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Industrialization of 16T Nb_3Sn magnet production for HE-LHC and FCC

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Motivation

Optimization of manufacturing performance of HL-LHC magnet by monitoring and controlling key performance indicators (KPI) such as cost and quality would be precursor to cost-effective manufacturing of Nb_3Sn magnets for HE-LHC and FCC. A continuous production-monitoring platform known as ***Manufacturing Execution System (MES)*** is proposed. A systems model is required that would integrate product design, production control and monitoring, data analytics, and manufacturing process optimization to form a ***multi-criteria decision-making support tool***. The ***MES, Bayesian networks and dimension reduction*** based analytics methods would enable accurate ***cost-driver identification and cost-driven optimization*** for sustainable production of Nb_3Sn superconducting magnets.

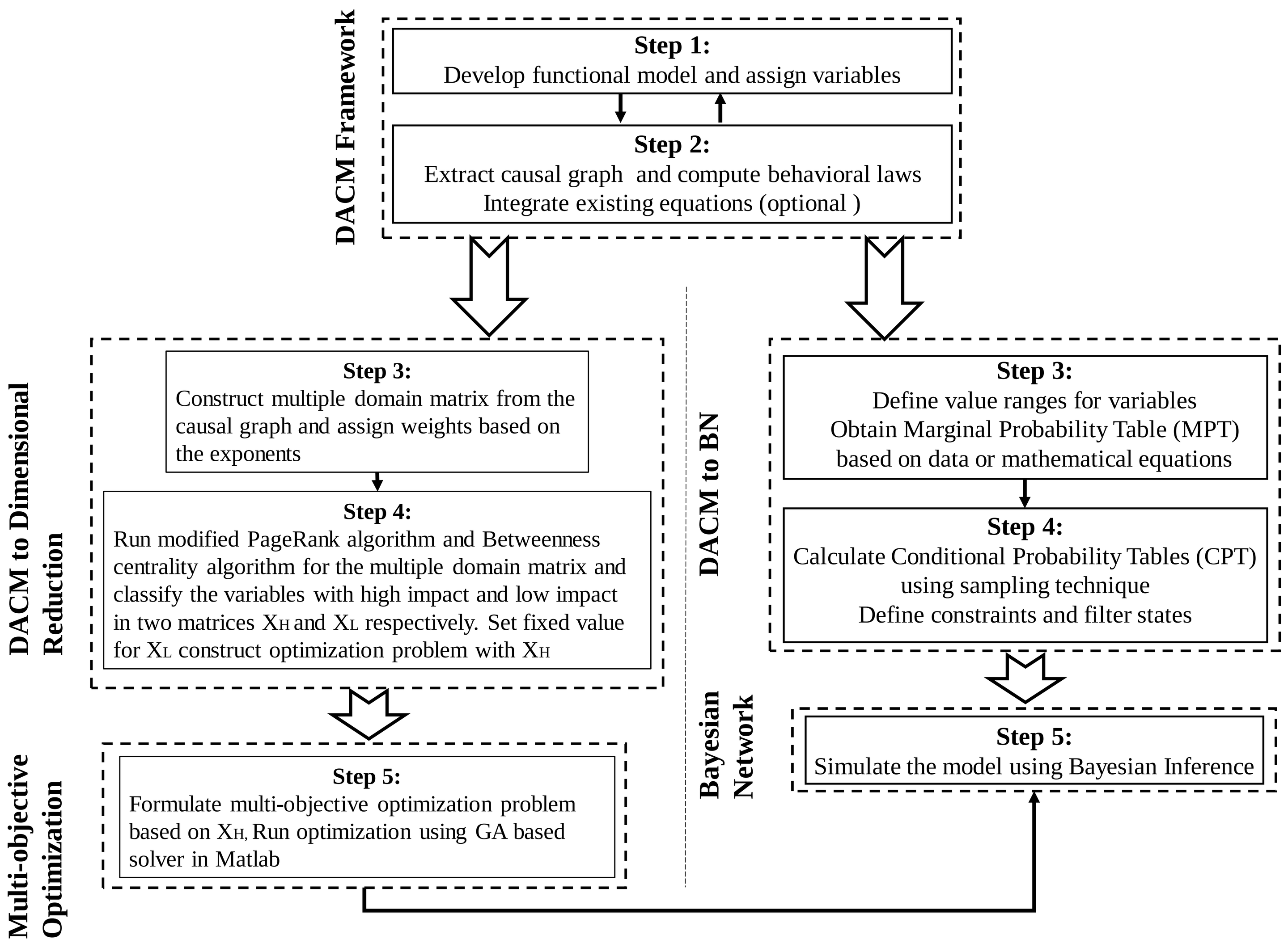

Figure 1: Combined framework for the developed methodologies

Methodology

The multi-criteria decision making tool is developed using the following methodology shown in Figure 1. The steps followed are:

1. Analyzing the functionality and establishing the cause-effect relationships between the variables using ***dimensional analysis conceptual modeling (DACM)***[1].
2. Applying ***graph centrality theory*** to the causal graph generated to find the effective number of variables and parameters which are needed for process optimization[2].
3. Adapting the causal graphs to remove loops in order to make direct acyclic graph (DAGs) in order to create ***Bayesian networks***. The Bayesian networks is used to estimate the cost of manufacturing and other performance metrics[3].

