Robust Digitalization of Manufacturing Applications

RoDi

Andreas Archenti, Monica Katherine Gonzalez, Mariano Coll

Swedish Manufacturing R&D Cluster Conference - Skövde, 22th of May, 2024

Agenda

1. Introduction

Background and motivation

Presented by Prof. Andreas Archenti

2. Project overview

Work packages, methodology and progress

Presented by Monica Katherine Gonzalez

3. Case study

Line level: Emulsion system

Presented by Mariano Coll

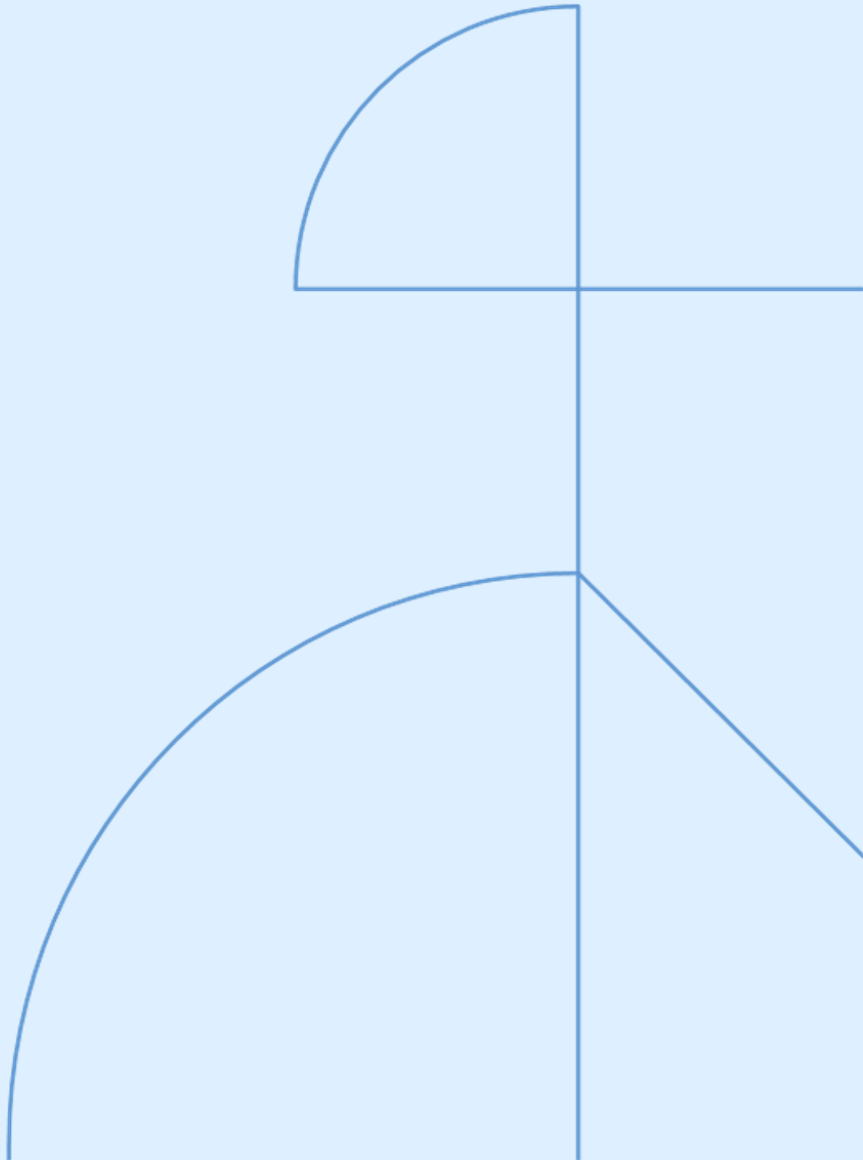
4. Outlook

Presented by Prof. Andreas Archenti

Introduction

Andreas Archenti (archenti@kth.se)

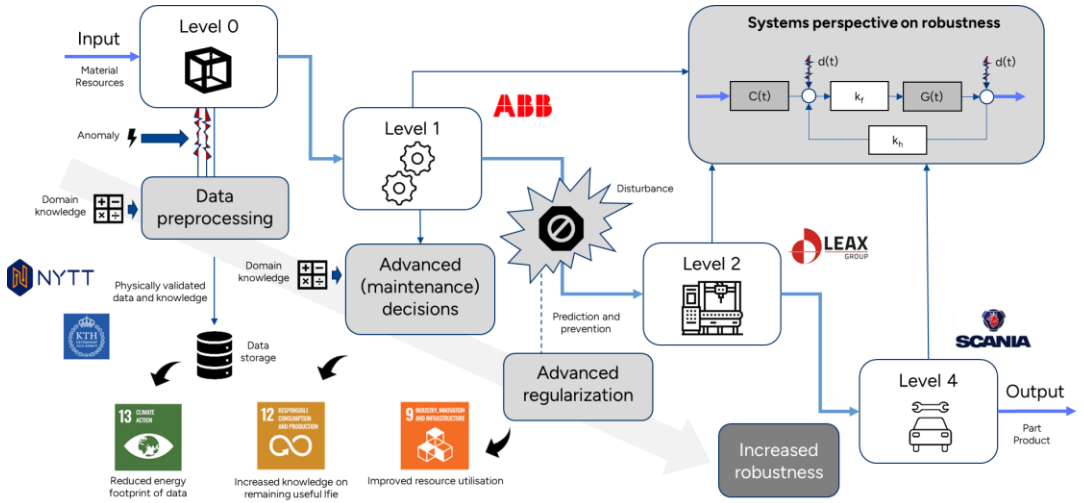
Prof. Industrial Dependability



Robust Digitalization of Manufacturing Applications - RoDi

General Information:

- Funded: FFI, Vinnova
- Budget: 10MSEK (50% from Vinnova and 50% in-kind contribution)
- Period: April, 2022 to March 2025
- Grant number: 2021-05068



Digitalization in manufacturing companies

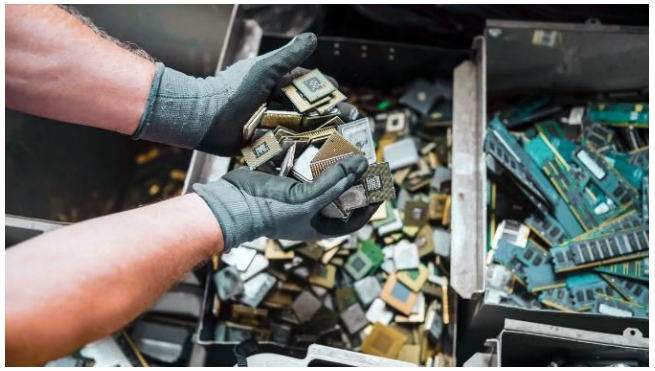
- Digitalization is rapidly changing the production environment
  - Data are nowadays collected on literally every level of production
- Data usage in business decision-making can enhance competitiveness
- "*Virtually free of cost*"

However,

- Data usage depends on data quality
- How to obtain reliable measurements?
- How to build trust in these large data sets?

Electronic waste and footprint

- More than 53.6 million metric tons of e-waste is generated each year
- By 2030, will exceed the 74 million metric tons
- Industry: main driver of consumption
- Massive amounts of data are captured and stored for further analysis
- Data storage is an intensive energy consumer, large contribution to the energy footprint of data



Source: Energy industry review

Source: MIT News (news.mit.edu)

