 seconds vs. Isograph ~35 minutes (see slide 12 from [PowerPoint Presentation - cern.ch])

ELMAS 4.9 – Customizable criticality classification





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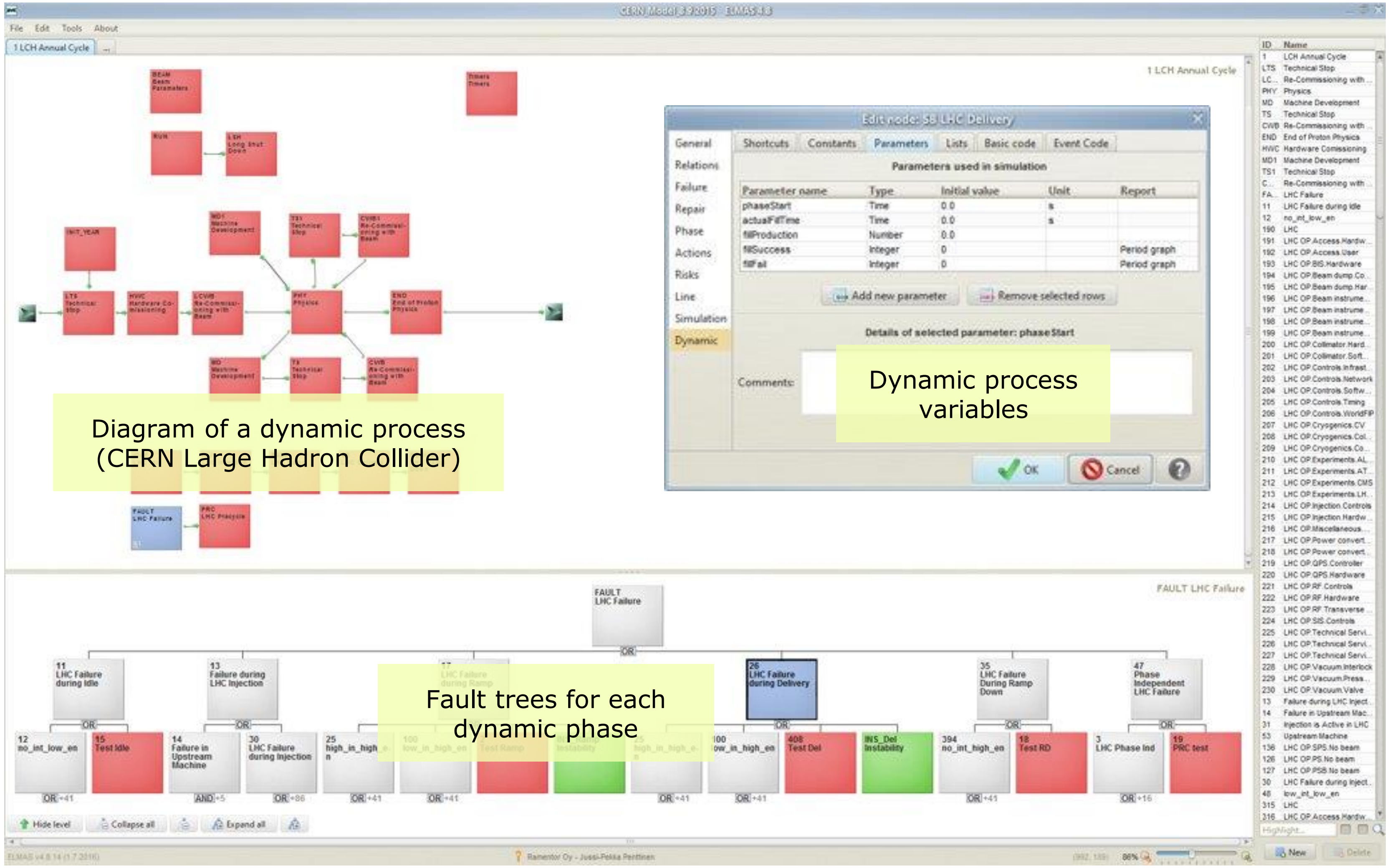
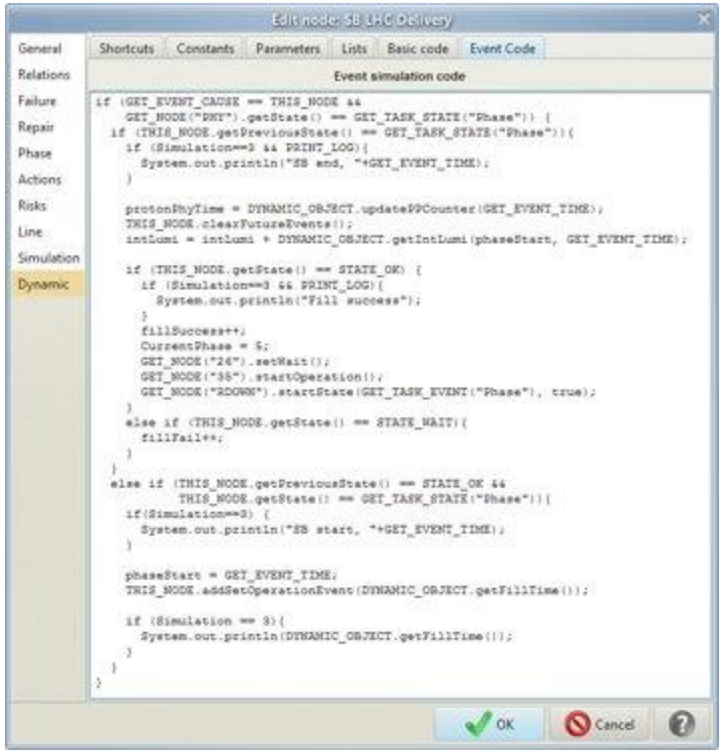
ELMAS 4.9 – Dynamic modeling





