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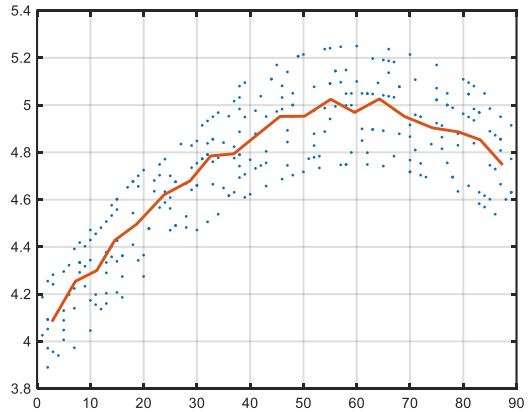

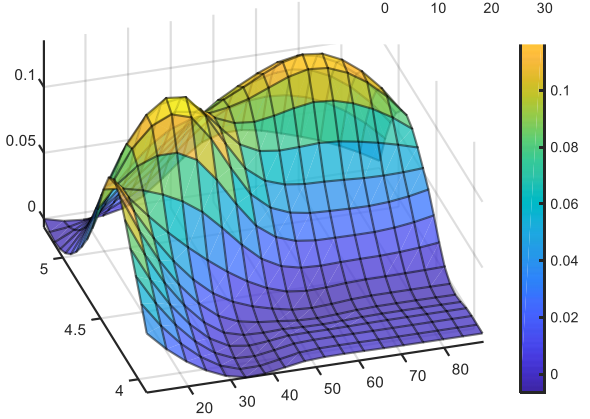

CIRP CMS 2018, Stockholm

Correlation analysis methods in multi-stage production systems for reaching zero-defect manufacturing

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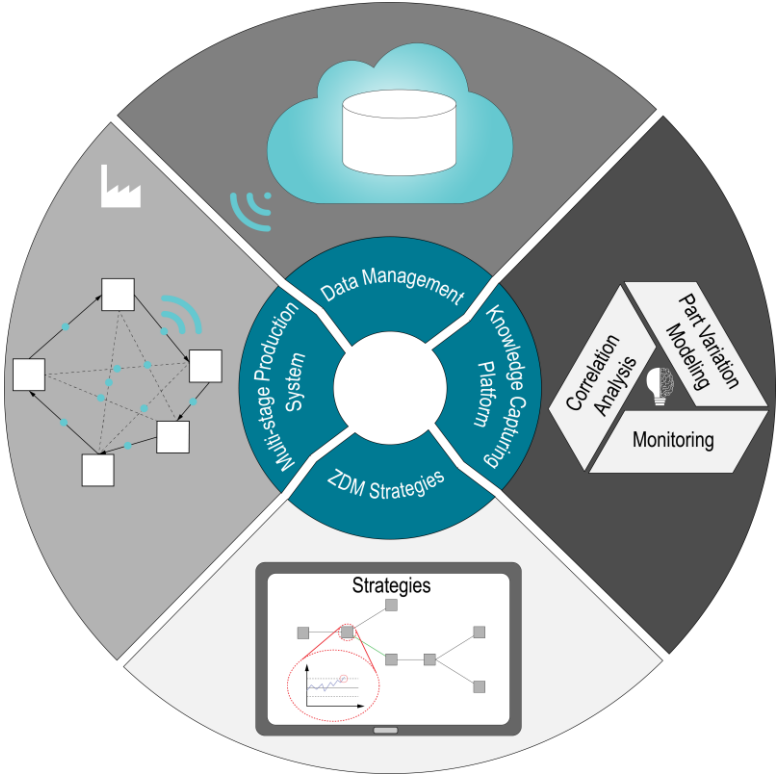
C. Reiff
C. Brantl
A. Verl
M.Colledani

Agenda

1. Introduction
2. Correlation Analysis
3. Results
4. Conclusion



Agenda

Introduction

Motivation

Increasing requirements from the market

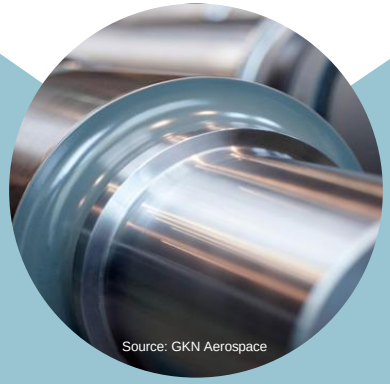
Time to Market

Efficiency

Quality

Flexibility

Costs



Increasing challenges on the industry

Introduction

ForZDM Approach

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723698" This presentation reflects only the authors' views and the Commission is not responsible for any use that may be made of the information contained therein.