In our project,

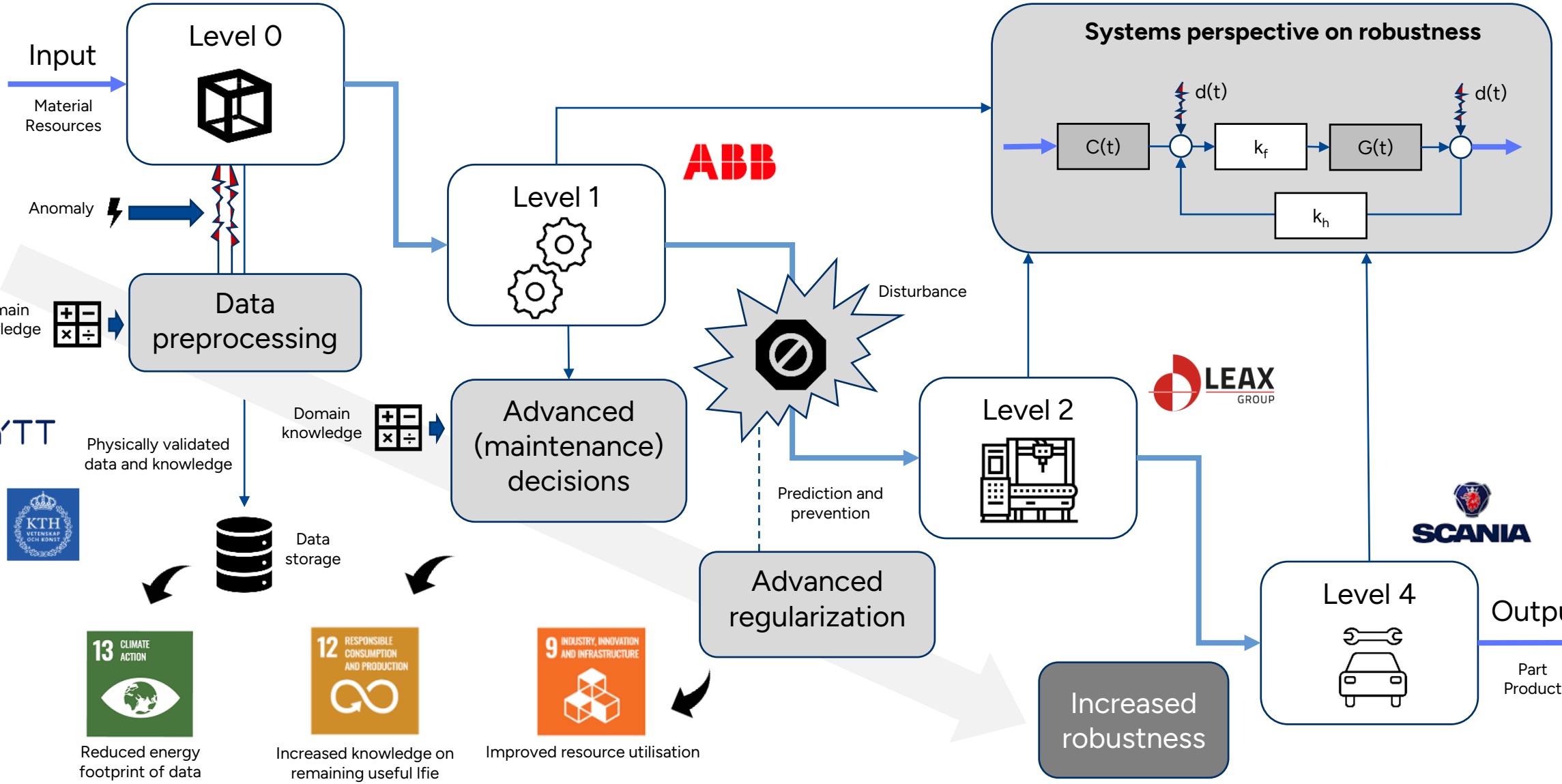
- A resource efficiency perspective of **maximizing the utilization of currently available data** resources (sensors and information provided by default)
- Understanding of the **relevance** of certain **data sources** to **prioritize** their collection over other less relevant ones and deploy new electronic equipment only if needed
- An approach to identify **issues in the data** before it is stored or processed, shifting the data quality validation, and monitoring ahead in the pipeline

Project overview

Monica Gonzalez (mgon@kth.se)

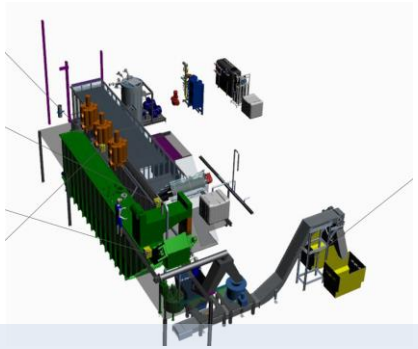
PhD candidate in Production Engineering

RoDi in a nutshell



RoDi consortium and case studies

SCANIA	Line level	Emulsion system
LEAX GROUP	Machine level	Hard skiving process
ABB	Component level	Gear box bench



Emulsion system

Hard skiving machining center

Gearbox (bench)

RoDi timeline and milestones

Activity	2022			2023				2024				2025		
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
WP1 **Robustness assessment and recommendation framework**					M1									
WP2 **Generalized systems perspective on robustness**														
WP3 **Physics-based data curing for robust decision making**									M2					
WP4 **Experimental validation of data curing in synthetic use-case**												M3		
WP5 **Robustification of industrial systems**														M4
WP6 **Project management and dissemination**														

Milestone	Description	Expected Date	Completion date
M1	Developed methods for the assessment of robustness potentials	2022-12-16	2023-02-16
M2	Algorithmic prototype for data preparation, robustification, and curation	2023-12-08	2024-03-30
M3	Demonstrated gains on synthetic use-case	2024-09-15	On-going
M4	Results implemented at the industrial partners; knowledge disseminated	2025-03-31	On-going

WP1: Robustness assessment and recommendation framework

Proposed Framework

1. **Functional analysis**
   - Definition of KPIs
   - Inventory of monitoring techniques
2. **Dysfunctional analysis (failure mode/criticality)**
   - Criteria and grading
   - MPN calculation
   - Categorization and prioritization
3. **Monitoring improvement suggestions**

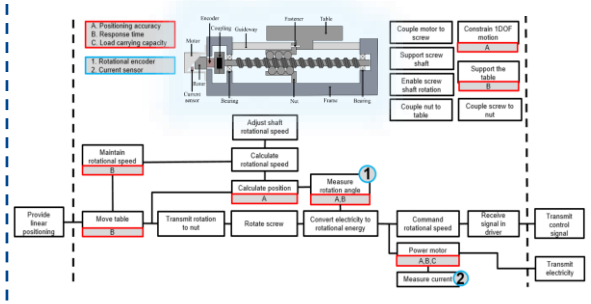
WP1: Robustness assessment and recommendation framework

Proposed Framework

1. **Functional analysis**
   - Definition of KPIs
   - Inventory of monitoring techniques
2. **Dysfunctional analysis (failure mode/criticality)**
   - Criteria and grading
   - MPN calculation
   - Categorization and prioritization
3. **Monitoring improvement suggestions**

WP1 Methods

1. Enhanced FAST: Functional Analysis System Technique



KPIs	Importance (weights)	Maintain rotational speed	Move table	Constrain 1 DOF motion	support the table	calculate position	...	...	...
Positioning accuracy	1	6	9	9	3	9	...	...	...
Response time	1	9	9	0	0	4	...	...	...
Load carrying capacity	1	0	5	0	9	0	...	...	...
Detection/monitoring	**Parameters (weights)**								
Rotational encoder	1	2	1	0	0	4	...	...	...
Current sensor	1	0	1	0	0	0	...	...	...

2. FMSA: Failure Mode and Symptoms Analysis

	Process or function	Failure mode	SEV	DET	DGN	PGN	MPN
FM14	Move motor	Abscense of movement (rotation)	3	5	3	3	135
FM20	Power motor	Loss of supply voltage	2	5	3	3	90
FM19	Receive signal in motor driver	Loss of control signal	3	3	2	3	54
FM18	Measure motor current	Incorrect current measurement	4	2	2	3	48
FM6	transmit rotation to nut	Abscense of rotation of the nut	4	3	2	2	48
FM11	measure rotation angle	Incorrect angle measurement	3	2	2	3	36
FM5	calculate position	Incorrect position estimation	3	2	2	3	36
FM8	couple nut to table	Locking part loseness	3	3	2	2	36
FM12	rotate screw	Rotational speed of the screw differs from the motor	4	2	2	2	32
FM10	calculate rotational speed	Incorrect rotational speed estimation	2	2	2	3	24
FM16	Enable screw rotation	Spalling	2	2	2	3	24
FM17	Support screw	Normal fatigue/Missalignment	2	2	2	3	24
FM1	Regulate rotational speed	Incorrect rotational speed	2	5	2	1	20
FM15	Command shaft rotational speed	Command is not executed	2	3	1	3	18
FM7	couple screw to nut	Locking part loseness	3	3	2	1	18
FM9	adjust shaft rotational speed	Unfeasibility to adjust the shaft speed	2	3	1	3	18
FM13	couple motor to screw	Locking part loseness	3	3	2	1	18
FM2	Move table	Lack/limited movement	3	2	2	1	12
FM3	Enable 1 DOF motion	Unconstrained motion in 2 or more DOF	2	2	2	1	8
FM4	support the table	Bending of linear guides/table	2	2	2	1	8

WP1: Robustness assessment and recommendation framework

Proposed Framework

1. **Functional analysis**
   - Definition of KPIs
   - Inventory of monitoring techniques
2. **Dysfunctional analysis (failure mode/criticality)**
   - Criteria and grading
   - MPN calculation
   - Categorization and prioritization
3. **Monitoring improvement suggestions**