Custom process
simulation code

ELMAS – Levels of Modelling and Analysis

ELMAS

Model definition

- Failure and maintenance data
- Condition monitoring data

- System/component hierarchy
- Expert knowledge (causality)

- Time-dependency of events
- Production phases/modes

- Break/downtime/repair costs
- Hazards

Models

- Component model (faults/maintenance)
- Causality model (fault tree)
- Process model (production)
- Risk model (availability/safety)

Analysis results

- Component reliability
- Maintenance schedule

- System reliability / availability
- Criticality / importance (TOP 10)

- Overall production / bottlenecks
- Total requirements / expectations

- Overall risk / LCC / Investments
- Maintenance optimization

Application Programming Interface (API)
+ Graphical User Interface (GUI)

Data → API/GUI → ELMAS → API/GUI → Results

ELMAS – Levels of Modelling and Analysis

Model definition (input)	ELMAS	Analysis results
A Failure and maintenance data Condition monitoring data	**A** Component model (faults/maintenance)	**A** Component reliability Maintenance schedule
B System/component hierarchy Expert knowledge (causality)	**B** Causality model (fault tree)	**B** System reliability / availability Criticality / importance (TOP 10)
C Time-dependency of events Production phases/modes	**C** Process model (production)	**C** Overall production / bottlenecks Total requirements / expectations
D Break/downtime/repair costs Hazards	**D** Risk model (availability/safety)	**D** Overall risk / LCC / Investments Maintenance optimization

Application Programming Interface (API)
+ Graphical User Interface (GUI)

Data → API/GUI → ELMAS → API/GUI → Results

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ELMAS – GUI, Import/Export and API

1) Model creation with Graphical User Interface (**ELMAS GUI**)
2) Import of failure / maintenance history and component hierarchy (**Excel format**)
3) Asset Performance Management (APM) or other system integration (**ELMAS API**)

Model definition

ELMAS

- **A** Component model (faults/maintenance)
- **B** Causality model (fault tree)
- **C** Process model (production)
- **D** Risk model (availability/safety)

Application Programming Interface (API)
+ Graphical User Interface (GUI)

Analysis results

1) Visualization of results with Graphical User Interface (**ELMAS GUI**)
2) Export of analysis results / cause-consequence relation model structure (**Html / Excel format**)
3) Analysis results / failure modes shown in Asset Performance Management (APM) or other system (**ELMAS API**)

Data → API/GUI → ELMAS → API/GUI → Results

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Questions or comments?