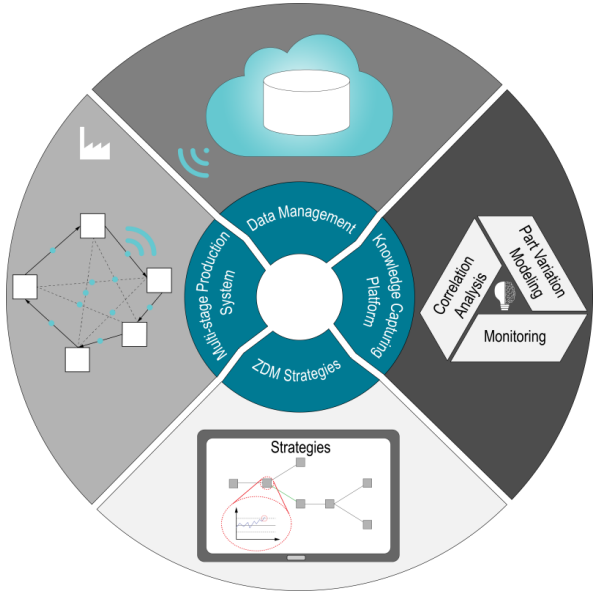
Objective:

Reaching **Z**ero **D**efect **M**anufacturing by reducing the appearance and propagation of defects in multi-stage production systems.

Procedure:

- Flexible data acquisition for different sensor systems
- Data driven interactive knowledge capturing platform for data analysis
- Defining ZDM Strategies for more competitive and robust multi-stage production systems
- Validation within three industrial use cases

Website: https://www.forzdmproject.eu/



Introduction

Motivation

Current ZDM approach as local solution:

- Improvement of single processes
- Process control (adjustable parameters)
- Not all deviations or defects can be avoided

Knowledge Capturing as new approach:

- Considering the complete system
- Downstream compensation / Feed forward control

➢ **Correlation Analysis**

Source: DMG MORI SEIKI CO., LTD.

Source: WFL Millturn Technologies

Source: DMG MORI SEIKI CO., LTD.

Source: DMG MORI SEIKI CO., LTD.

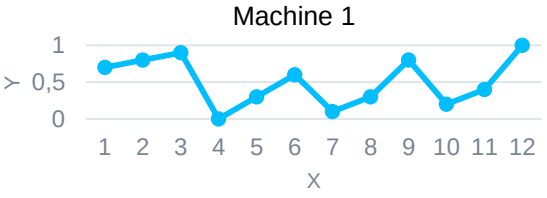
End of Line Control

Defect Propagation

Rework

Introduction

Motivation

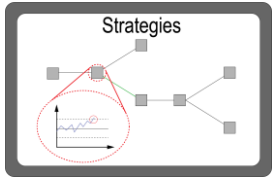


Correlation Methods

Correlation Index Matrix

	1	2	3
1	1.00	0.94	0.03
2		1.00	0.04
3			1.00

Knowledge



Source: DMG MORI SEIKI CO., LTD.

Source: WFL Millturn Technologies

Source: DMG MORI SEIKI CO., LTD.

Source: DMG MORI SEIKI CO., LTD.

