WP3: Maintenance and Diagnosis Final Report

Cranfield University
ABB OGP Technology & Innovation
ABB Corporate Research Germany

energy smartOps
The energy solutions of tomorrow

Cranfield UNIVERSITY

ABB
Power and productivity for a better world™

WP3 Maintenance and diagnosis
Objectives

- Prototypic reactive maintenance planning algorithms for industrial use cases will be developed. The algorithms will be based on integrated models of the electrical and the processing subsystems of the plants.

- To develop and optimize new methodologies for predictive equipment condition monitoring through statistical process monitoring of multivariate data typically employed for monitoring process, electrical and mechanical machinery.

- Technology, methods and instrumentation for automatic detection of leakage in safety valves.

- To define a new concept for representation of plant and equipment topology that will enable more efficient collaboration between personnel from the electrical, process and mechanical disciplines.

WP3: Multivariate statistical process predictive monitoring using operational data

Cristóbal Ruiz Carcel , CRANFIELD

energy smartOps

- **TASK**

  To develop and optimize new methodologies for predictive equipment condition monitoring (CM) through statistical process monitoring of multi-variate data

- **OUTCOMES**
  - Application of Spectral Kurtosis on acoustic emission data
  - Experimental data acquisition for the Cranfield Case study
  - Application of different multivariate algorithms using experimental data
  - Experimental data acquisition for the ABB-PL case study
  - Combination of process and vibration data for fault detection and diagnosis
  - Quantification of energy wastage due to faults applied to experimental data using CVA-based system identification

- **SECONDMENTS**
  - Secondment at ABB Corporate Research Centre in Krakow for the acquisition of experimental data in a compressor test rig (6 weeks)

Publications
Cristóbal Ruiz Carcel , CRANFIELD

CONFERENCES

- Presentations at WCEAM 2012, UKACC 2014 , WCICA 2014, Comadem 2014
- Organization of Special Session at UKACC 2014

JOURNAL PAPERS

- Ruiz-Cárcel, C., Hernani-Ros, E., Cao, Y., and Mba, D., 2014, Use of spectral kurtosis for improving signal to noise ratio of acoustic emission signal from defective bearings, *Journal of Failure Analysis and Prevention*, 14, 363–371.
- Elasha, F., Ruiz-Carcel, C., Mba, D., Jaramillo, V-H., Ottewill, J.R., 2014, Detection of machine soft foot with vibration analysis, *Insight*, 56, 622-626
- Ruiz-Cárcel, C., Hernani-Ros, E., Chandra, P., Cao, Y., Corsar, M., Mba, D., Application of linear prediction, self-adaptive noise cancellation and spectral kurtosis in identifying natural damage of a rolling element bearing in a gearbox, *International Journal of Acoustics and Vibration (Accepted)*
- Ruiz-Cárcel, C., Cao, Y., Mba, D., Lao, L., Samuel, R.T., 2015, Statistical process monitoring of a multiphase flow facility, *Control Engineering Practice* (*Submitted*)
- Ruiz-Cárcel, C., Jaramillo, V-H., Mba, D., Ottewill, J.R., Cao, Y., 2015, Combination of process and vibration data for improved condition monitoring of industrial systems working under variable operating conditions, *Mechanical Systems and Signal Processing* (*Submitted*)
- Ruiz-Cárcel, C., Lao, L., Cao, Y., Mba, D., 2015, Canonical Variate Analysis for performance degradation under faulty conditions, *Reliability Engineering & System Safety* (*Submitted*)

Training
Cristóbal Ruiz Carcel, CRANFIELD

TRAINING

- Modules in Process Systems Engineering:
  - » Introduction to Process System Engineering (October 2011 Cranfield)
  - » Process Plant Operations (October 2011 Cranfield University Cranfield)
  - » Advanced Control Systems (January 2012 Cranfield)
  - » Process simulation and design (January 2012 Cranfield)

- Other courses
  - » Introduction to Labview
  - » Linear Regression and Correlation Coefficients
  - » Design of Experiments
  - » Communicating Your Progress
  - » Choosing The Right Statistics
  - » Writing and producing quality conference papers
  - » Dot Net C# course (Imperial college)

- Languages: German course, 1.5h per week

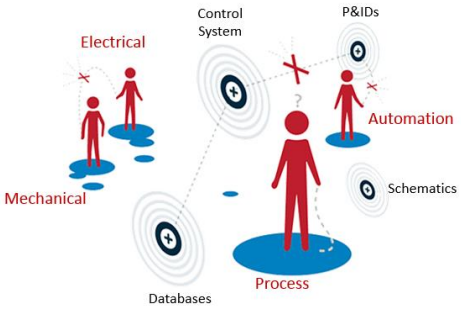
WP3: Visualization of plant connectivity (process, electrical and mechanical)

