A SCALABLE AND OPEN PLATFORM FOR COMPLEX SYSTEM BEHAVIOUR ASSESSMENT

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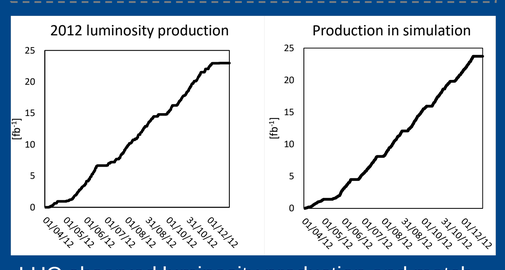
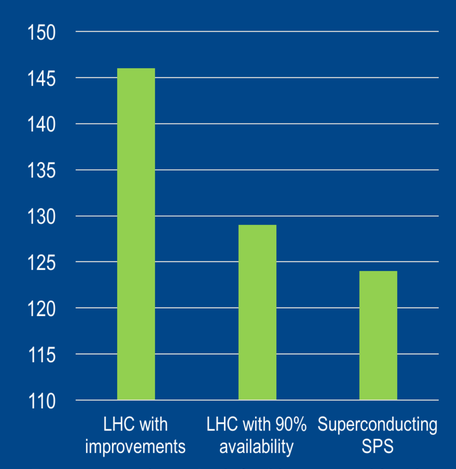
ABSTRACT

Particle accelerators exhibit complex behaviour emerging from the interaction of diverse machine systems, services, beam and environmental conditions. Since 2015 we have explored the fitness of probabilistic reliability engineering to particle accelerators. The investigation relies on the LHC as a use-case. Results indicate that the approach, already well established in manufacturing, automotive, pharmaceutical, process and other industries fits well the needs of particle accelerator facilities. Consequently, an R&D project has been launched to develop an open method to model and simulate the behaviour large systems efficiently. It does not rely on graphical user interfaces, permits specifying large sets of equipment characteristics in time and space saving manner, adequately addresses building models in a collaborative fashion, is data store agnostic and is incrementally extensible to different modelling techniques and simulation engines. Considering the processing requirements, the implementation by Ramentor will also permit deployment in a distributed computing cluster, leading to simulation speedup by a factor 10 to 100. The approach and tool will help building reliability, availability and energy efficiency into the designs of a future circular collider. Ramentor will offer the suite to industrial clients for the assessment and improvement of energy efficiency and availability in very diverse domains such as data centres, cargo handling and natural gas distribution.

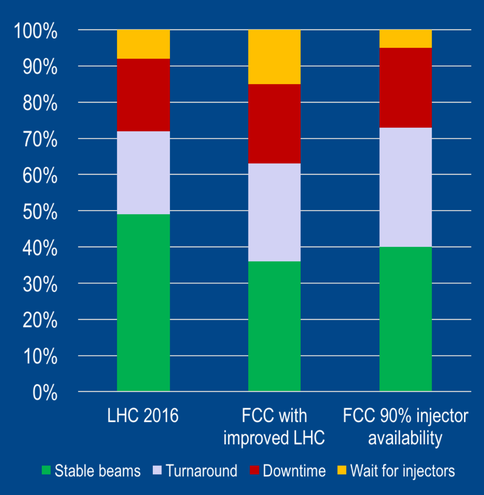


LHC observed luminosity production and match of simulated luminosity production using probabilistic availability modelling and Monte Carlo based simulation with Ramentor's tool.

Outlook of FCC-hh luminosity production based on LHC model and simulation:



Days to produce 1 ab^{-1} of integrated luminosity at the FCC-hh with different injector scenarios.



FCC-hh fraction of stable beams for baseline and injector availability improvement scenario, compared to the LHC operation.