…

Defect — Downstream Compensation — OK

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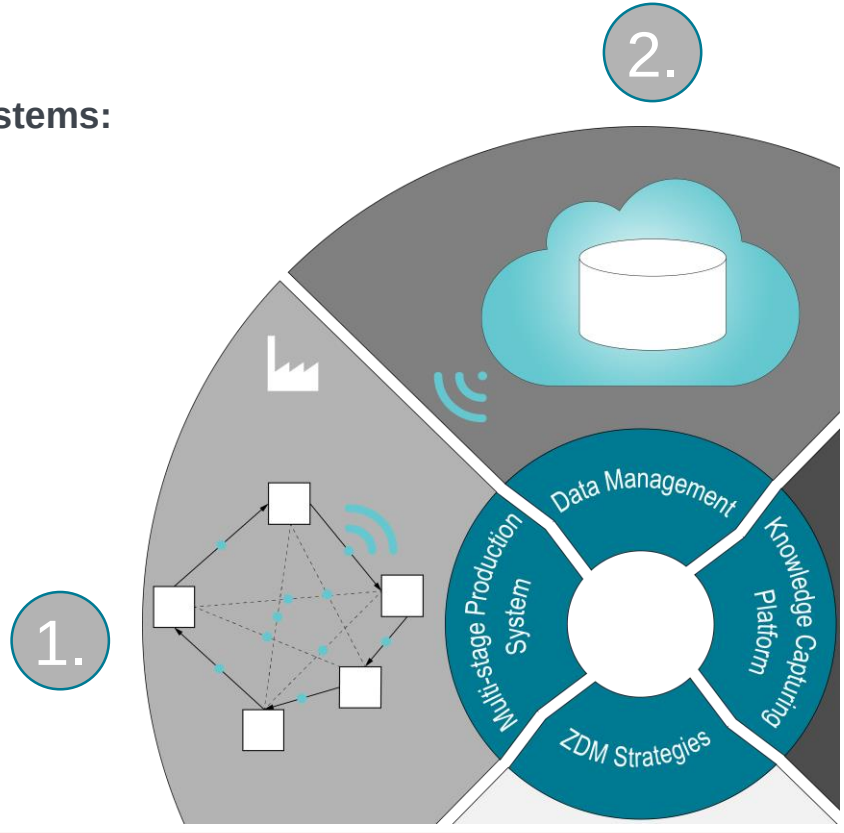
Introduction

Fundamentals (Architecture) for the Knowledge Capturing

1. **Data Acquisition in Multi-stage Production Systems:**
   - Sensors systems
   - Manuel measurements
   - Machine data
   - Operator feedback

2. **Data Management:**
   - Central data gathering platform
   - Synchronization of all existing data
   - Structuring and filtering of the data



Agenda

1 Introduction

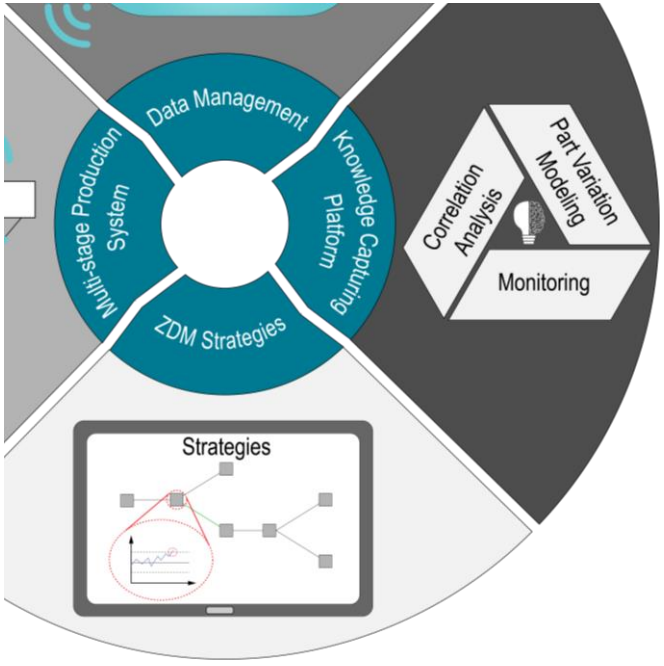
2 Correlation Analysis

3 Results

4 Conclusion

Correlation Analysis

Objective



Development of a Correlation Analyzing Tool

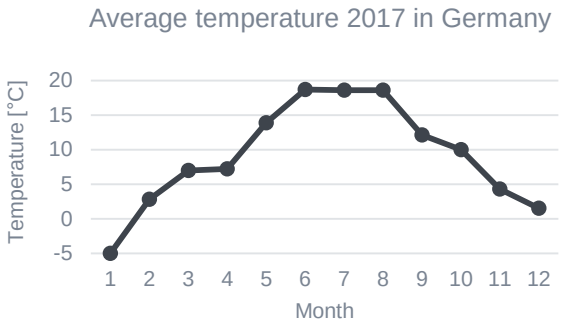
- Knowledge extraction for more transparency in multi-stage production systems
  - Interaction with the Part Variation Modeling Tool and modern monitoring systems
- Using statistical and analytical methods for analyzing different data sets
- Flexible and generic solution in means of a software application

