Collider Availability Modelling and Potential Applications in Industry

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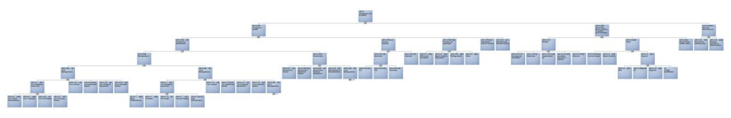
Abstract

This contribution presents our collider availability model used in FCC study. The model represents failure logics, operations and calculates the integrated luminosity productions, which is one of the key performance indicator for colliders. The operation phases are essential part of the collider model, as several steps are required to prepare the collider for collisions. This means that the luminosity production is not linearly dependent on availability and must be modelled separately. The models allows deriving availability budgets for FCC systems to guide their designs and testing different operation scenarios. We see high potential in applying combined reliability and operation models also in process and manufacturing industry. In this field, often the key performance indicator is the process performance. This can be modelled similarly to the luminosity production in the collider model. Our collaboration between CERN, Tampere University of Technology and Ramentor lead to development of an Open Modelling Approach for Availability and Reliability of Systems (OpenMARS). It answers the modelling needs of today's complex and dynamic systems. The approach is based on ELMAS (Event Logic Modelling and Analysis Software), which Ramentor has used successfully in various industry sectors. For analysis of the OpenMARS models, we developed a calculation engine, which permits efficient parallel simulation in a distributed computing cluster.

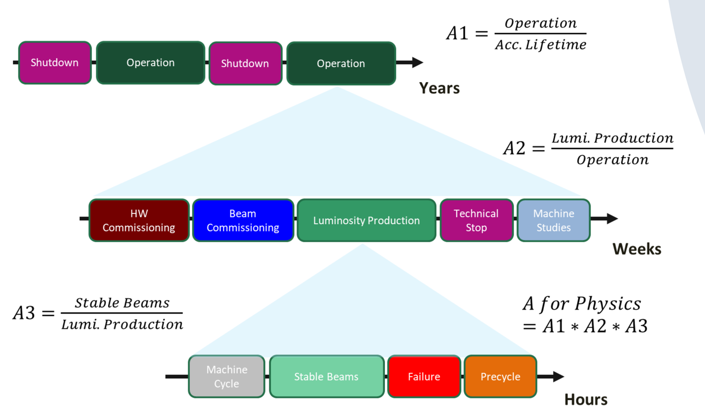
An Open Modelling Approach for Availability and Reliability of Systems (OpenMARS)

We have developed the OpenMARS for analysis of large and complex systems with dynamic behaviors. The approach allows to define models with any of the most common risk assessment modelling techniques, such as **fault tree analysis (FTA)**, **reliability block diagram (RBD)**, **Markov analysis**, **failure mode and effects analysis (FMEA)** and **Petri net**. Specially, with OpenMARS a modeler can combine the most suitable techniques to accurately include all the details that affect the system behavior. Models can interact with the property values and state changes in other models. For example, in **dynamic modelling** the operation phase model can update the property values in other models. OpenMARS models can include also **mathematical and logic functions**. This is needed for example to model application specific **key performance indicators (KPI)**, such as overall equipment effectiveness (OEE). To make sure that OpenMARS is always applicable, we have enabled a possibility for the modeler to extend the build in features of the techniques for special needs. Our approach is **scalable** and **open** to support and combine additional modelling techniques.

Collider Availability Modelling



Fault tree model of each subsystem
(e.g. Cryogenics)



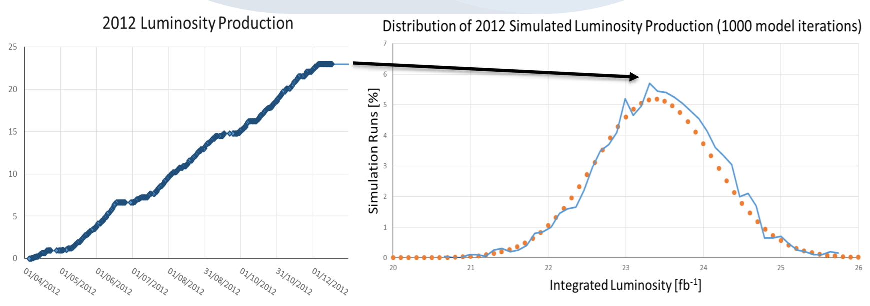
Dynamic operation phase model
(e.g. Injection -> Ramp -> Stable Beams)