The dimension reduction method is applied to simplified case study for optimizing the performance and cost of manufacturing of the support structure (bladder and key) for 16T magnets and is shown in Figure 2. A case study involving manufacturing components of turbine using additive manufacturing was used to validate a decision making tool developed using Bayesian network (shown in figure 3).

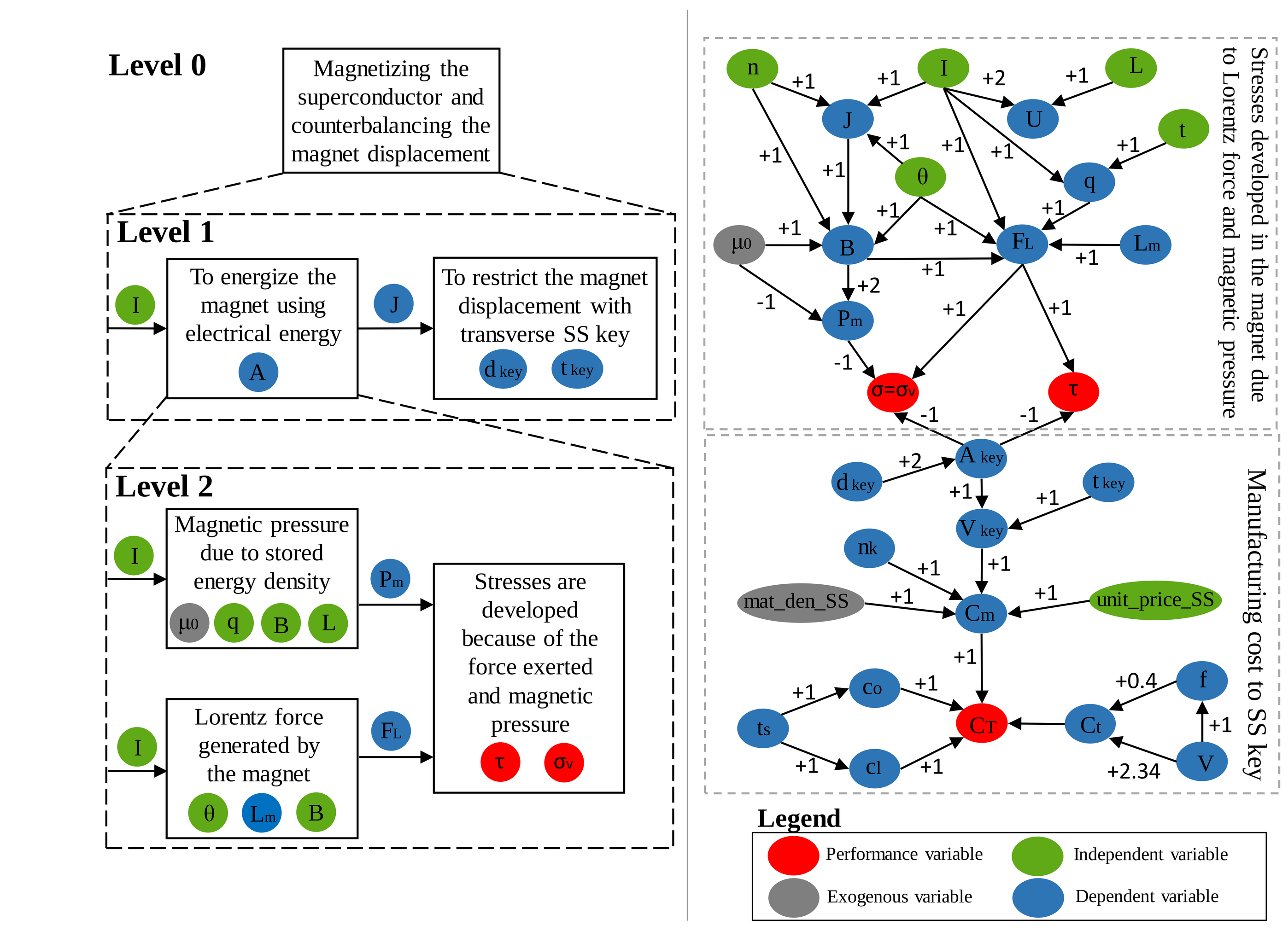

Figure 2: Functional model and causal representation of magnet behavior

Implementation at CERN

Industry 4.0 would mean the conventional factories need to undergo transformation to smart factories. Implementation of supporting hardware (sensors and control systems) and software (data processing and analytics) at the Large Magnet Facility (LMF) would be the first step towards digitalization. The ideas developed herein would help provide the necessary groundwork to help transition to smart factories of the future.