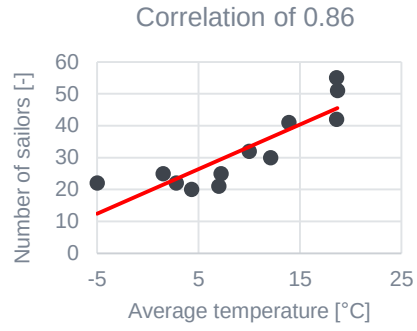
Development of a data driven Correlation Analyzing Tool

Correlation Analysis

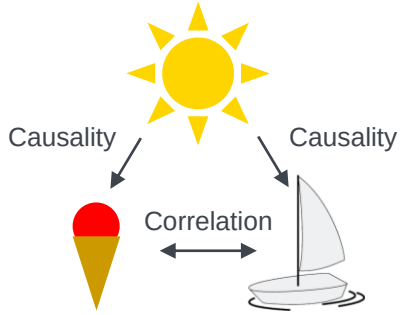
Fundamentals

A correlation is a dependency between two data sets.





But a correlation between two variables does not mean that the two variables are causally related. Instead, correlations only provide a first indication that this may be the case.



Correlation Analysis

Methods

Cross Correlation – Bravais-Pearson for metrically scaled data sets:

Correlation coefficient: $$r_{X,Y} = \frac{\mathrm{cov}(X,Y)}{\sigma_X \, \sigma_Y} = \frac{E\,[(X-\bar{X})(Y-\bar{Y})]}{\sigma_X \, \sigma_Y}$$

Legend

cov	Covariant
σ	Standard deviation
E	Expected value

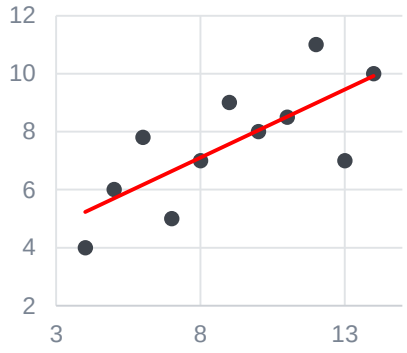
- r will always be between 1 and -1
  - the closer $|r|$ is to 1 the more an increase in one variable associates with an increase in the other
  - if x and y are independent r is close to 0

Correlation Analysis

Correlation

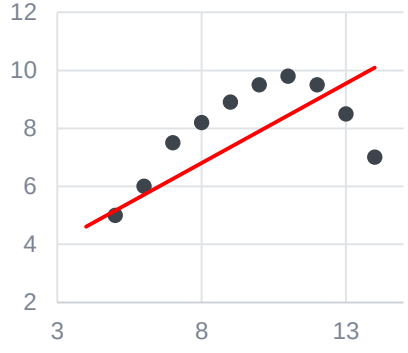
Normal distribution:

$r = 0{,}816$



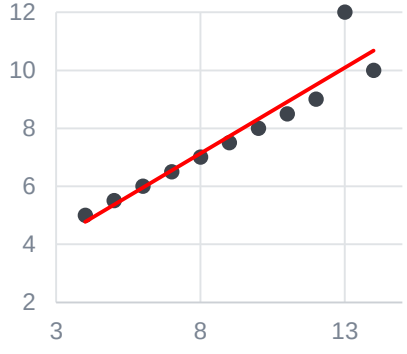
Parabolic function:

$r = 0{,}816$



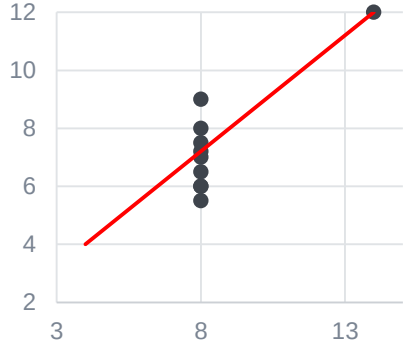
Outlier I:

$r = 0{,}816$



Outlier II:

$r = 0{,}816$

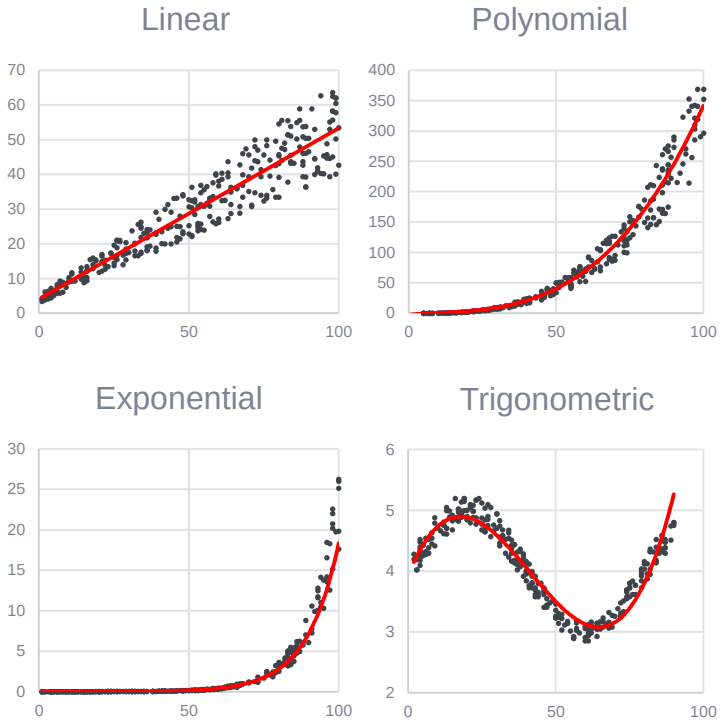


Correlation Analysis

Challenges

- Different kind of functions within the data sets
- Assignment and traceability
- Timestamp (clock synchronization)
- Different sampling rates of the sensor systems
- Identification of correlations without a causality
- Each data set has their own specific characteristics

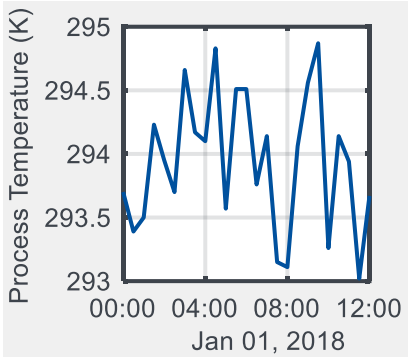
➢ **Type of features**

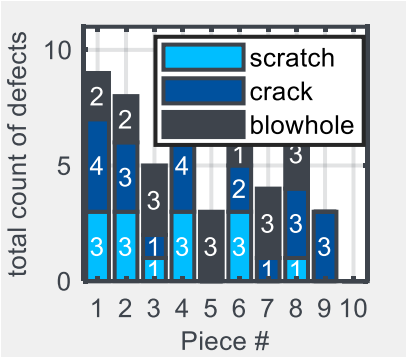


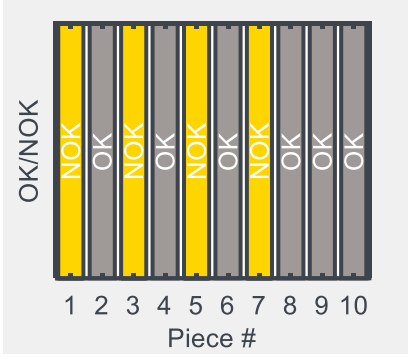
Correlation Analysis

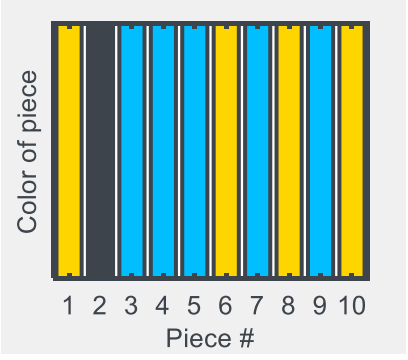
Type of features with examples

	Scale	Classification	Distribution
I	Metric (Ratio/Interval)	Quantitative	Continuous Discrete
II	Ordinal	Quantitative	Continuous Discrete
III	Nominal	Qualitative (with general ordering)	Discrete
IV	Nominal	Qualitative (without general ordering)	Discrete