Risk/Reliability Management

AFRY RELIABILITY TOOLS / AFRY X

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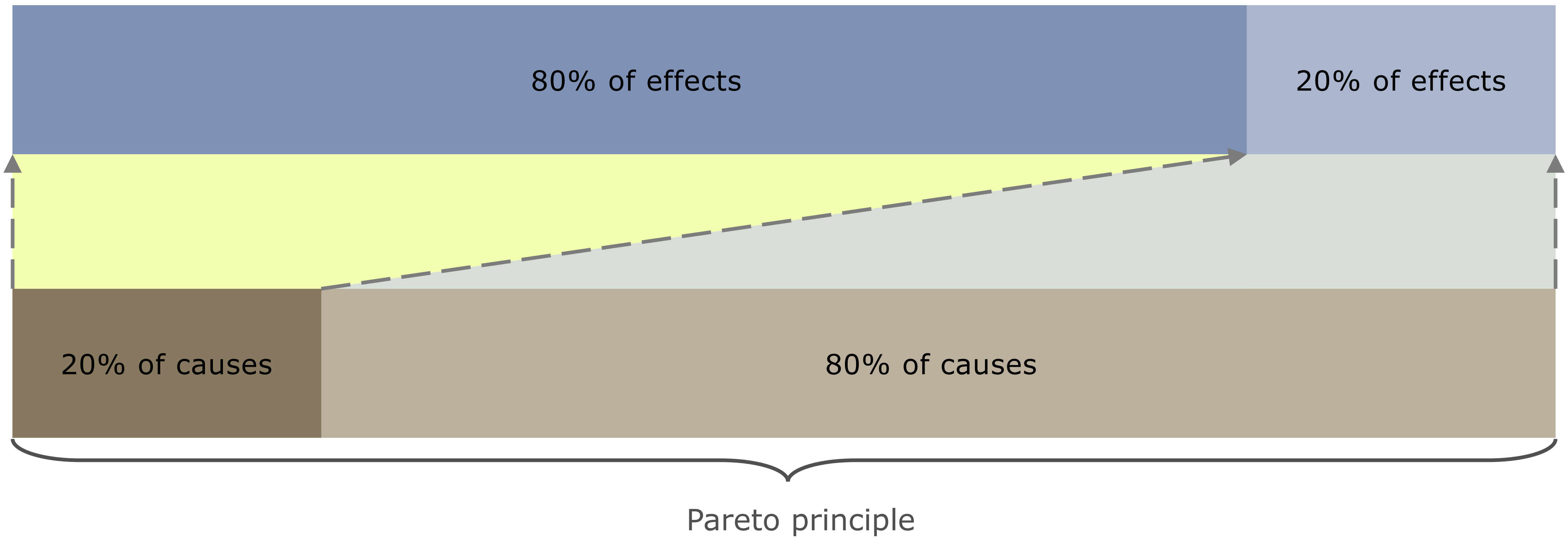
"For many events, roughly 80% of the effects come from 20% of the causes"

Vilfredo Pareto

Risk/Reliability Management



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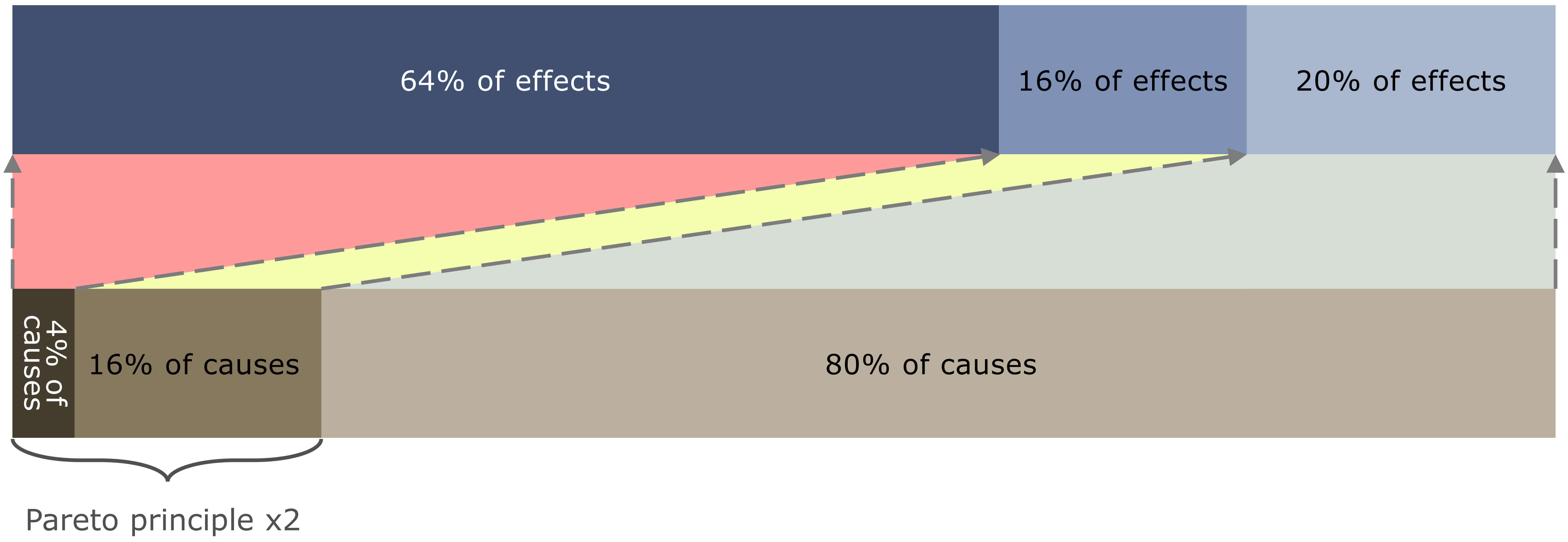
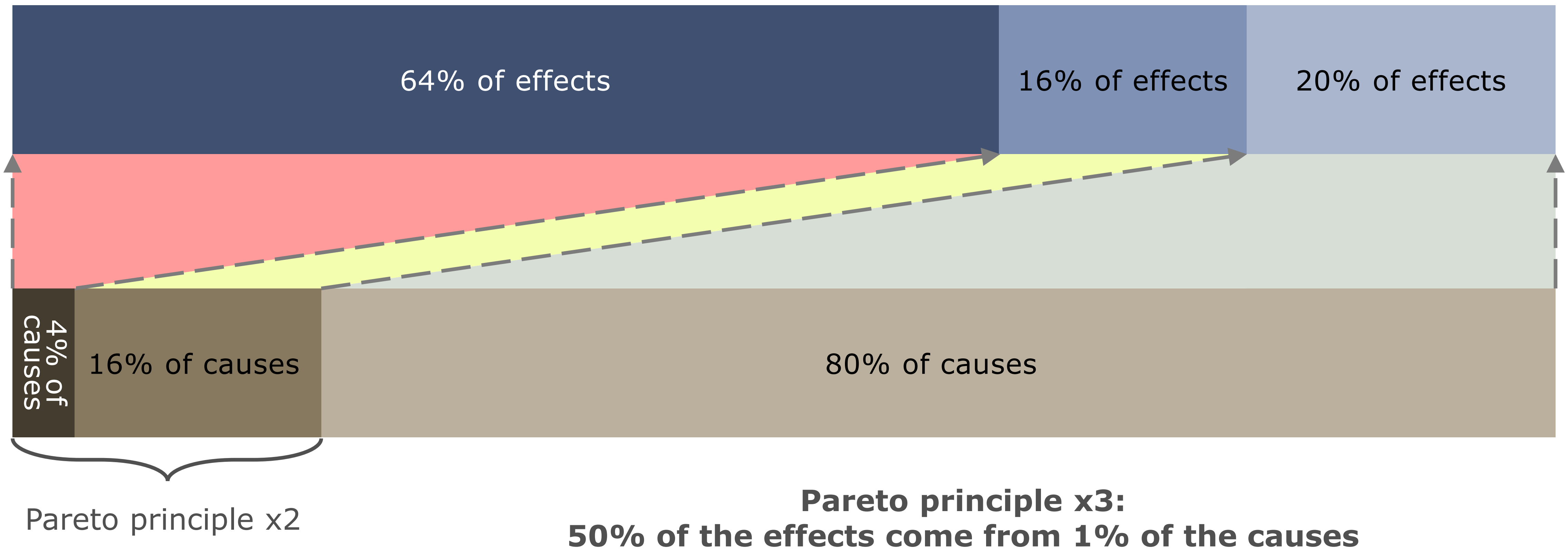
Risk/Reliability Management