WP1 Methods

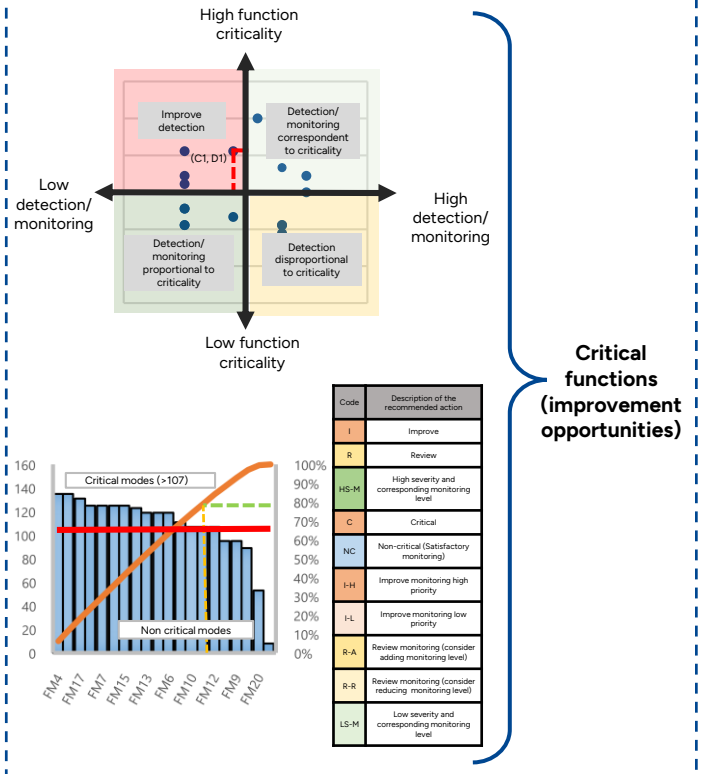
1. Enhanced FAST: Functional Analysis System Technique

KPIs	Importance (weights)	Maintain rotational speed	Move table	Constrain 1 DOF motion	Support the table	calculate position		
Positioning accuracy	1	6	9	9	3	9		
Response time	1	9	9	0	0	4		
Load carrying capacity	1	0	5	0	9	0		
Detection/monitoring	Parameters (weights)							
Rotational encoder	1	2	1	0	0	4		
Current sensor	1	0	1	0	0	0		

2. FMSA: Failure Mode and Symptoms Analysis

	Process or function	Failure mode	SEV	DET	DGN	PGN	MPN
FM14	Move motor	Abscense of movement (rotation)	3	5	3	3	135
FM20	Power motor	Loss of supply voltage	2	5	3	3	90
FM19	Receive signal in motor driver	Loss of control signal	3	3	2	3	54
FM18	Measure motor current	Incorrect current measurement	4	2	2	3	48
FM6	transmit rotation to nut	Abscense of rotation of the nut	4	3	2	2	48
FM11	measure rotation angle	Incorrect angle measurement	3	2	2	3	36
FM5	calculate position	Incorrect position estimation	3	2	2	3	36
FM8	couple nut to table	Locking part loseness	3	3	2	2	36
FM12	rotate screw	Rotational speed of the screw differs from the motor	4	2	2	2	32
FM10	calculate rotational speed	Incorrect rotational speed estimation	2	2	2	3	24
FM16	Enable screw rotation	Spalling	2	2	2	3	24
FM17	Support screw	Normal fatigue/Missalignment	2	2	2	3	24
FM1	Regulate rotational speed	Incorrect rotational speed	2	5	2	1	20
FM15	Command shaft rotational speed	Command is not executed	2	3	1	3	18
FM7	couple screw to nut	Locking part loseness	3	3	2	1	18
FM9	adjust shaft rotational speed	Unfeasibility to adjust the shaft speed	2	3	1	3	18
FM13	couple motor to screw	Locking part loseness	3	3	2	1	18
FM2	Move table	Lack/limited movement	3	2	2	1	12
FM3	Enable 1 DOF motion	Unconstrained motion in 2 or more DOF	2	2	2	1	8
FM4	support the table	Bending of linear guides/table	2	2	2	1	8

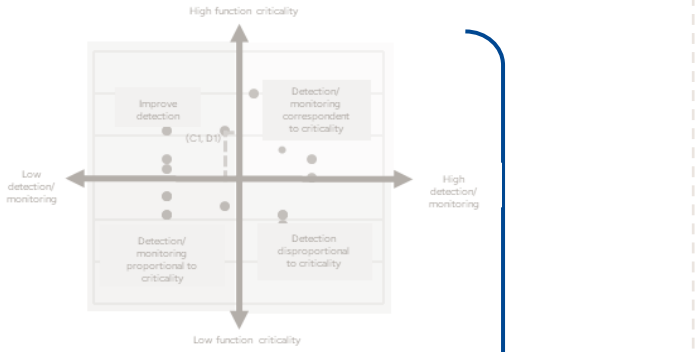
WP1 Outcome

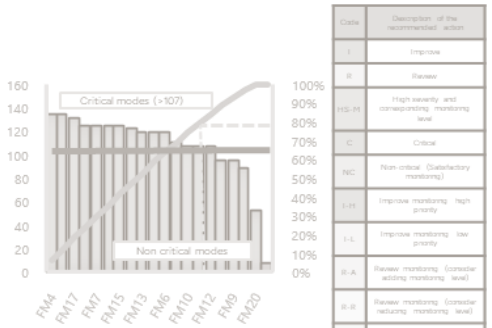


Critical functions (improvement opportunities)

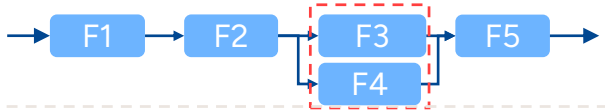
WP2: Generalized systems perspective on robustness

WP1 Outcome



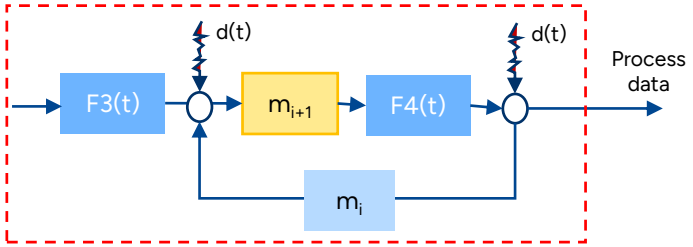


Critical functions (improvement opportunities)

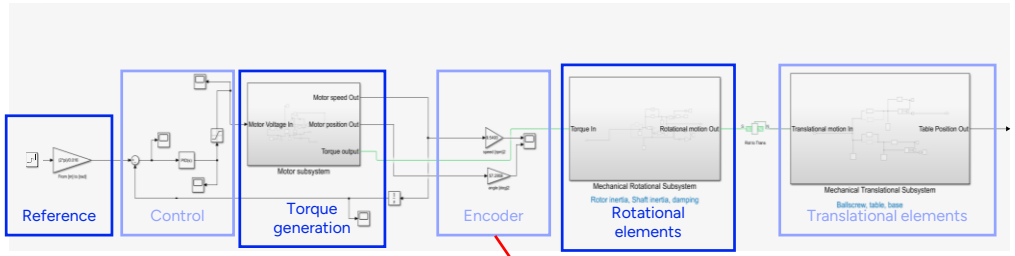


WP2 Methods

Functional building blocks (physics-based models)