Correlation Analysis

Categorized overview of methods

Different analytical and statistical methods are needed in order to achieve applicable results

I. Metric

- Bravais-Pearson
- Covariance

II. Ordinal

- Spearman's Rho
- Modified Spearman's Rho (MSR-I)
- Kendall's Tau
- Modified Kendall's Tau (MKT-II)
- Chi-Square Test
- Yate's Correction

III. / IV. Nominal

- Point-Biserial Correlation
- Cramer's V
- Biserial Rank Correlation
- Tetrachoric Correlation
- Phi-Coefficient

Correlation Analysis

Correlation between two type of features

		Metric	Ordinal	Nominal	
				Dichotom	Polytom
Metric		Bravais-Pearson Covariance	Spearman's Rho Kendall's Tau MI - Correlation …	Point-biserial cor. Cramér's V	Cramér's V
Ordinal			Spearman's Rho Kendall's Tau MI - Correlation …	Cramér's V Biserial rank correlation	Cramér's V
Nominal	Dichotom			Tetrachoric correlation Phi-coefficient	Cramér's V
	Polytom				Cramér's V

Agenda

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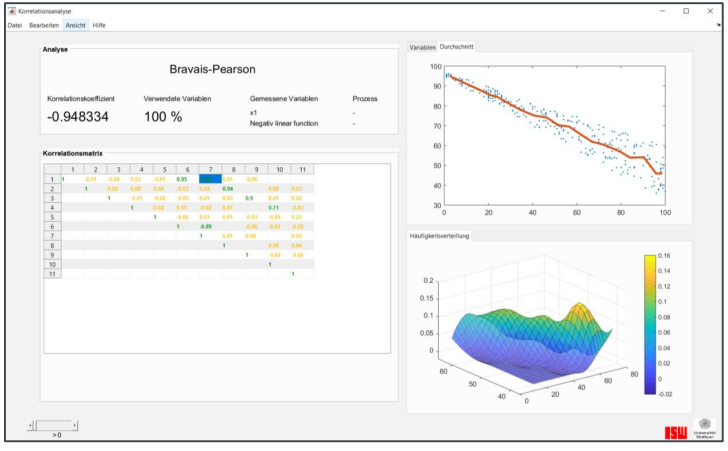
Results

Development of the Correlation Analyzing Tool (CAT)

Data driven solution for the identification of correlations within multi-stage production systems

- Software application with a GUI
- Import of different file formats (.csv, .txt, .xlsx, …)
- Modeling and connecting data set to process stages
- Mode for automatic identification of the type of feature
- Various analyzing methods
- Plots for user-friendly visualization of the results