Risk/Reliability Management



Pareto principle x3:
50% of the effects come from 1% of the causes

Risk/Reliability Management

Risk/Reliability Management

Business / Economic Risk
- Total production, Key performance indicator (KPI)
- Life-cycle cost (LCC), Maintenance cost, Spare part stock cost
- Return of an investment time

Other Risks
- Safety/health risk
- Environmental risk
- Project risk

Model and Analysis

Operation / Performance Modelling
- Process phases / production modes
- Buffers, delays, throughput / speed
- Available resources, spare parts

Reliability Modelling
- Fault tree analysis (FTA) / Uncertain events
- Maintenance planning, Condition monitoring
- Causes-consequence-logic / Risk assessment

Reliability Tools

ELMAS
- System / process failures and maintenance

Stock
- Spare part storage optimization

Fleet
- Operation and maintenance of several vehicles / other systems

Customized tool
- Combine modelling techniques and include domain-specific details

Failure / Maintenance / Process Data + Expert Knowledge

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Risk/Reliability Management

Risk/Reliability Management

Business / Economic Risk
- Total production, Key performance indicator (KPI)
- Life-cycle cost (LCC), Maintenance
- Return of an investment time

What is the Key Performance Indicator (KPI) to optimize?

Other Risks
- Safety/health risk
- Environmental risk
- Project risk

Model and Analysis

Operation / Performance Modelling
- Process
- Buffer
- Available resources, spare parts

What (dynamic) process details affect to the KPI?

Reliability Modelling
- Fault tree analysis (FTA) / uncertain events
- Ma
- Causes-consequence-logic / Risk assessment

What can fail? How long it takes to recover?