$$L_{\mathrm{Int}}(t) = L_p t_L (1 - e^{-t/t_L})$$

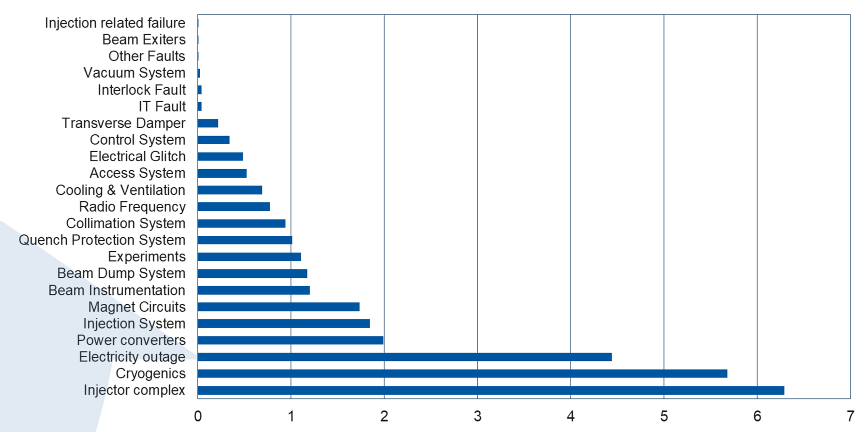
Key performance indicator
(e.g. Integrated luminosity production)

The model combines:
- 1) Different subsystem fault trees
- 2) Dynamic operation phases
- 3) Key performance indicator

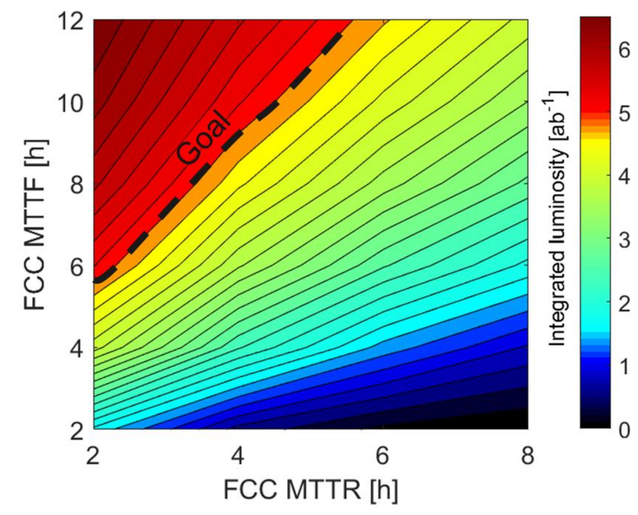
The analysis of the model:
- a) Current situation from the data
- b) Estimates for similar system with different parameters
(e.g. Upgrade from LHC -> FCC)



Analysis result:
(e.g. Current LHC luminosity production)

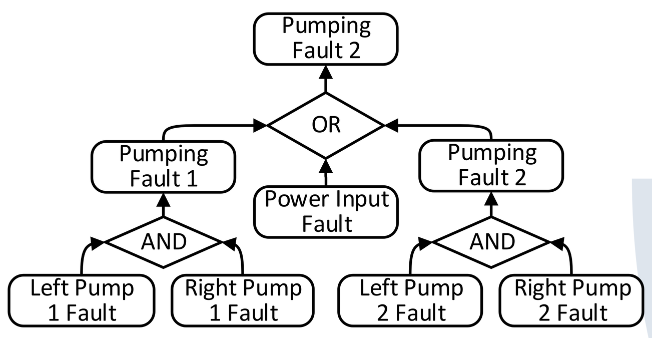


Allocation result:
(e.g. Failures allowed for each FCC subsystem)



Sensitivity analysis:
(e.g. How to achieve FCC performance goal?)

Simplified Availability Model of Multi State Industrial Process

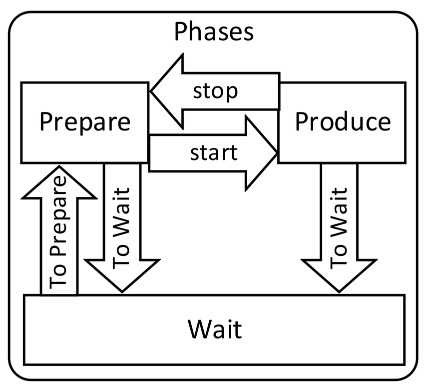


Fault tree model of each subsystem

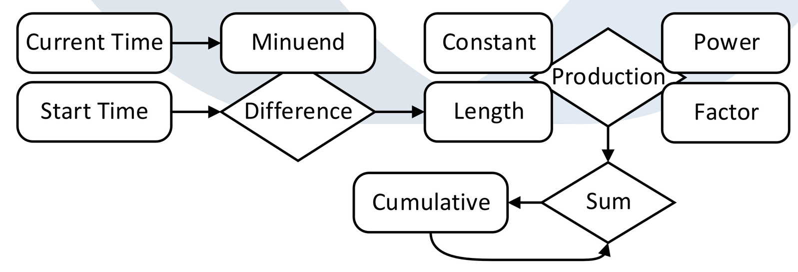
Combined modelling techniques:
- 1) Fault tree analysis (FTA)
- 2) Markov model
- 3) Function model

Model input data:
- a) Failure and repair history
- b) Expert judgement

Scenario analysis (What if?)
- Use different component?
- Improve subsystem failure rate?
- Increase production phase length?
- Change production factor?
- Change maintenance schedule?



