



Development of computational tools for criticality analysis of process systems, utilizing Industrial IoTs

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Introduction

Traditional sensitivity analysis based on reliability models, such as logic-tree or fault-tree analysis, together with existing FMECA techniques, are powerful and well established methods for the identification of critical parts of equipment / events affecting the system functionality and safety. However, they share a common limitation since they do not explicitly take into account process models and process interactions; this may overestimate the real system efficiency and provide misleading information regarding rating critical components or events. This paper presents, in a uniform framework, computational tools and algorithms for criticality analysis of process systems, which embodies: system logic via DFLD/ Fault-Tree Diagnosis System FTDS, explicit process and safety models, equipment reliability data and occurrence probabilities of external events/utilizing sets of data collected via Industrial IoTs. The criticality analysis framework is used as a guide for improvements towards safer and more efficient systems design and/or condition-based maintenance activities whereas the proposed computational toolset is based considering process and equipment interactions, equipment failure, stochastic process variations and external events related to process operations and safety. Important extensions are also presented for the use of such criticality analysis tools for safety and maintenance considerations. A module for rating all the equipment, operations and events according to the associated criticality index is utilized, coupled with a condition based maintenance framework for enhancing overall system efficiency and safety. The computational tools and the algorithms are demonstrated via case studies. The developed software and methodology coupled with valuable sets of information from dedicated Industrial-IoTs is applied in order to rank the criticality of the parts/subsystems/systems/events and then to propose a maintenance/safety policy which fulfills certain efficiency and safety targets.

Criticality Analysis of Process Systems

The objective of the criticality analysis module is to identify the relative importance of equipment (un)availability (or other external events affecting the process operations) over a time horizon by taking into account process interactions, reliability models, parameter variations and operational characteristics of a process system. Criticality analysis comprises: size reduction of the system state space, translation of process flow-sheet into DFLD (automatic generation of fault-trees/n-order cut sets); Estimation of state probabilities as a function of time and system's efficiency; Estimation of a system criticality index as a function of time; Estimation of a combined flexibility-reliability-criticality index for each part of equipment or event; Criticality based maintenance.

Follows the description of the fundamental computational modules:

MODULE GRAPHS: - SYSTEM AGGREGATION, DFLDs and FAULT-TREE GENERATION

An aggregation utility is employed in order to cope with complex large-scale systems reducing the size of the corresponding state space while guaranteeing the



upper and lower bounds of system performance indexes. Here, Directed Functional Logic AND/OR Digraph representations are employed that can automatically be transformed into fault-trees/ minimal cut set, bounding easily reliability and criticality indexes for complex system.

MODULE CRI: CRITICALITY RATING OF PROCESS SYSTEMS

In this module the quantitative metrics of *combined flexibility-reliability index FR* and *combined flexibility-reliability criticality index, FRC* are estimated for measuring the expected level of critical operation of process systems taking into account interactions between process undesired critical operations (as a result of systems malfunctioning, equipment degradation or even the occurrence of certain events based on IIoT information sets) while a *relative criticality index CRI* is ranking all equipment or events according to their relative importance (sensitivity) for system's operations. The results from such a relative ranking can guideline preventive maintenance planning and scheduling.

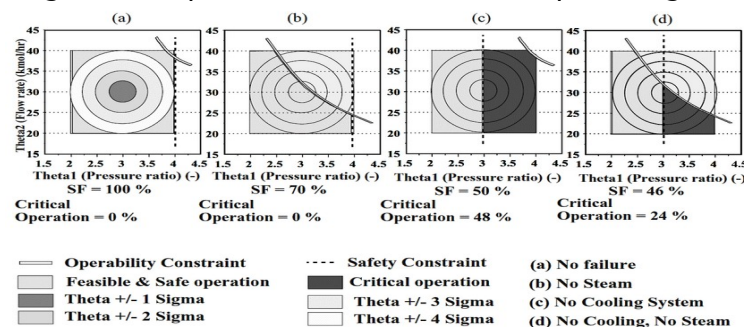


Figure 2: Feasible Region of operation and Regions of Critical Operation

MODULE MAINTENANCE: CONDITION-BASED and PREVENTIVE MAINTENANCE

In this module, we developed algorithms and tools for the planning and execution of preventive and condition-based maintenance. The algorithms rely on the criticality analysis as it is performed by module CRI ; additionally, it requires quantitative information regarding maintenance resources and logistics (number of service crews, man hours/job, personnel availability, job durations etc) and maintenance tasks (equipment maintenance specifications, list of scheduled preventive maintenance activities).

Results and discussion

While the criticality analysis computational tools developed in this work predict variable information regarding the overall system expected critical operations, the relative importance of the equipment to the process and identification of process and/or reliability bottlenecks, utilizing Industrial Internet of Things (IIoT) as they have been developed NITLAB and tested on the real field by Pangaea R&D interfacing/monitoring external events, advocating labor and material-saving as well as safety advantages for processes and operators in the field. However, as it is shown via case studies, the proposed methodology could be an efficient tool for the proper balance of preventive and condition based maintenance activities and the prediction of their impact to process operational decisions.

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References

Andrews J., 1990 'Applications on the digraph method of fault tree construction to a complex control configuration', *Reliability Eng. And Systems Safety*, vol. 28, pp. 357-384.



- Boyes H. et. al., 2018, *The industrial internet of things (IIoT): An analysis framework*, *Computers in Industry*, Volume 101, Pages 1-12
- Iverson D.L., 1992, 'Automatic Translation of Digraph to Fault-Tree Models', *Proceeding Annual Reliability and Maintainability Symposium*, pp.354-362.
- Paulsen C. et. al., 2018, "Criticality Analysis Process Model Prioritizing Systems and Components, NISTIR 8179
- Sisinni E. and Jennehag U, 2018, *Industrial Internet of Things: Challenges, Opportunities and Directions*, *IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS*, VOL. 14, NO. 11
- Straub D. A. and Grossmann I. E., 1993, 'Design optimization of stochastic flexibility', *Comp. Chem. Engng.* 17(4), pp. 339-354.
- Thomaidis T.V. and Pistikopoulos E.N., 1995, 'Optimal Design of Flexible and Reliable Process Systems', *IEEE Trans. on Reliability*, 44(2), pp. 243-250.