Reliability Tools

ELMAS
- System / process failures and maintenance

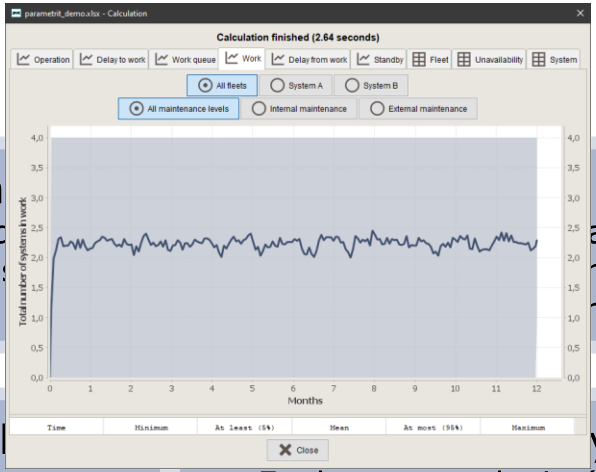
Stock
- Spare part storage optimization

Fleet
- Operation and maintenance of several vehicles / other systems

Customized tool
- Combine modelling techniques and include domain-specific details

Failure / Maintenance / Process Data + Expert Knowledge

Risk/Reliability Management



Risk/Reliability Management

Business / Econom
- Total production, Key performance inc
- Life-cycle cost (LCC), Maintenance co
- Return of an investment time

Other Risks
- afety/health risk
- nvironmental risk
- roject risk

Model and Analysis

Operation / Performance Model
- Pr
- Bu
- Av

y Modelling
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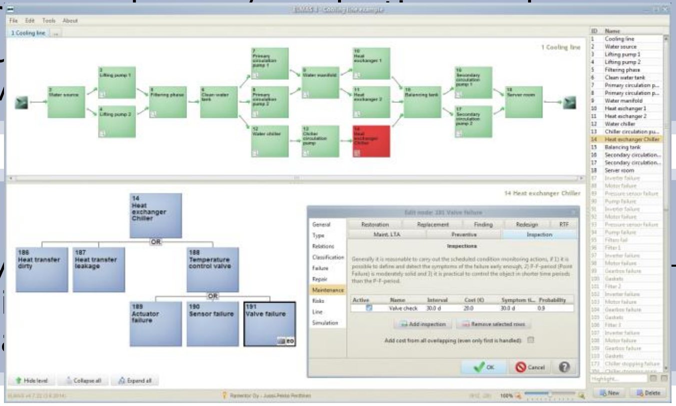

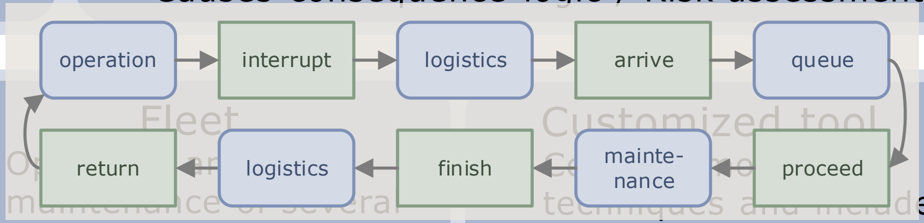

Reliability Tools

- Sy
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vehicles / other systems

e
domain-specific details

Failure / Maintenance / Process Data + Expert Knowledge

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Model-Based Systems Engineering (MBSE)

Risk recognition and classification (qualitative)	Maintenance / reliability modelling (quantitative)	System operation / behavioral modelling	History data capitalization / Condition monitoring	Risk / performance assessment
✓ Fault Tree Analysis (FTA) ✓ Failure Modes And Effects And Criticality Analysis (FMEA / FMECA) ✓ Criticality classification and risk prioritization	✓ Failure / repair time estimation (probability distribution) ✓ Reliability Centered Maintenance (RCM) ✓ Downtime, break and repair cost modelling	✓ Process flow / block diagram ✓ Dynamic production phase / logic modelling ✓ Fleet interaction modelling ✓ Buffer capacity modelling	✓ Failure / maintenance history import ✓ Production / stress profile definition ✓ Automatic fault tree creation ✓ Resource and spare part costs import	✓ Discrete Event Simulation (DES) ✓ Scenario analysis ✓ Maintenance optimization ✓ Risk-Informed Decision Making (RIDM)