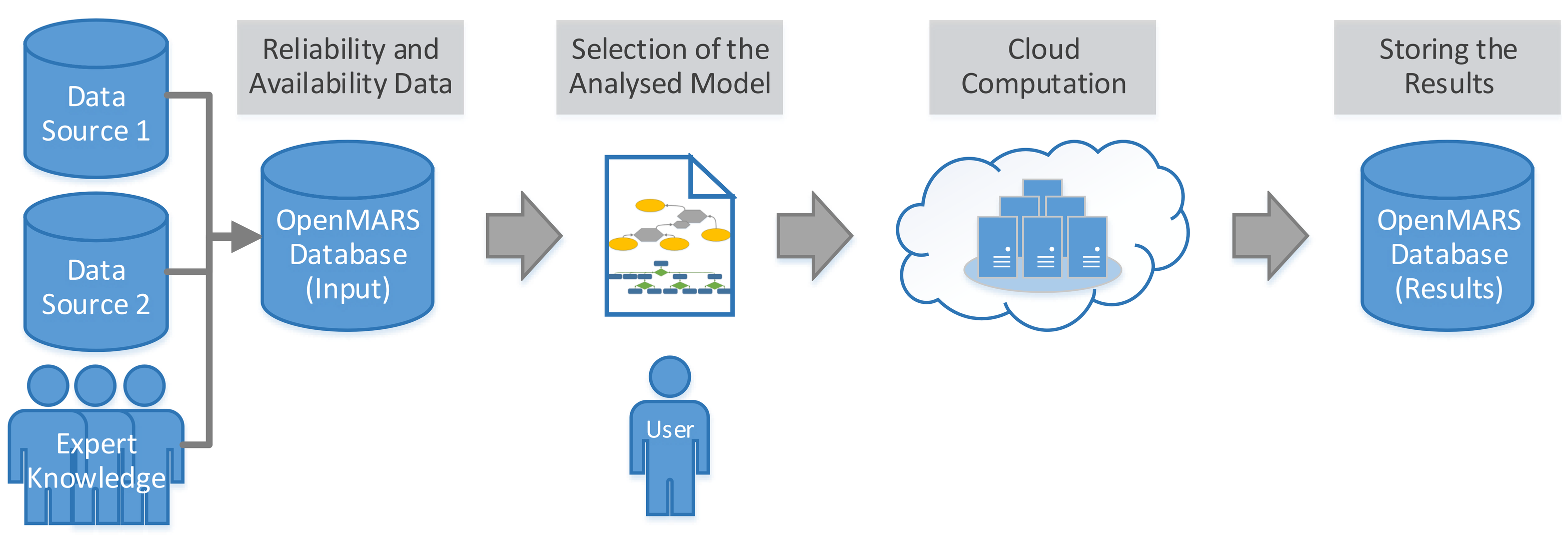
Dynamic operation phase model



Key performance indicator

Analysis of the current situation
- Reliability (Number of failures)
- Availability (Downtime)
- Importance (Top 10 lists)
- Maintenance (Costs/resource needs)
- Production (Integrated luminosity)

Parallel Stochastic Discrete Event Simulation in a Computing Cluster



We have developed a calculation engine, which simulates results from the model by using the Monte-Carlo method. Distributed processing architecture permits efficient parallel calculation in a computing cluster. The parallelization is made by dividing the simulation rounds between cores.

Case Examples from Various Industry Sectors

1 Molding Crane in steel industry
- Verifying current state reliability, availability and cost effects to production
- Quick fixes and maintenance plan optimization
- Reduced overall cost risks by 23%

2 District Cooling Plant
- Locating the most critical failure modes concerning cooling power production
- Understanding how the increasing cooling power needs affect the overall power availability of the plant

3 NPP Cooling Water Pumping
- Verifying current state reliability, availability and cost effects
- Spare part policy and maintenance plan optimization
- Reduced overall cost risks by 10%

4 Biomass Power Plant Boiler
- Verifying that the design solutions meet the set RAM requirements during the design and implementation phase
- Reduced overall cost risks and extremely expensive design changes later on

5 Combined Heat Power Plant
- Verifying that the design solutions meet the set RAM requirements during the design and implementation phase
- Reduced overall cost risks and extremely expensive design changes later on

6 District Heating Plant
- Locating the most critical failure modes concerning heating power production
- Focus improvement investments: 7.1% of the failure modes caused 75% of the overall lost power production

7 110kV Substations (Air-insulated)
- Understanding what power input availability the AIS substation can provide for customers behind single/multiple lines
- Substation availability verified to be sufficient (99.999+ %)

8 110kV Substation (Gas-insulated)
- Verifying that the GIS substation design can provide sufficient availability required by the mission critical customers
- Improving preliminary design availability from 99.99+ % to 99.999+ %

9 Underground HVAC systems
- Optimize design solutions during the design phase
- Reduced overall cost risks by 55% (~15M€ in 40 years)

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