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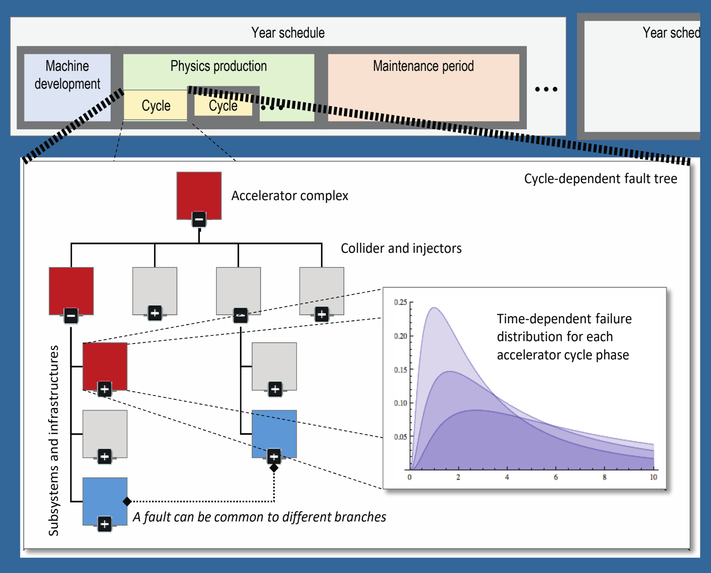
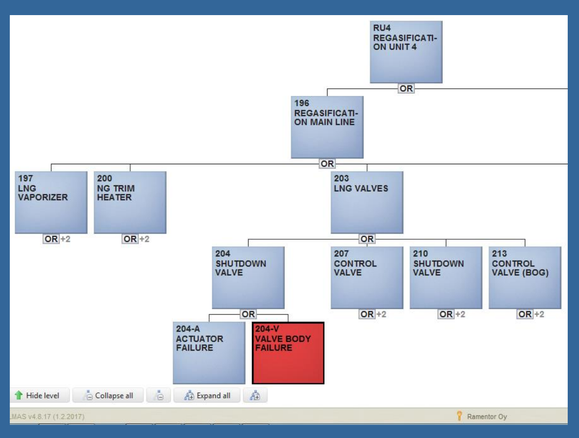
Probabilistic Availability Modeling and Simulation



INTERACTING MODELS

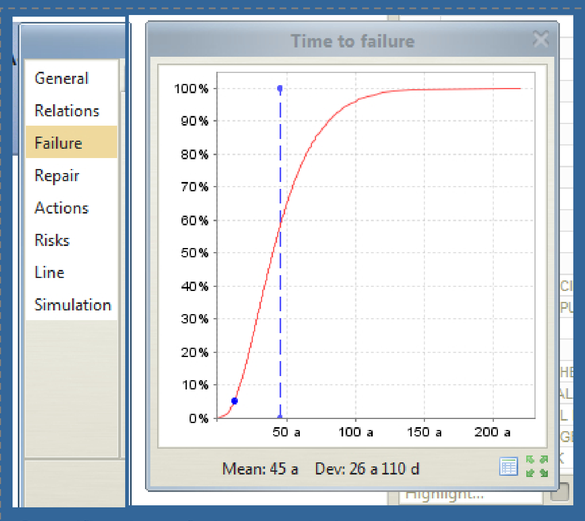
- Different types of models describe the system layout and behaviour for different modelling and simulation purposes.
- **FTA**, **ETA**, **FMEA**, **RBD** and extended variants for failure descriptions
- **Markov** model, **state charts**, **Petri nets** for operation cycles and schedules at different levels from seconds to tens of years.
- Models can be interlinked with events to describe the dynamic system (e.g. a fault can trigger a state change and a state change can alter a failure rate)
- User-supplied production functions can be placed in different model nodes to report on the system's behaviour during and at the end of simulation. For instance, the top node of the LHC collider contains a luminosity production function, the KPI of the collider.
- High-speed Monte Carlo simulation is used to analyse the system's behaviour under different operation conditions. Effects are seen as results of the production functions.



Typical representation of a fault tree in GUI.

INTERACTIVE MODEL CREATION

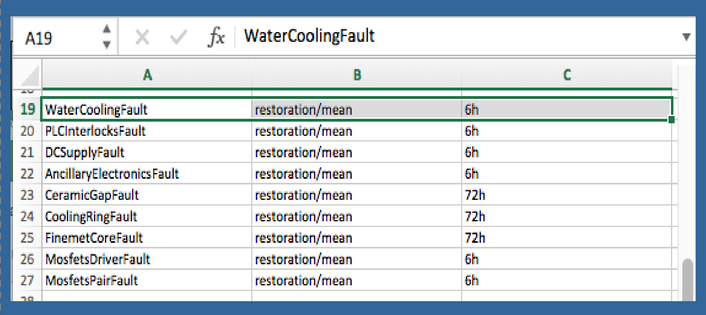
- Systems and behaviour are modelled as directed graphs (elements, operators, links).
- Smaller models can be created with a graphical user interface (drag & drop).
- During a simulation, the user interface informs about the system state (e.g. faults, states).
- Common faults and redundancies are quickly introduced and assessed with copy/paste and linking functionalities.
- Elements can be grouped in folders for re-use in different places in the project.