Model-Based Systems Engineering (MBSE) – Maturity increases

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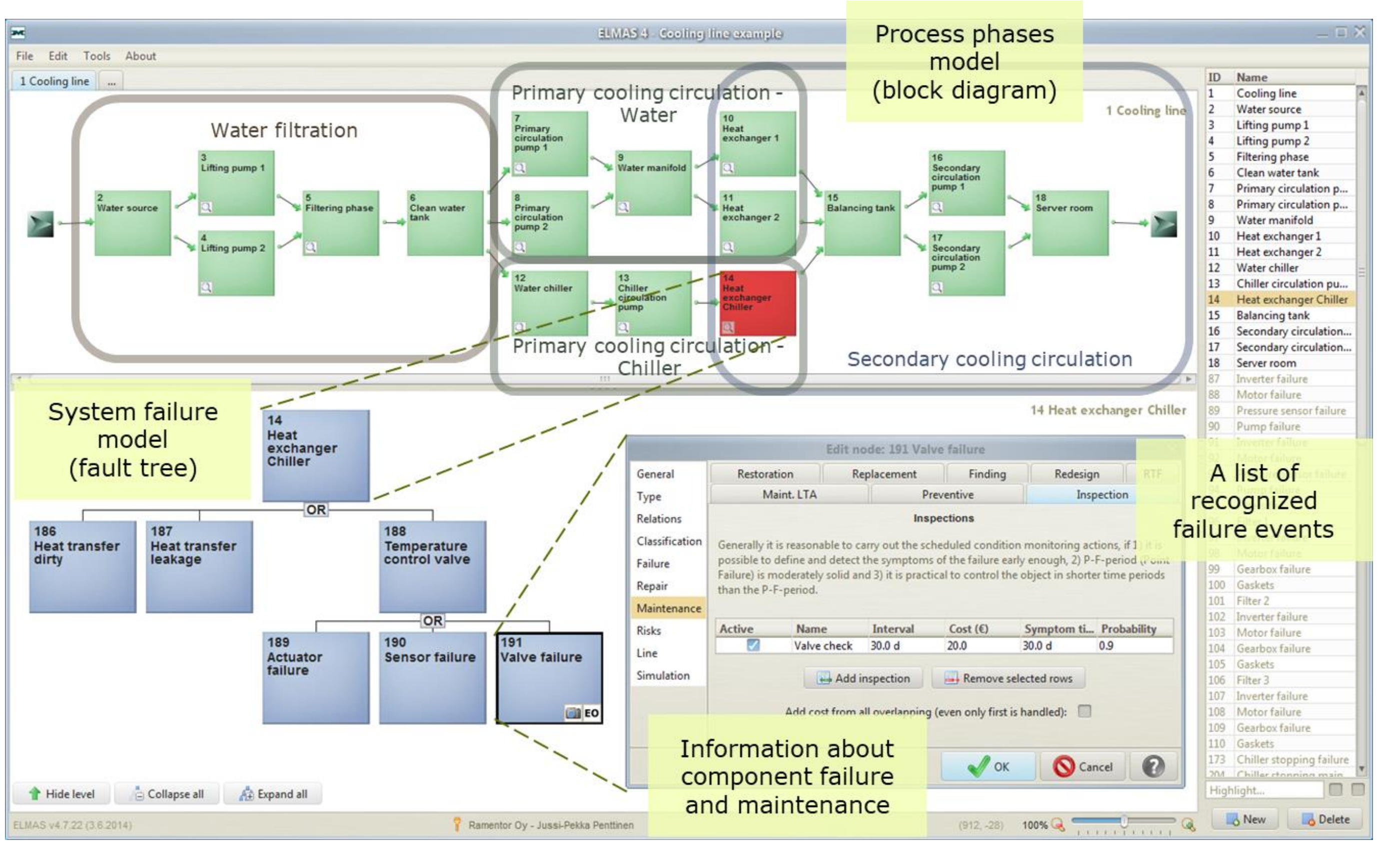
Probabilistic Risk/Performance Assessment

- ELMAS tool for failure modelling
  - Systematic approach to understand potential consequences and risks of component failures
  - Quantitative reliability/availability/risk results
  - Include dynamic process phases/modes
  - Include maintenance planning (RCM)
  - Include criticality classification (FMECA)
- More than 15 years of experience in challenging reliability/risk analyses
  - CERN Particle Collider Availability Model
  - AFRY Reliability Management
  - Other References and Customer cases
- New approach adapts to special reliability modelling needs
  - Based on a CERN research: OpenMARS
  - Published in RESS journal
  - Developed further in a doctoral dissertation