CERN and it's collaborators would benefit from the ***improved efficiency of the production, better utilization of resources, optimized supply chain, higher standards of quality assurance, and higher reliability in the systems***. Based on the research and market study a customized ***MES*** is proposed for the winding house as a pilot case study at the LMF.

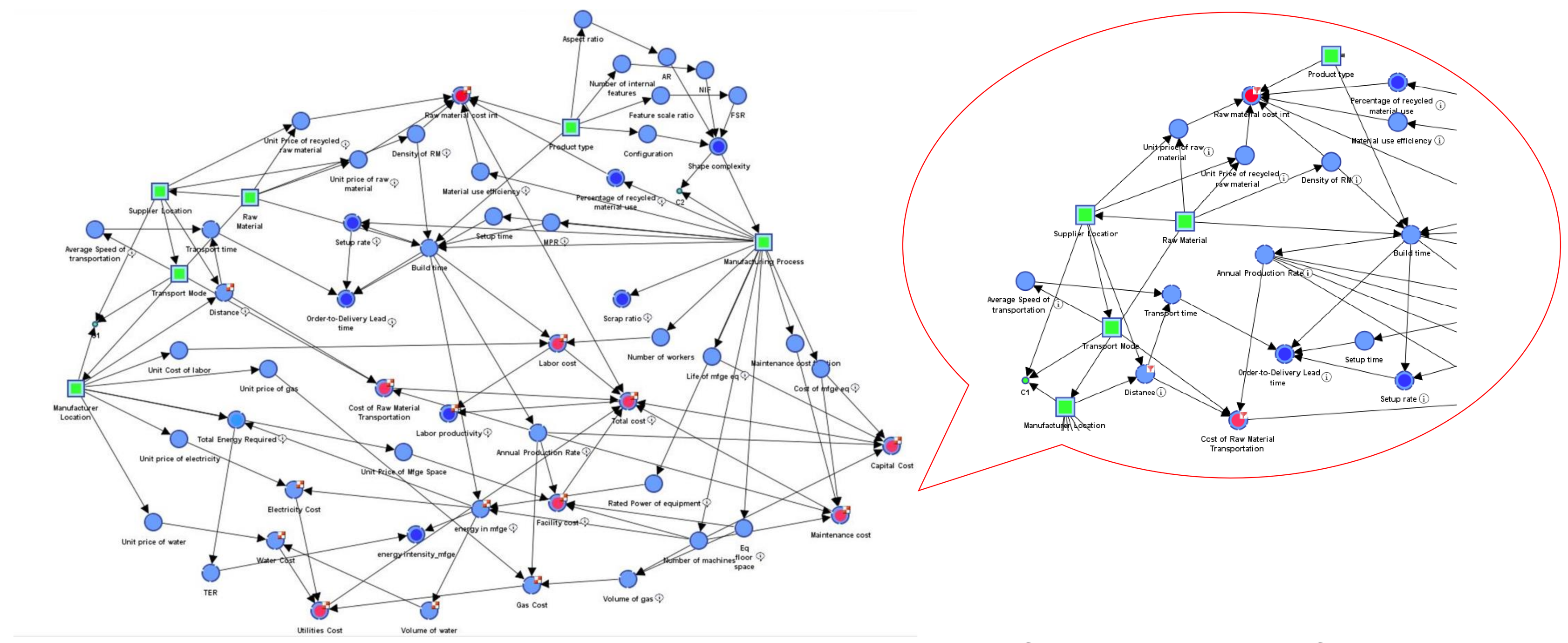

Figure 3: Bayesian network based decision making tool for additive manufacturing

Results

The results of the two case studies are as follows:

- Dimension reduction
  1. Dimension reduction methodology ***identified and reduced the number of variables to matrix X_H (high impact variables)***, later to be used for optimization problem
  2. Cost optimization using genetic algorithm was performed for manufacturing of the support structures of 16T magnet
- Bayesian network
  1. A multi-criteria decision making tool was developed to improve manufacturing related decisions of production volumes, type of manufacturing process, type of raw material, modes of transportation, and raw material and manufacturing locations by taking into consideration ***manufacturing cost, order-to-delivery lead time, labour productivity, scrap ratio, amongst other important performance indicators*** as seen in Figure 4.
  2. Sustainable cost-effective manufacturing decisions were attained for production of turbine component using additive manufacturing process.