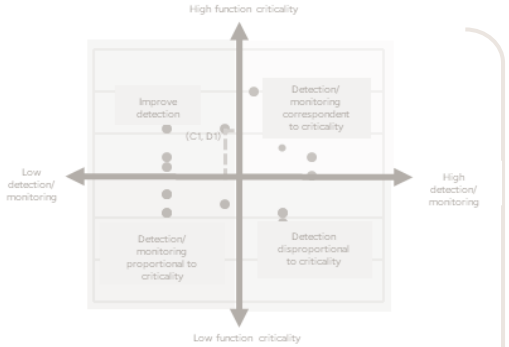
Sensitivity analysis- simulation

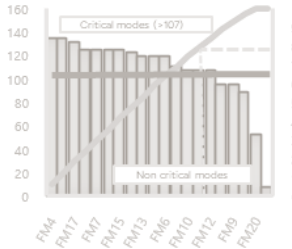


- Noise
- Outliers
- Mising data points
- Level shift

WP2: Generalized systems perspective on robustness

WP1 Outcome

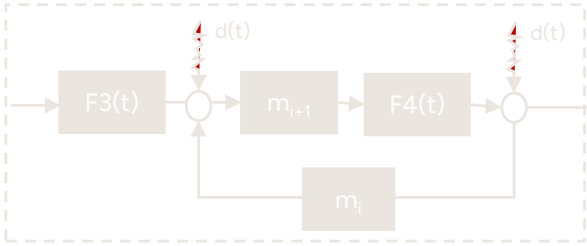




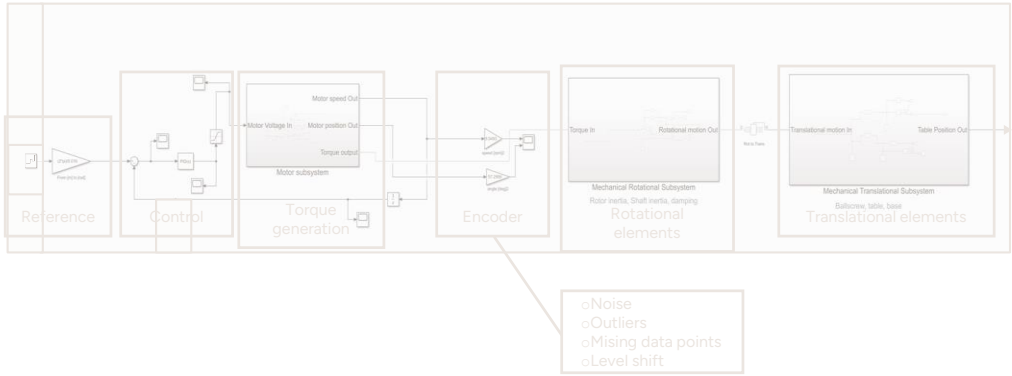
Critical functions (improvement opportunities)

WP2 Methods

Functional building blocks (physics-based models)



Sensitivity analysis- simulation



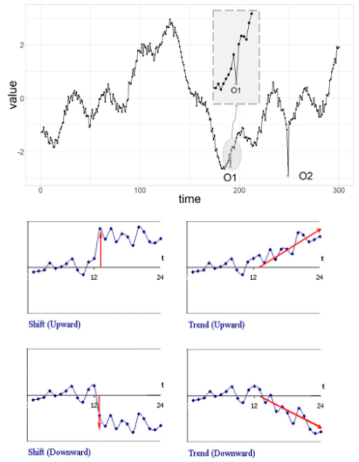
WP2 Outcome

- Understanding of data quality (errors in time series data)
- Error propagation paths
- Requirements for data preparation (**Physics-based data curation**)

WP3: Physics-based data curing for robust decision making

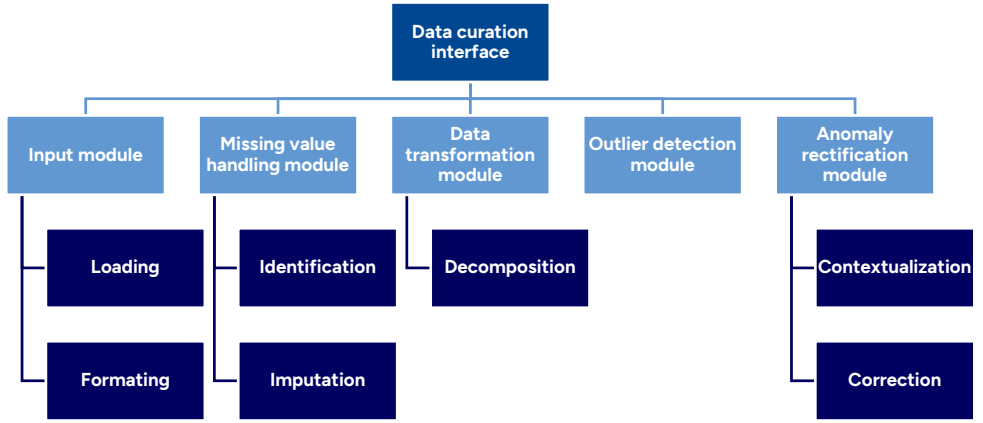
WP2 Outcome

- Understanding of data quality (errors in time series data)
- Error propagation paths
- Requirements for data preparation (**Physics-based data curation**)



WP3 Methods

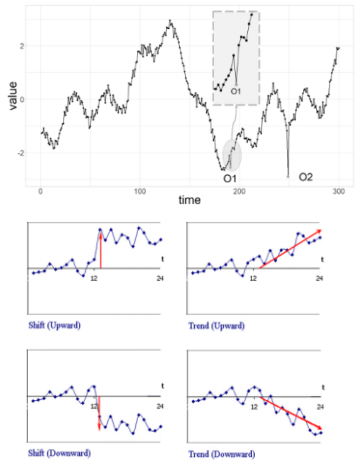
Software and visualization interface



WP3: Physics-based data curing for robust decision making

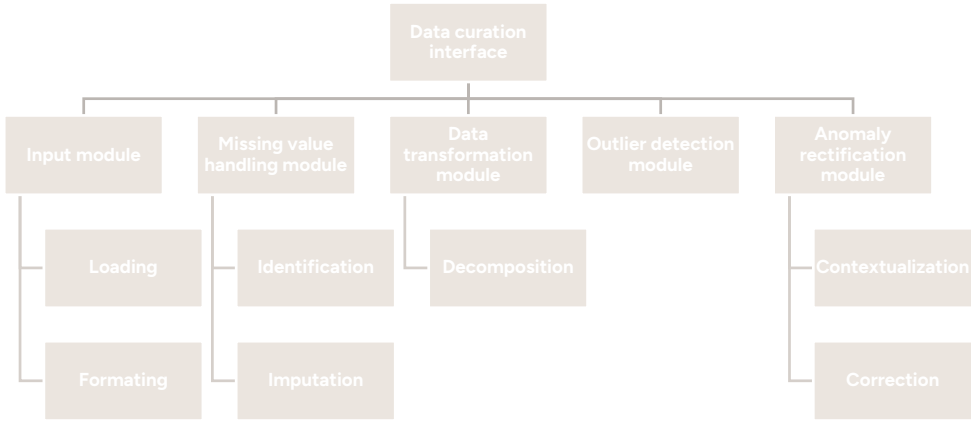
WP2 Outcome

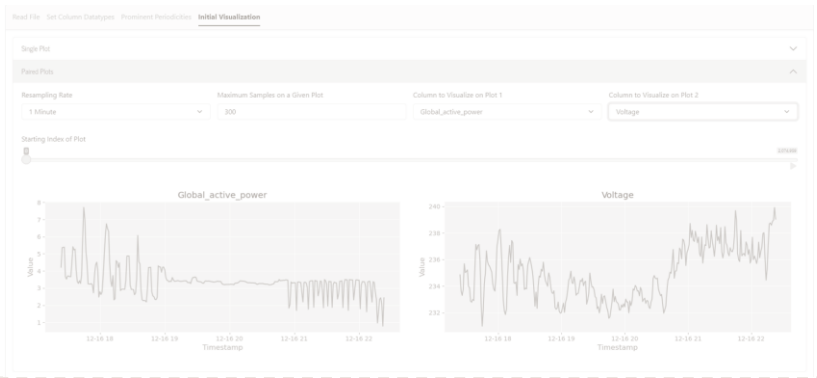
- Understanding of data quality (errors in time series data)
- Error propagation paths
- Requirements for data preparation (**Physics-based data curation**)