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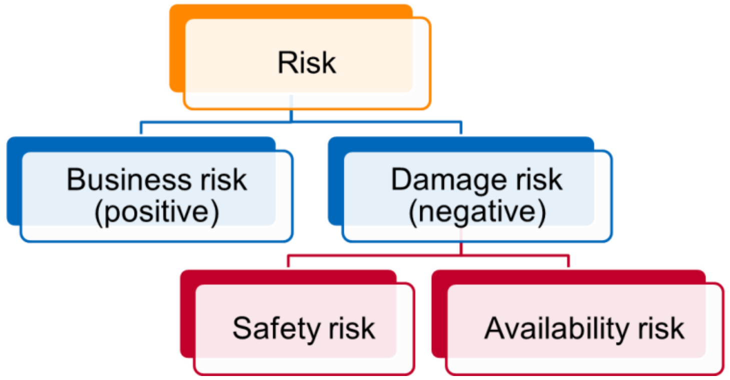
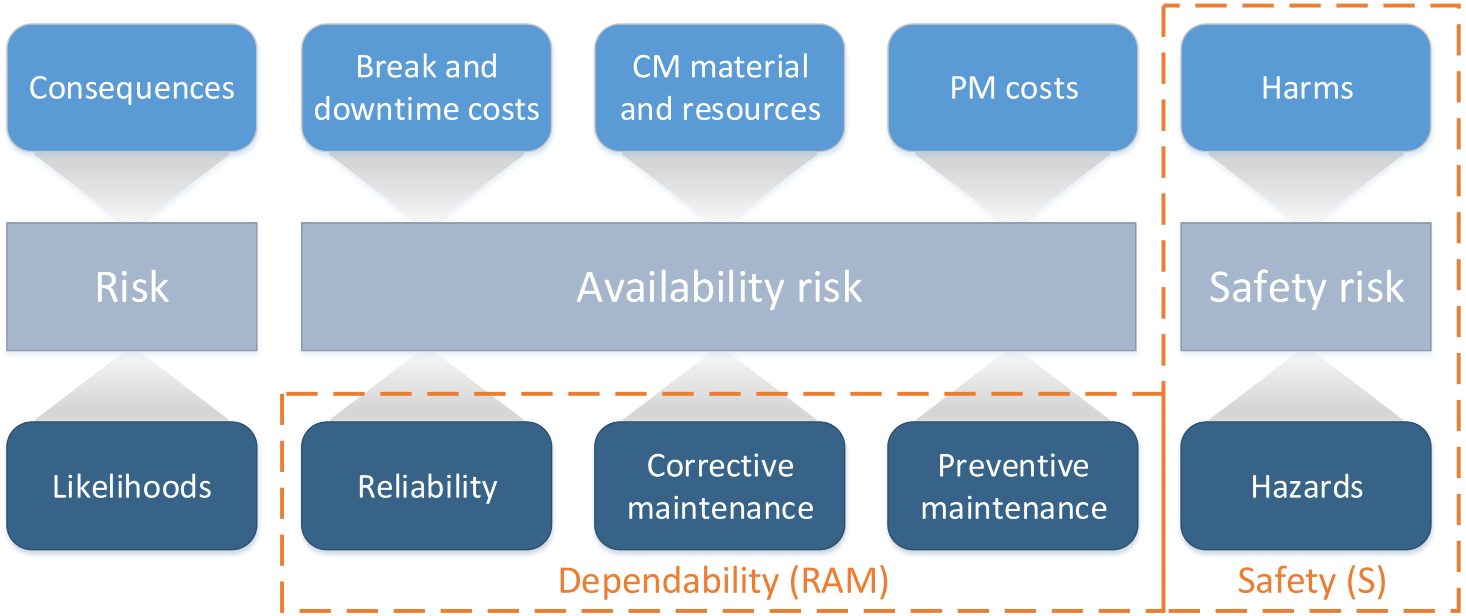
Risk Assessment – Terminology

Risk = Positive risk – Negative risk

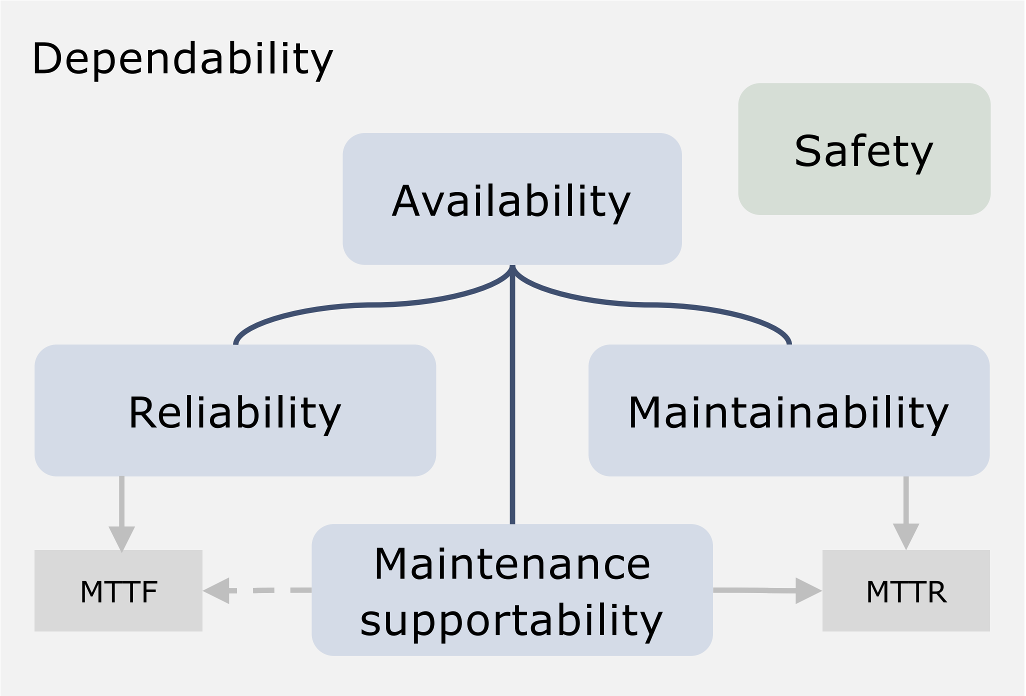
Negative (damage) risk = Availability risk + Safety risk