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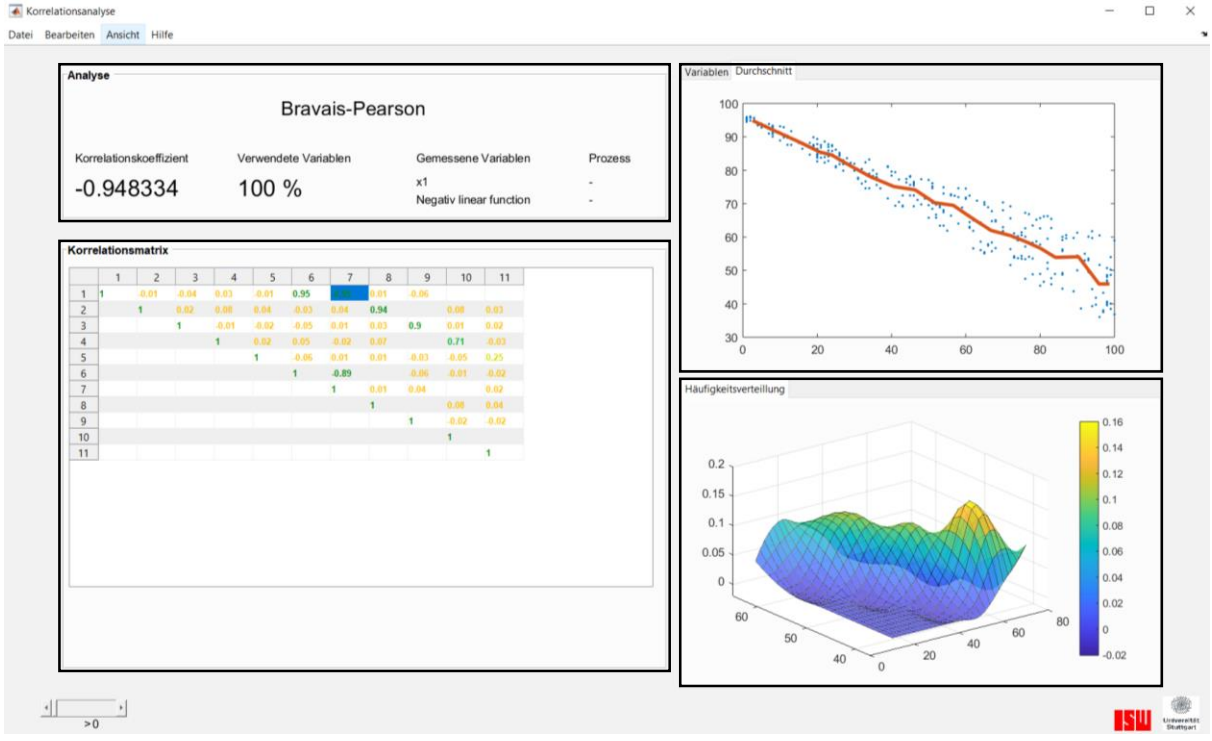
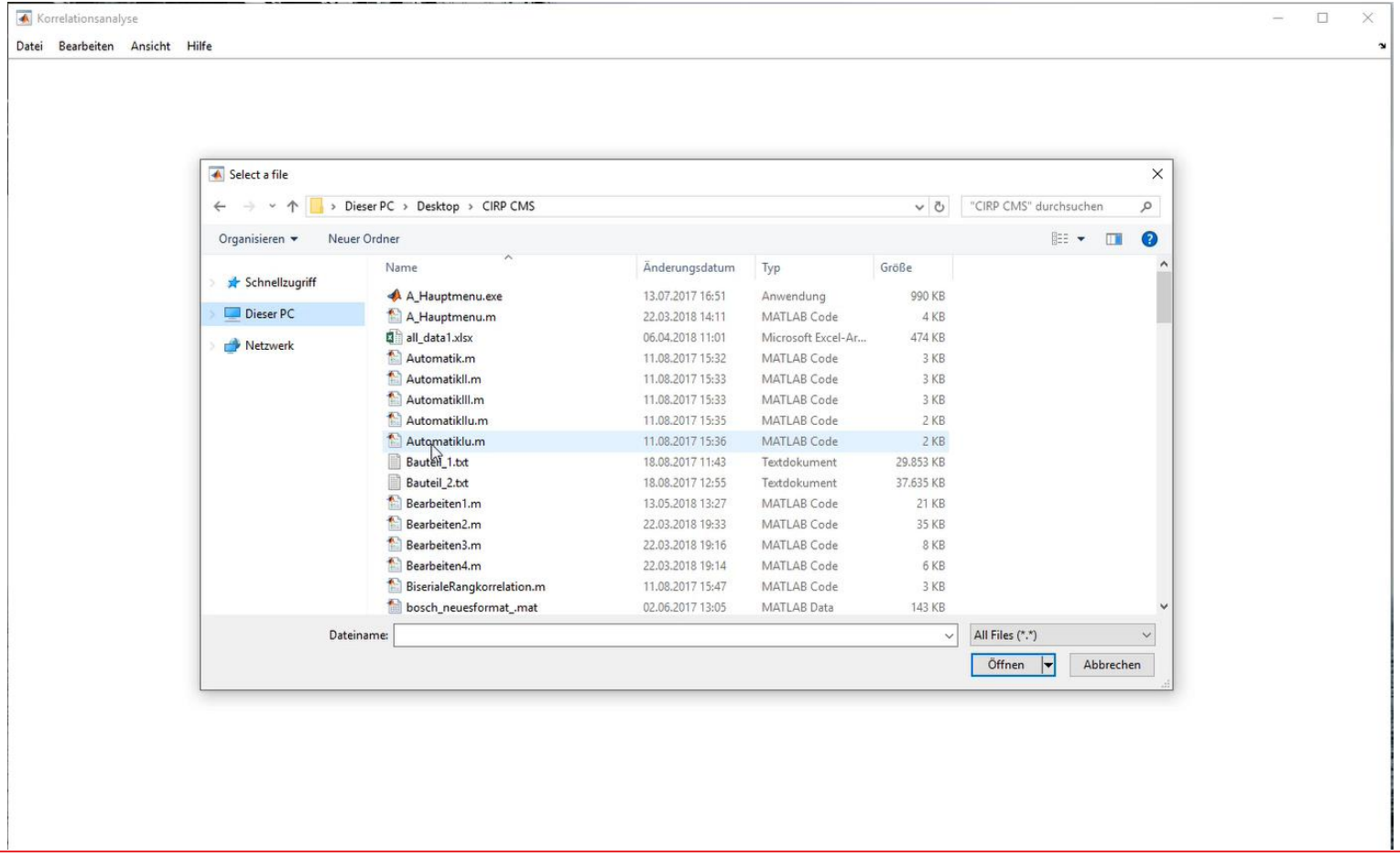
Results