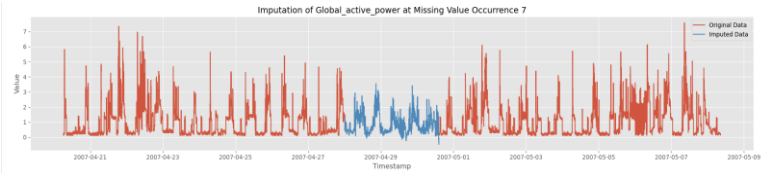
WP3 Methods

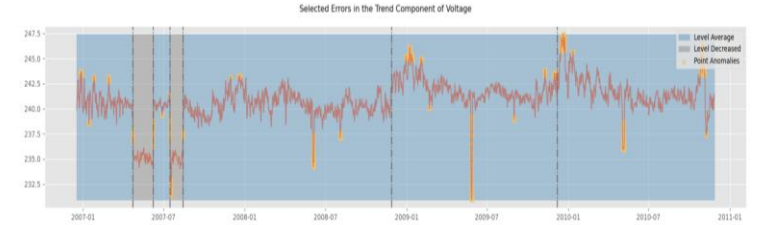
Software and visualization interface





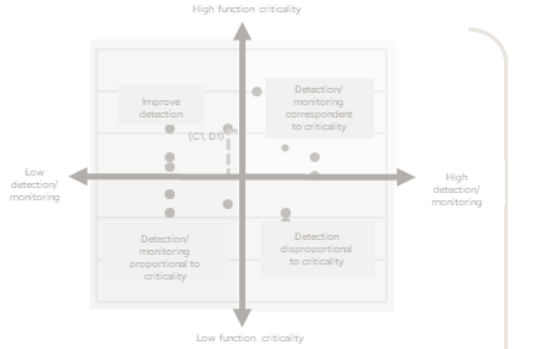
WP3 Outcome

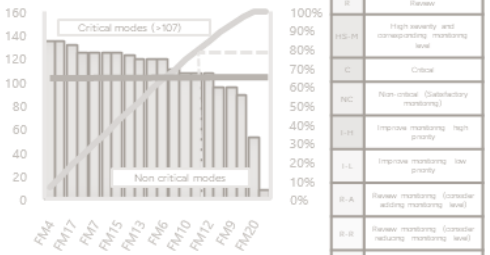




WP4: Experimental validation of data curing in synthetic use-case

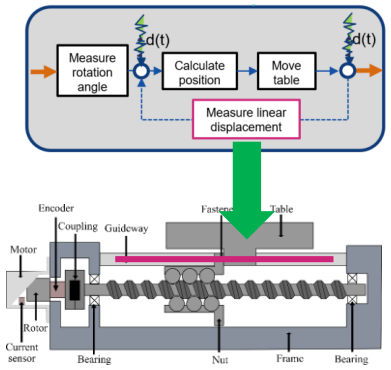
WP1 Outcome

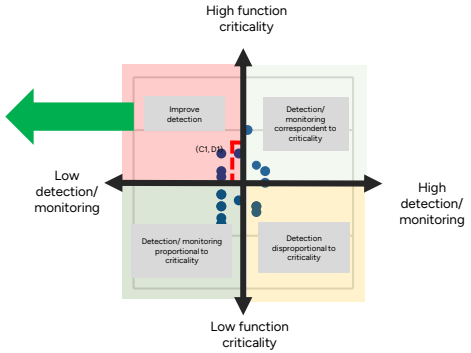




WP4 Methods/Outcome

Experimental validation in lab environment and optimization

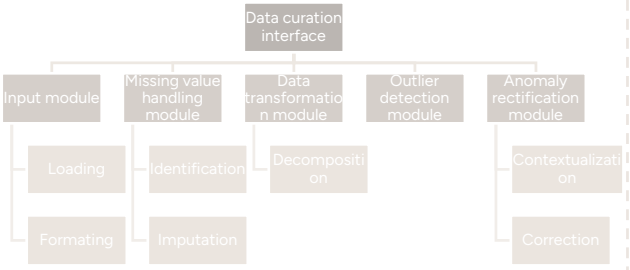




WP4: Experimental validation of data curing in synthetic use-case

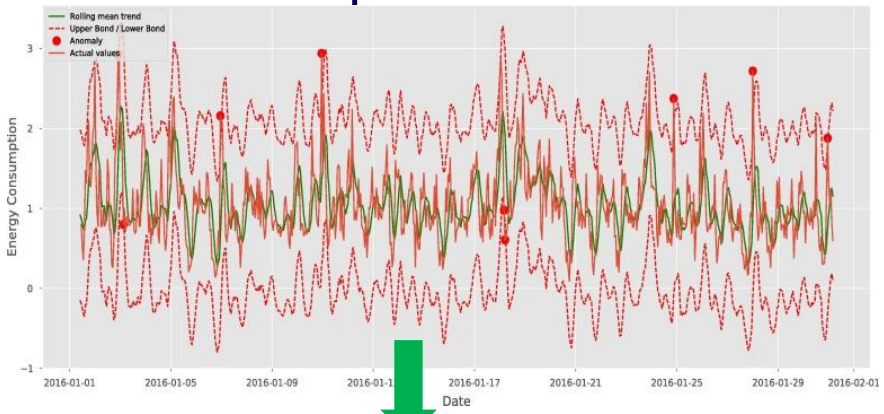
WP3 Methods/Outcome

Software and visualization interface

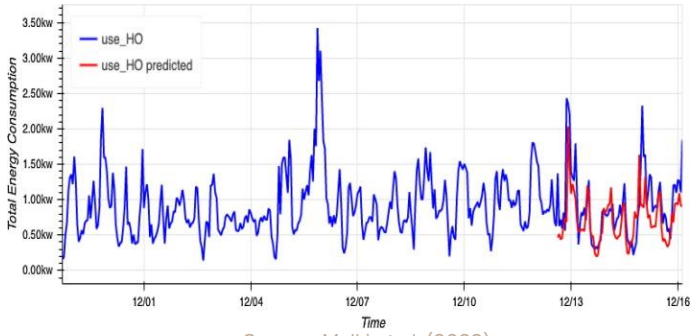


WP4 Methods/Outcome

Experimental validation in lab environment and optimization



Data robustification and decision- making

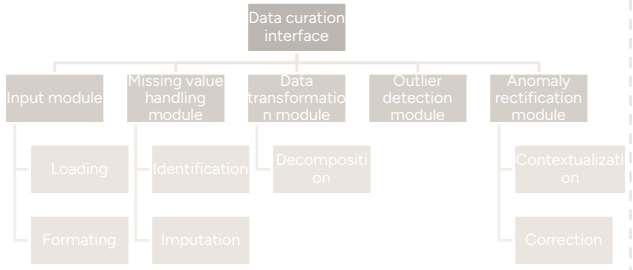


Source: Malki et al. (2022)

WP4: Experimental validation of data curing in synthetic use-case

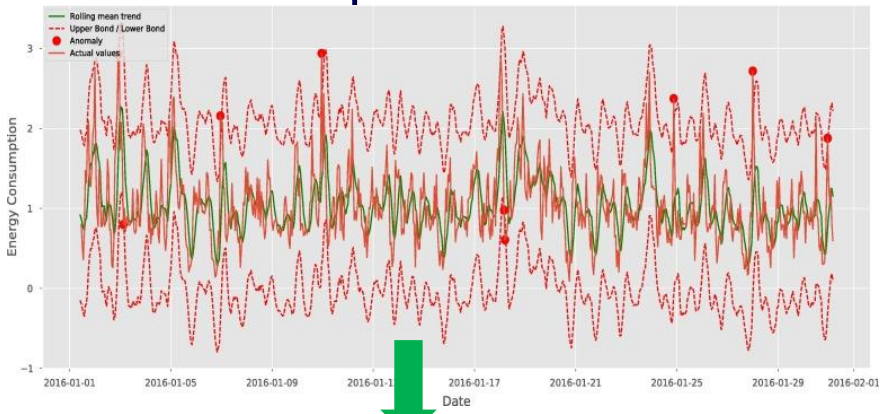
WP3 Methods/Outcome

Software and visualization interface

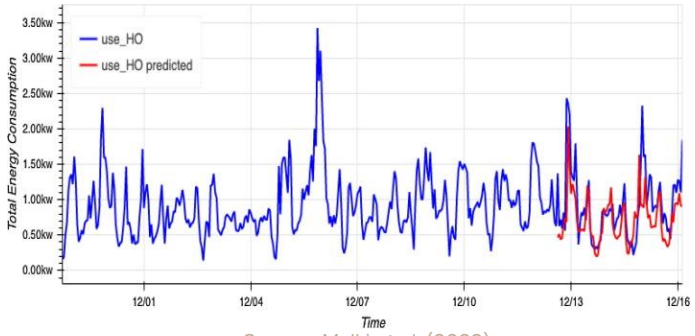


WP4 Methods/Outcome

Experimental validation in lab environment and optimization



Data robustification and decision- making



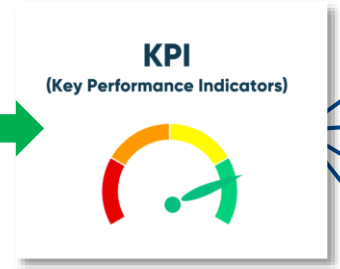
Source: Malki et al. (2022)

WP5 Industrial implementation

Line level → Emulsion system

Machine level → Hard skiving process

Component level → Gear box bench



- Quality
- Productivity
- Maintenance
- ...