David Dorantes Romero, ABB-NO

energy smartOps

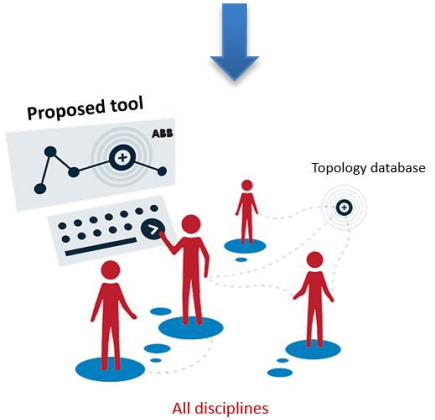
TASK

- Tools for capturing and visualizing information about plant-wide dependencies
- More efficient collaboration between experts from different disciplines, supporting troubleshooting activities



MOTIVATION

- Connectivity information is difficult to extract from the available solutions
- Push for integrated operations and remote collaboration
- Time-consuming to make inferences from disparate sources of information



METHODOLOGY

- Extract plant metadata from CAE/DCS tools
- Integrate topological information from process schematics, notification and electrical system
- Design by using visualizations (following user centric design methodologies)

WP3: Visualization of plant connectivity (process, electrical and mechanical)

David Dorantes Romero, ABB-NO

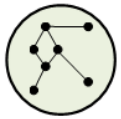
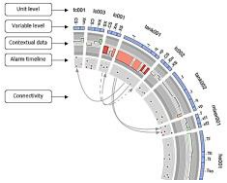
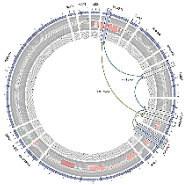
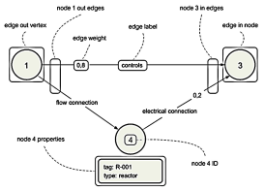
energy smartOps

RESULTS

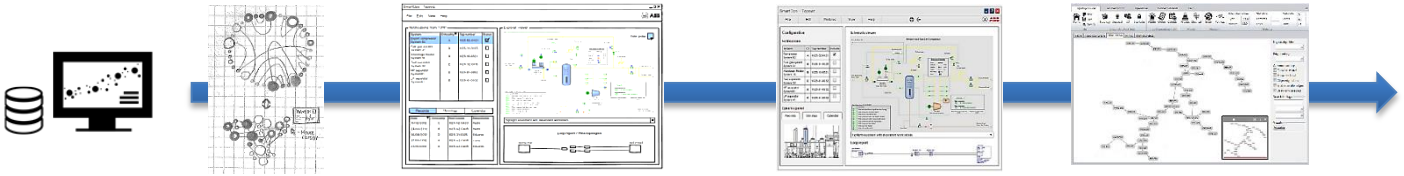
- Study of human, technology and workflows associated to the analysis of connectivity



- Proposal of (1) methods for generating information-rich visualizations based on data extracted from different sources, (2) property-graph model for storage of connectivity data, and (3) methods for searching and highlighting propagation paths

- Concept development for visualization tool, including algorithms for linking information from disparate sources (High-fidelity WPF prototype)



Activities
David Dorantes Romero, ABB-NO

NETWORK ACTIVITIES

Collaboration partners
- ABB Germany CRC: Topology Engineering Group
- Imperial College: Part time PhD program with Prof. Nina Thornhill
- Statoil: User studies & access to end-users
- Oslo Design and Architecture School: Supervision of bachelor and master students

Secondment
- Imperial College Oct-Nov 2013
- Imperial College Jul-Aug 2014

Site visits (Statoil)
- Kårstø gas processing plant
- Kollsness gas processing plant
- Fornebu headquarters
- Sandsli on-shore support centre

TRAINING

Technical Courses
- C# programming (ICL)
- Computer supported collaborative work (University of Oslo)
- Design of P&IDs (ABB)

Courses from Graduate School at Imperial
- Presentation skills
- Time management
- Assertiveness
- Communicating science
- Entrepreneurship
- Organizations
- Academic writing skills

Other courses
- Basic IP
- Elementary orwegian (A1)
- Basic Norwegian (A2)
- Intermediate Norwegian (B1)
- Norwegian society course (50 hrs)

DISSEMINATION

Conference papers
1. *Human Factors and Ergonomics Society Annual Meeting*, San Diego USA, 2013
2. *24th European Symposium on Computer Aided Process Engineering ESCAPE 24*, Budapest, Hungary, 2014
3. *Emerging Technologies and Factory Automation,* Barcelona, Spain, 2014
4. *International Symposium on Systems Integration*, Tokyo, Japan, 2014
5. *25th European Symposium on Computer Aided Process Engineering ESCAPE 25*, Copenhagen, Denmark, 2015

Other events
1. ABB Open House, August 2013
2. ABB Open House, March 2014
3. ABB Open House, March 2015