Risk Assessment - Dependability

- Dependability
  - The ability to perform as and when required
- Availability
  - The portion of time the item performs as expected
  - Formed by the ratio of failure and restoration times
- Reliability
  - How often failures occur?
  - Mean time to failure (MTTF), failure distribution
- Maintainability/Maintenance supportability
  - How long it takes to restore an item back to operation?
  - Mean time to restoration (MTTR), repair time distribution
  - Maintainability = How simple it is to repair the item
  - Maintenance supportability = Performance of the maintenance organization (can affect also to failures, e.g., wrong maintenance/repair)



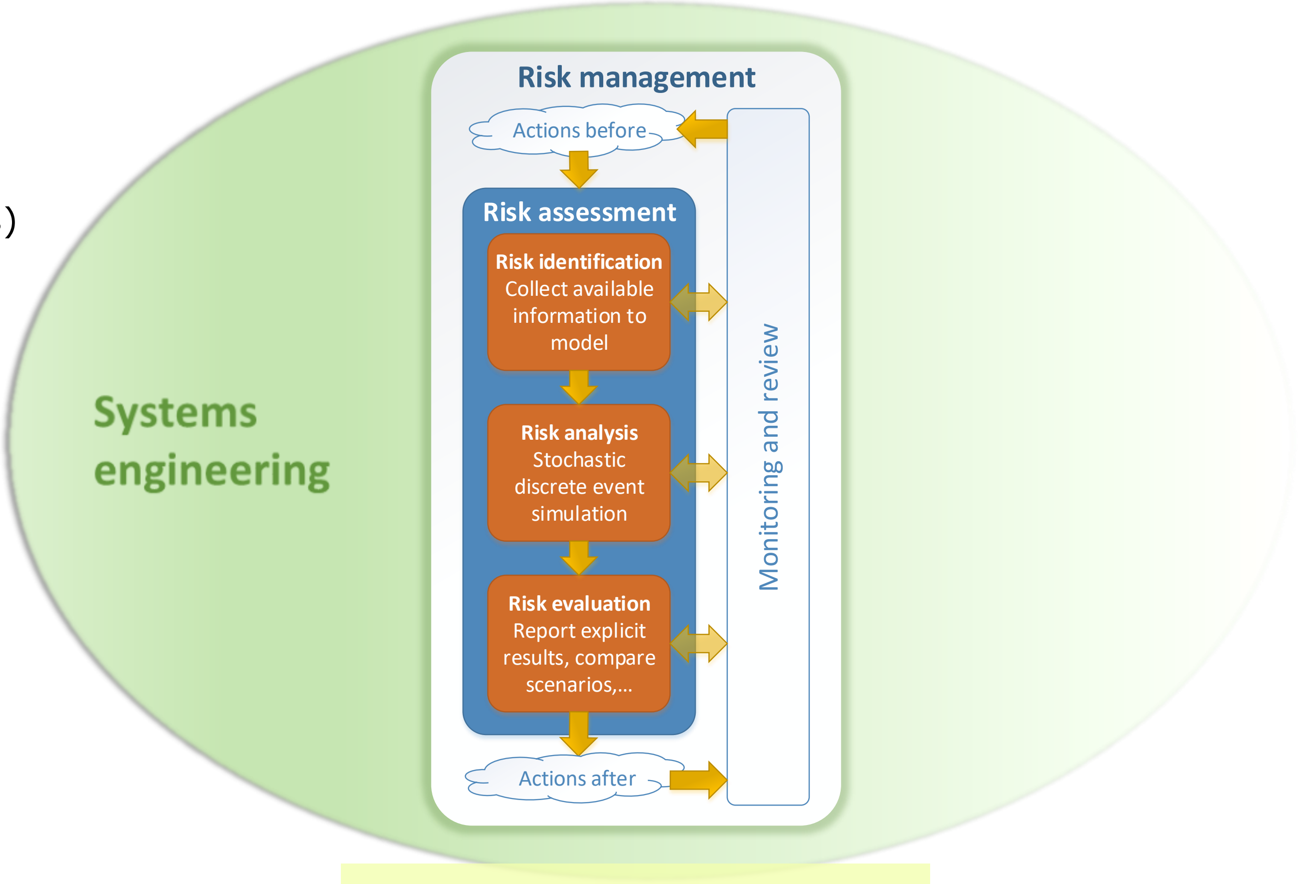
(mean) availability = MTTF / (MTTF + MTTR)

unavailability = 1 - availability

Risk Assessment – Standard definitions

- 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.
- Risk assessment
  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

ISO GUIDE 73:2009



ISO 31000:2009, NASA SE 2007

Questions or comments?

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AFRY RELIABILITY TOOLS

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Making Future

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