Case studies

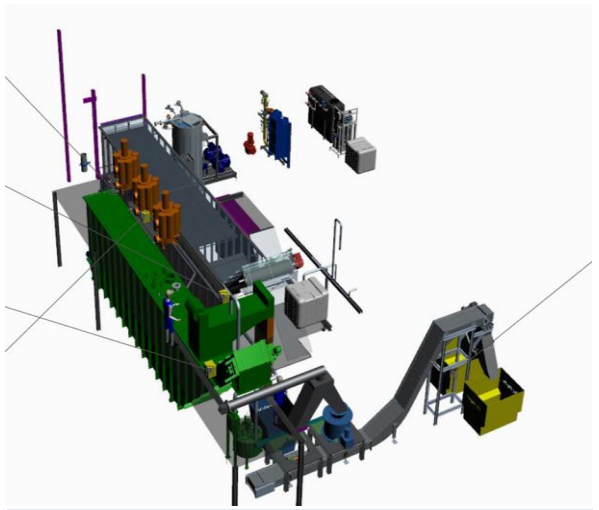
Mariano Coll

Industrial PhD student - Scania

RoDi case studies

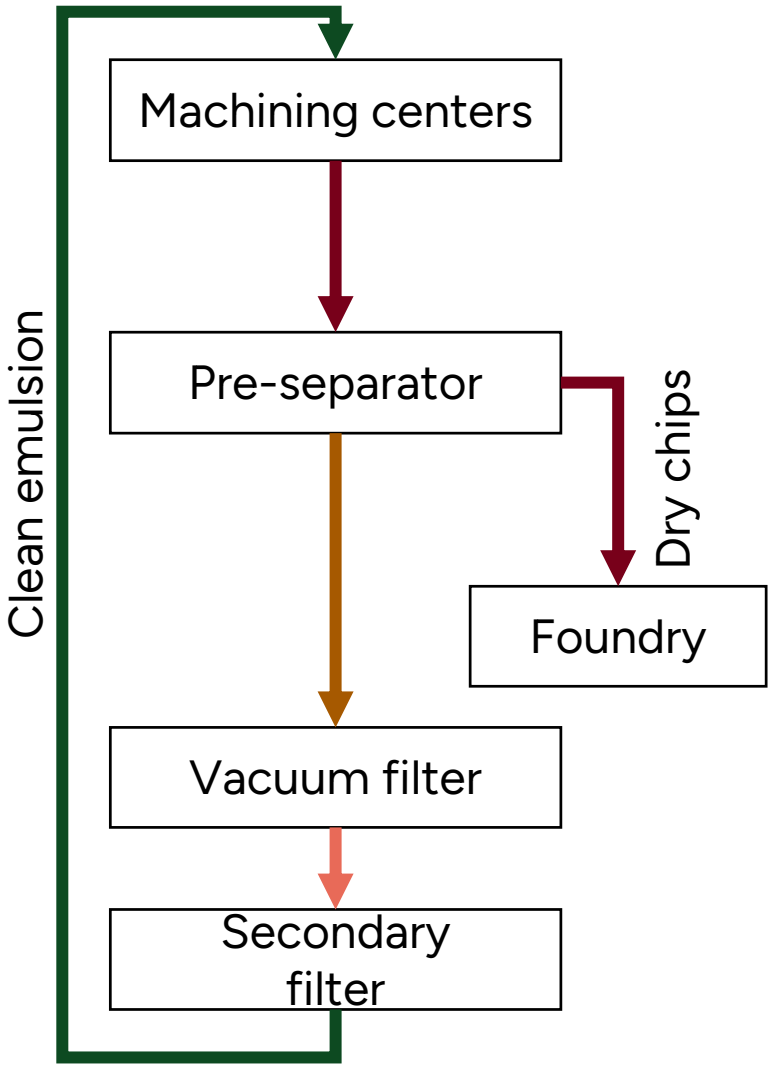
COMPONENT: Gearbox (bench)