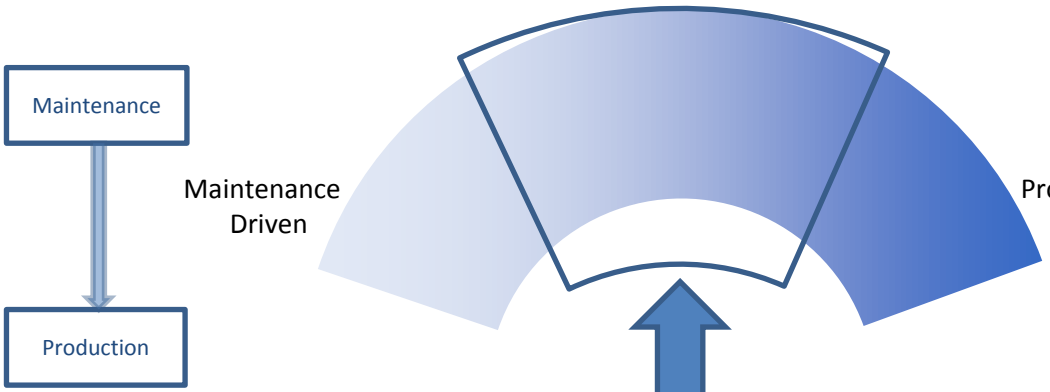
WP3: Short-term maintenance and production scheduling for process plants

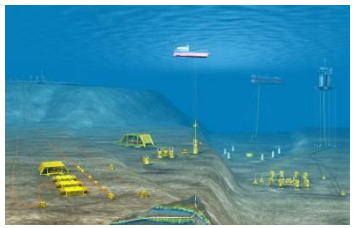
Matteo Biondi, ABB-DE

energy smartOps

RESEARCH AIM

- Integration of maintenance and production on an operational level
- Propose an optimization-based approach for the integration of the two decision processes





Subsea installations

Steel-making process

Automotive industry

Activities
Matteo Biondi, ABB-DE

NETWORKING

- Secondment: “Opportunistic maintenance planning of subsea processing plants” @ Statoil Research Center, Rotvoll – Trondheim(NO)
- Secondment: “Optimization based maintenance planning” @ Carnegie Mellon University – Pittsburgh (USA)
- Site Visit: Kollsnes gas processing plant (Statoil), Łódź drives and electrical motors factory (ABB)

PUBLICATION

- Biondi et al. “Tighter Integration of Maintenance and Production in Short-term Scheduling of Multipurpose Process Plants”, *ESCAPE 25 Conference*, Copenhagen, Denmark, 2015

TRAINING

Training	Description
Optimization Modeling, Conceptual Design and Integrated Process Operations	Short optimization course @ Carnegie Mellon University
Project Planning, Analysis and Control	Project management course @ ABB Switzerland
Power Speech Seminar	Seminar on presentation skills
SmartOps Professional Skills Course	Series of mini-courses on soft-skills for researchers @ Imperial College London
Language course	German language course and exam (telc Deutsch B2)
Subsea Awareness Course	Introductive course on subsea technologies and operations @ Society for Underwater Technology

WP3 Achievements

INTENDED OUTCOME

Develop and validate improved algorithms for predictive process monitoring that can provide information about the presence of faults, their origin, and their impact on the system performance.

Define new concepts for representing plant and equipment dependencies over process, electrical and mechanical domains that can support collaboration during fault diagnosis and risk analysis.

Develop an optimization based approach for the joint maintenance and production scheduling of process plants, by explicitly taking into account information on system degradation coming from a predictive process monitoring system.

METHODOLOGY DEVELOPED

Data-based methods such as Canonical Variate Analysis (CVA) were used for fault detection, diagnosis, and estimation of performance degradation. These methods were validated in an experimental multiphase flow facility operated under changing operational conditions.

Parsing algorithms to extract process connectivity from disparate data sources were developed. A graph data model proposed for integrating and storing connectivity; and visual analytics were applied in the design of a graphical user interface to be used in connectivity analysis.

A mixed integer programming approach (MILP) has been used to model the joint maintenance and production scheduling problem. A multi-time scale and aggregated approach have been used to address the different time dynamics between maintenance and production as well as to keep the problem solvable from a computational point of view.

MEASURE OF SUCCESS

CVA successfully detected and diagnosed different process faults seeded in the experimental plant. The methodology proposed quantified an energy waste of 8.15kWh over 80 min. caused by a partial pipe blockage.

Connectivity graphs covering different domains allow much faster understanding of how faults could propagate between systems and sub-systems and can point to the root-cause faster than using manual analysis. Energy and cost are saved due to reduced down-time.

Production and maintenance tasks are seamlessly planned over the scheduling horizon in order to meet production requests. The operation mode of plant equipment is varied accordingly and to meet the long term maintenance objectives.