Explanation of the GUI

- Details about the analysis
  - Correlation coefficient
  - Used amount of data
  - Source
  - Related processes
- Correlation matrix
- Plot of the two data sets
  - Mean value
- 3D-Plot of the frequency distribution



Results



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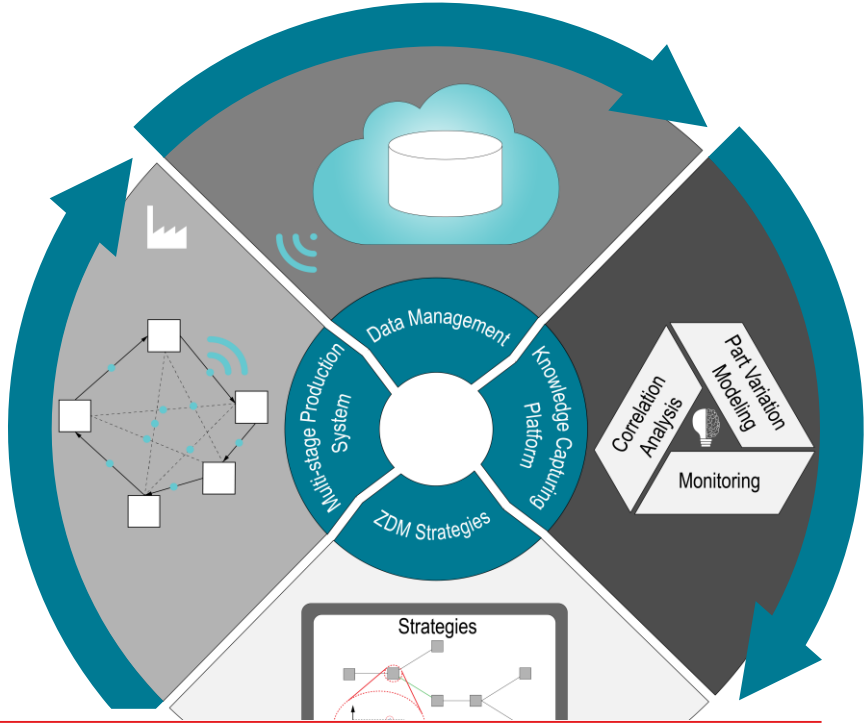
Conclusion

Correlation Analysis within multi-stage production systems

- The tool is one of three big developments within the ForZDM Knowledge Capturing Platform
- To support the approach of ZDM:
  - The existing analytical and statistical methods are able to handle various characteristics of data sets
  - The tool gets more transparency into the multi-stage production system
  - Dependencies can be identified and used for Downstream Compensation Strategies



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Thank you!

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