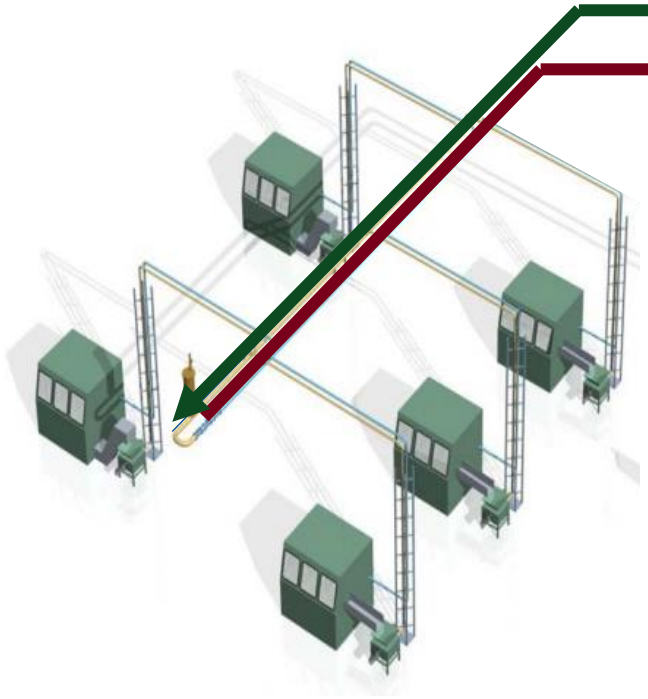
MACHINE: Hard skiving machining center

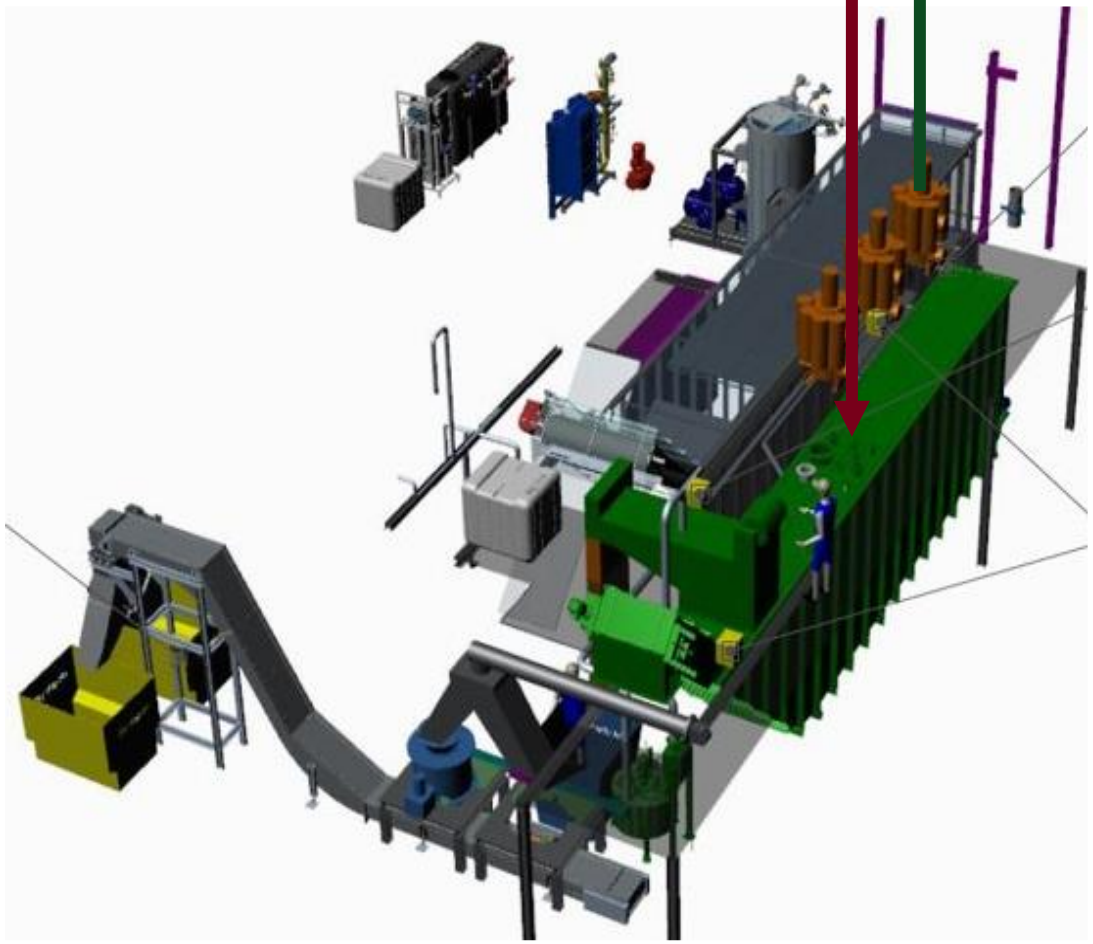


PROCESS: Emulsion system

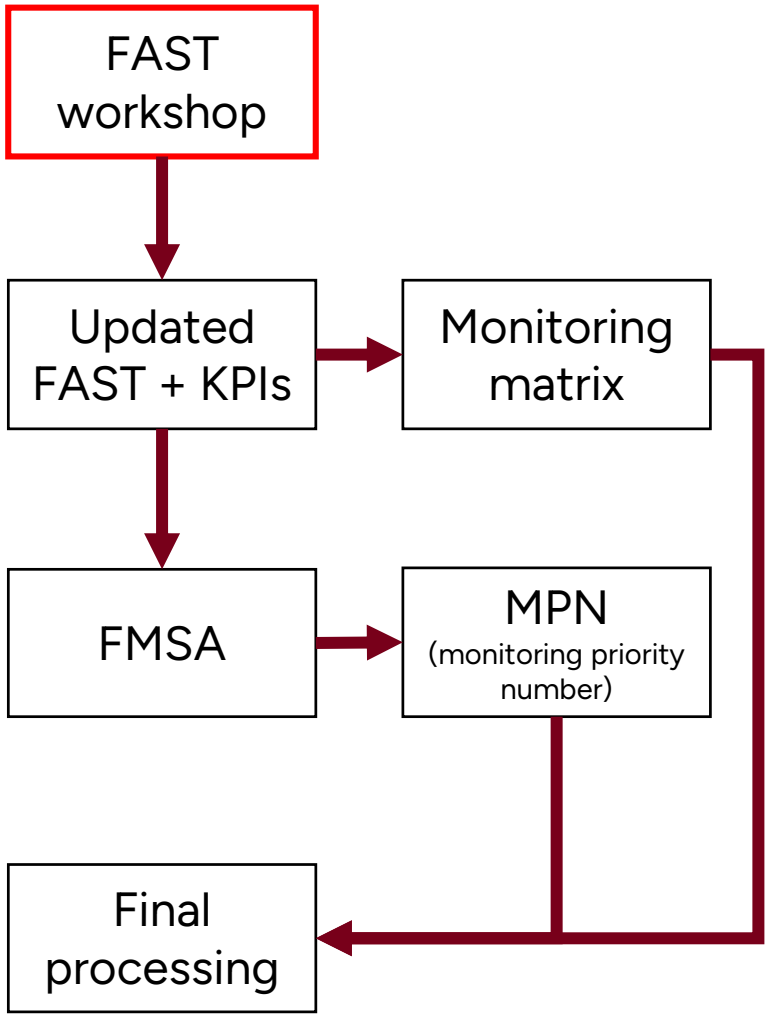
Case study – Emulsion system Scania

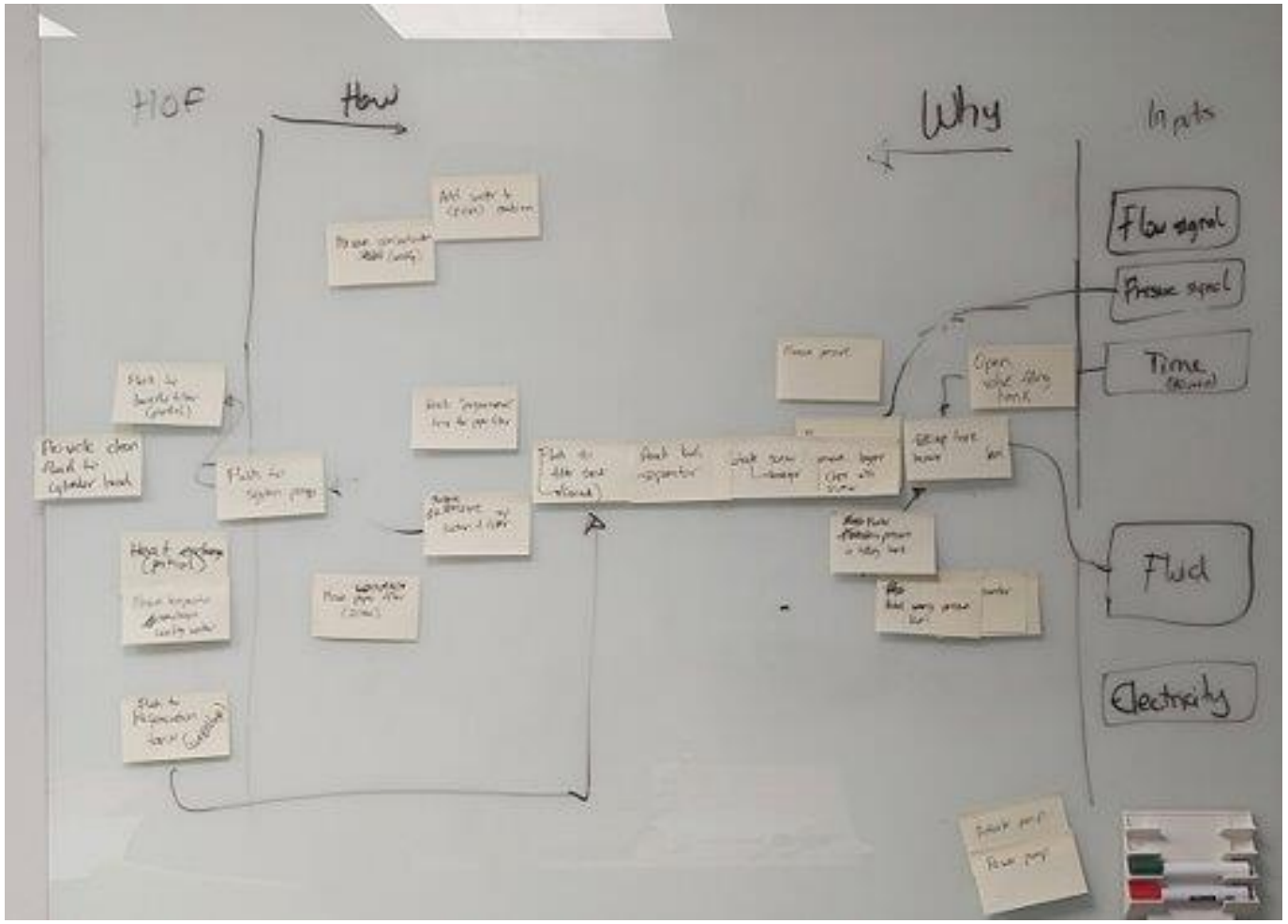




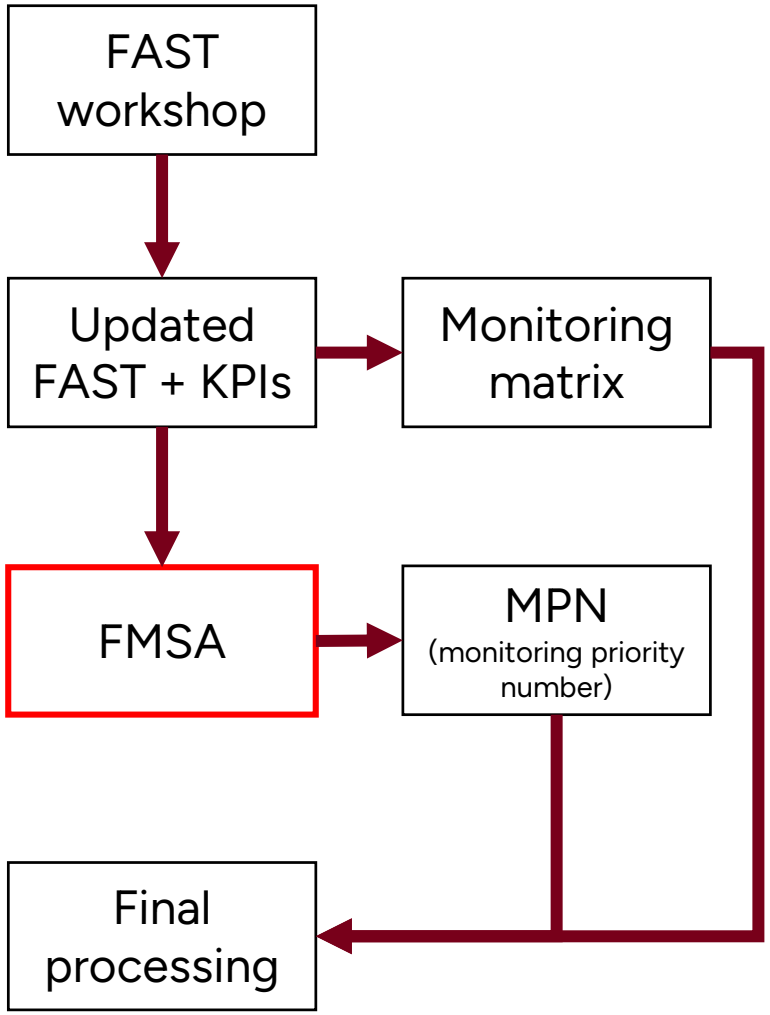


WP1 process – Functional & dysfunctional assessment





WP1 process – Functional & dysfunctional assessment



Failure mode and symptoms analysis

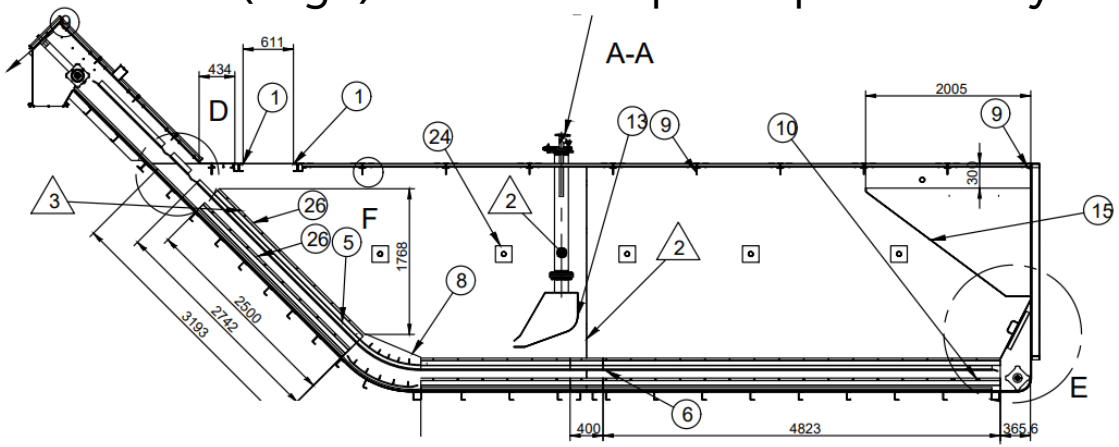
FMSA

	Process or Function	Componen	Failure mod	Cause of failure	Effect of failure	Failure sympto	Detection method	Monitoring location	Monitoring frequenc	DET	SEV	DGN	PGN
1	Measure supply temperature	Termometer	Unable to measure temp accurately	Contamination Damage Broken sensor cable	Fluid distributed to machines out of specification Wrong temperature compensation Affect machined parts (distortion)	Sudden changes in the temperature Temperature warnings at the machines	Machines sense out of specification coolant? Visual contrast with termommeter gage Min or max value is displayed	Local Control system Machine temperature monitoring	Continuous monitoring	H	M	H	H
2	Measure supply pressure	Pressure gage	Unable to measure pressure accurately	Mechanical vibration clogging Damage Broken sensor cable	Information to control of pumps will be wrong Fluid distributed to machines out of specification	Machines receive emulsion pressure out of tolerance	Visual Leackage machines sense out of specification coolant Visual contrast with pressure gage Min or max value is displayed	Local Control system Machine pressure monitoring	Continuous monitoring Visual	H	H	H	H
3	Measure supply flow	Electromagnetic flowmeter	Unable to measure flow accurately	Damage Broken sensor cable Bubbles in the fluid	Unstable flow reading or no readings	Machines wont receive enough flow Extra fluid in the system not used	Visual Energy consumption monitoring Min or max value is displayed	Local Control system	Continuous monitoring	VH	VH	H	H
4	Conduct fluid (partial) to viavent flushing	Valve	Unable to conduct fluid properly	Loss of air Wear, rubber seal Mechanical blocking Pilot valve broken	Affected fluid flow unable to open close valve	Delays in filling return pipe Leackeges fault messages in	Visual Error messages Position sensor on valve	Local Control system	Inspection round Continuous monitoring	H	VH	H	H