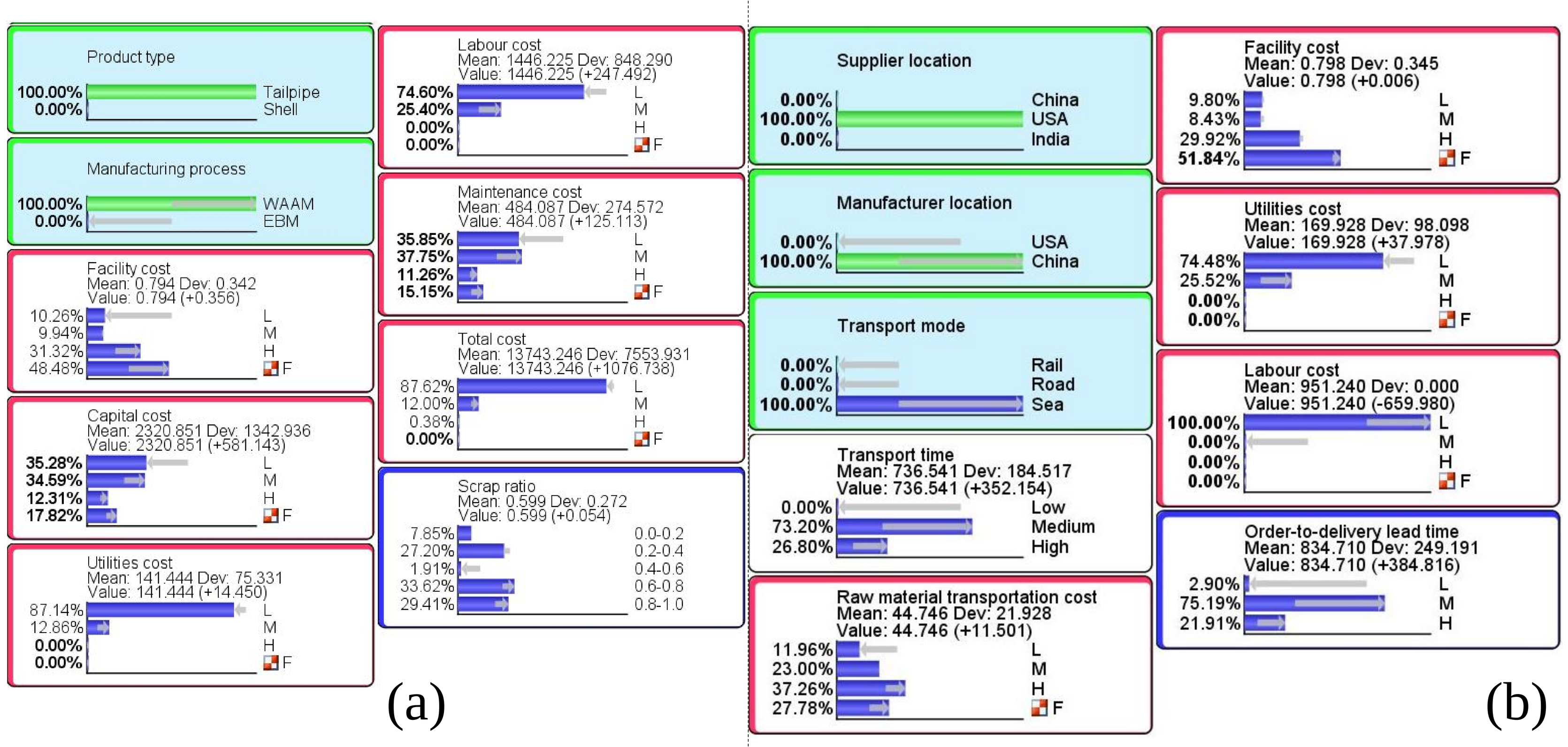

Figure 4: Bayesian inference based analysis of manufacturing decision choices and its implications on key performance indicators

Future work

1. Dimension Reduction can be used as a precursor to developing the Bayesian network, reducing the number of nodes would reduce the overall uncertainty arising from a bigger network.
2. By introduction of sensors and control on the manufacturing line, the data collected from the line would be used for analysis in the models.
3. Realization of step 2, would mean a ***more transparent and efficient manufacturing line***, and a possibility for creation of ***digital twins***.

1. E. Coatanéa et al., "A conceptual modelling and simulation framework for system design". Computing in Science and Engineering, 18(4), 42.
2. A. Chakraborti et al., "A Dimension Reduction Method for Efficient Optimization of Manufacturing Performance" in 29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM 2019), Limerick, Ireland. (Accepted)
3. S. Panicker et al., "Tracing the Interrelationship between Key Performance Indicators and Production Cost using Bayesian Networks" in CIRP Conference on Manufacturing Systems 2019 , Ljubljana, Slovenia. (Accepted)