Specification of characteristics with mode and state dependent Cumulative Distribution Functions (CDF) permit fine tuned sensitivity analyses.

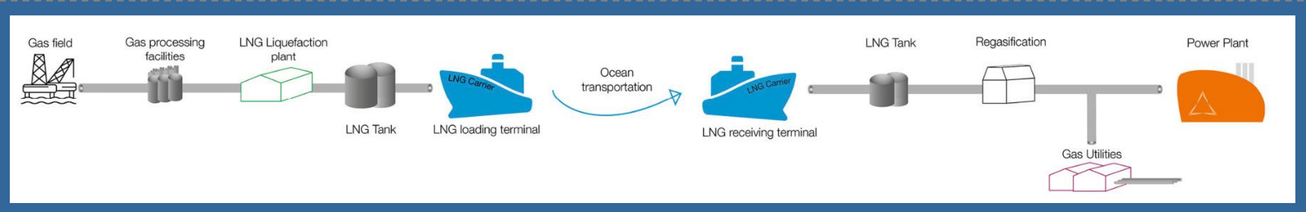
RICH ELEMENT CHARACTERISTICS

- States and modes for element characteristics permit specifying different RAMS properties.
- Cumulative Density Functions (CDF) for characteristics rather than simple value provide more close-to-reality description.
- CDF manipulation gives a fast and powerful tool to assess the effects of failure behaviour to test the effects of planned reliability improvements in terms of benefit and cost.
- Repair and maintenance specifications for elements permit analysing the effects of maintenance and asset management scenarios on the overall performance & cost.



SCALABLE MODEL SPECIFICATION

- Table-based model specification permits definition of large models with few rows and mass-parameterization.
- Models can be extended with user-defined component classes that have characteristic reliability behaviour under different conditions.
- **WHAT-IF analysis** can be quickly performed by changing the behaviour of individual machine components or entire groups of components.
- Data storage is technology independent (CSV files, Excel, JSON, database).
- Collaborative, incremental development by sharing & composing models is possible.



FROM PARTICLE COLLIDERS TO INDUSTRY

The Liquid Natural Gas (LNG) value chain comprises a number of steps from production to consumption that call for an integrated overall efficiency optimization approach. Wärtsilä, a global energy solution provider picked up the approach that is now developed in the scope of the FCC study, focusing on building reliability and availability into the design of an LNG terminal from the early concept phase on. Ramentor's engagement is now focusing on the regasification process (after transport by ship), avoiding unplanned stops and optimizing repair and maintenance strategies.

Platform Key Requirements

Open and efficient language

- Tool-independent model and element characteristics specification
- Store and configuration manage models, developed in a collaborative fashion
- Specify large amounts of system elements and characteristics in a time and space saving way

User interface and tool independence

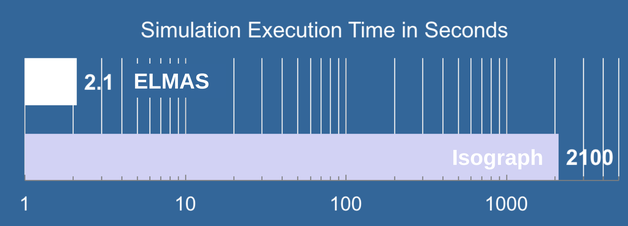
- View models and parameters independent of a specific tool
- Store models in different formats
- Tool-independent simulation specification

Extensibility

- Add additional modelling concepts as needed (e.g. FTA, ETA, FMEA, RBD, Markov models, state charts, Petri Nets)
- Permit additional user-defined data types and functions **without a need to program in a specific language**
- Share and compose models and data

Performance

Single processor performance of the ELMAS Java-based, operating system independent simulation engine is already today outperforming competing commercial tools (see plot below, note the logarithmic scale). With a recently launched, targeted R&D project to decouple the model specification and simulation engine from user-interfaces and custom user-supplied code, the Monte Carlo simulation based assessment of a system will be parallelizable in a computing cluster. This will permit iteratively scanning parameter spaces to better understand the impact of a system change on reliability, availability and to understand the ratio between capital expenditure, operation expenditure and system performance gain.



SUMMARY

We develop an open specification and platform independent parallel computation ecosystem based on a commercial software solution to model complex technical systems. The specification will be made public in the course of 2017. The environment has been used to re-produce the LHC operation performance that serves as a baseline for FCC availability budget and requirements finding.

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