5	Conduct fluid (partial) to heat exchanger	Heat exchanger	A proportion of the fluid was not conducted to the heat exchanger	Wrong readings from temperature sensors Not enough cooling flow Clogged heat exchanger Valves not working propperly	Incorrect temperature in the emulsion to the machines	System cannot stabilize temperature in the correct parameters Temperature warnings at the machines	Persistent temperature warnings Machines sense out of specification coolant	Local Control system Machine temperature monitoring	Continuous monitoring	H	VH	H	H
6	Conduct fluid to secondary filter	Filter elements	Unable to filter fluid	Dirt Low pneumatic pressure Leackages in the seals	Clogged filter Decrease of filtration capacity big pressure loss in the filter Low pneumatic pressure causes bad regeneration	Backflushing performed too often	Differential pressure check Backflush counter what triggers the backflush, time or pressure?	Local Control system	Inspection round Periodical particle measuring	L	M	L	H
		Geared motor	Unable to rotate for regeneration	Dirty Plug valve stucked Blocked filling hole	Prevents gear motor to turn and comute between dirty to clean filters	Noise Overheating Delays in commuting filter Circuit braker trips	Visual Error messages	Local Control system	Inspection round				

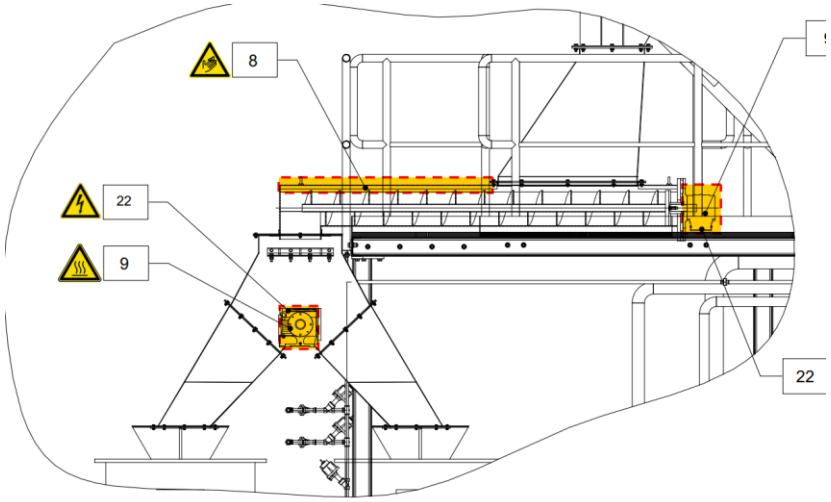
- Functions and associated components
- Failure modes, causes, effects and symptoms
- Detection method, monitoring location and frequency
- Rating detection, severity, diagnostics and prognosis

Functions that require and get most benefit from monitoring improvement

F26 (High): Transfer chips to spiral conveyor



F25 (High): Transfer chips to centrifuges



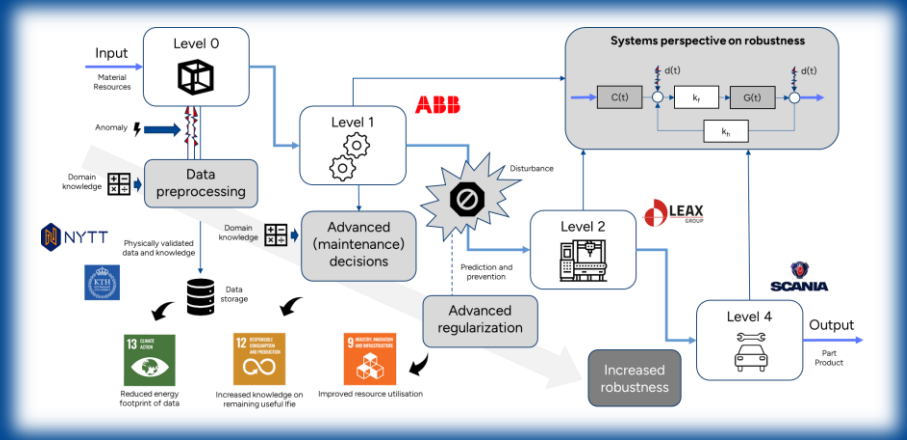
This functions are critical because:

- In case of failure the complete machining line stops (Emulsion system and machining centers).
- May require significant intervention time (drain system and repair).
- Contact with chips generate highest degradation on components.
- Low detection or monitoring subsystems

Outlook

Andreas Archenti (archenti@kth.se)

Prof. Industrial Dependability



KTH
VETENSKAP
OCH KONST

Thank you for your attention!

Andreas Archenti (archenti@kth.se)
Monica Katherine Gonzalez (mgon@kth.se)
Mariano Coll (Mariano.Coll@scania.com)