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DRESDEN concept

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PROFESSUR FÜR WERKZEUGMASCHINENENTWICKLUNG UND ADAPTIVE STEUERUNGEN

Contributions to an FMEA/FMSA Based Methodology to Improve Data Quality of Cyber Physical Production Systems Through Digitalisation: a Use Case Approach

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1. Introduction
   Description, concepts, motivation, goals, challenges

2. Solution concept
   Use case for validation

3. Implementation details

4. Summary and outlook

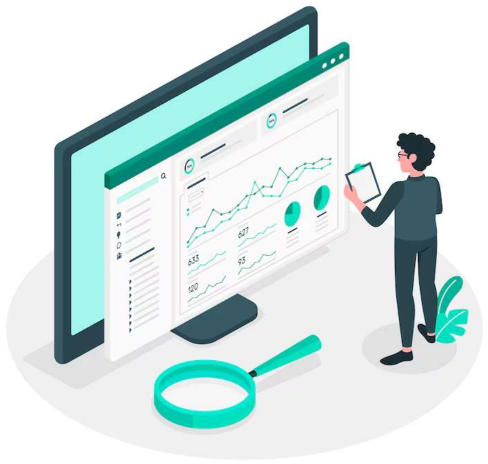
1. Introduction:
Description, concepts, motivation, goals, challenges

Aim

The objective is therefore to adopt a scientifically established data-driven objective approach for managing the FMEA/FMSA methodologies

Data driven approach utilizes AI (machine learning, predictive data analytics) on historical and operational data;

Objective approach → does not rely on the estimation team's expertise



Data Driven Images - Free Download on Freepik

Further points:

1. The initial stage of the FMEA methodology involves identifying all imaginable failure modes within a product or process. Subsequently, the potential origins and consequent effects of these prospective failures must be established.
2. The next step involves evaluating the risk level associated with each failure mode, using predetermined criteria.
3. Finally, methods must be devised to detect, reduce, or prevent failures with the aim of aligning the product or process with high quality and risk objectives.

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Concepts

FMEA's Risk Priority Number (RPN)

A quantitative outcome, offering a straightforward approach to evaluate risk:

- The measure RPN is calculated using the following three components:

1. **Severity** (Sev): Indicates the gravity of potential consequences should an issue arise.
2. **Occurrence** (Occ): Reflects the likelihood of an issue arising. To determine the frequency of occurrence, all potential causes of failure and their probabilities must considered.
3. **Detection** (Det): This signifies how challenging it is to identify an issue. A higher score suggests that an issue is less likely to be spotted by engineers during product development testing or by customers after release.

$$RPN := Sev * Occ * Det.$$

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Concepts cont.

FMSA's Monitoring Priority Number (MPN)

A quantitative outcome, offering a straightforward approach to evaluate risk:

- The measure RPN is calculated using the following three components:

1. **Detection** estimation (Det), which characterises the overall recognisability of a fault condition.
2. Failure **severity** (Sev) is evaluated based on its associated risk,.
3. anticipated accuracy of **Prognosis** (Pgn) and **Diagnosis** (Dgn).

$$MPN = Det * Sev * Pgn * Dgn.$$

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A <u>high value</u> for MPN is indicative of the <u>efficacy</u> of a procedure for the detection, diagnosis and prognosis of a defect type.

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Related work

The efficacy of this method in determining the likelihood of "**failure occurrence**" has been previously validated through the application of deep learning techniques to historical and operational data in the aviation industry [6]

Further points :

[Failure occurence Stock-Fotos, lizenzfreie Bilder, Vektorgrafiken und Videos]

In contrast to Blancke's [7] stochastic technique, which can calculate probabilities from limited data, the data-driven approach relies on historical and operational data collected during the utilisation phase.

1. [6] M.-A. Filz, J. E. B. Langner, C. Herrmann, and S. Thiede, "Data-driven failure mode and effect analysis (fmea) to enhance maintenance planning," Computers in Industry, vol. 129, p. 103451, 2021
2. [7] O. Blancke et al., "A holistic multi-failure mode prognosis approach for complex equipment," Reliability Engineering & System Safety, vol. 180, pp. 136–151, 2018,

The proposed data-driven methodology advocates a paradigm shift in the manufacturing sector, transitioning from subjectively designed individualistic concepts traditionally employed in addressing FMEA/FMSA frameworks towards objectively established, harmonised solutions.

[Paradigm shift Stock-Fotos, lizenzfreie Bilder, Vektorgrafiken und Videos]

2. Solution concept:
Use case for validation

Strategy

It is crucial to **identify appropriate sensors**, and thus, the **corresponding failure detection algorithm** for each specific failure scenario.

Within this use case, **a methodology for the data mining-compatible digitisation of CCPSs is developed**, enabling companies to independently upgrade existing machinery or digitise new equipment.

By examining the resulting effect pattern descriptions, this study establishes measurement technology requirements and determines suitable sensors and their optimal placement, and thus, the corresponding failure detection algorithm for each specific failure scenario.

Following the integration of sensor technology into the machine's IT infrastructure, **an experimental validation** was conducted for individual data sources and measurement locations.

The results demonstrate that, using this method, an appropriate sensor and corresponding failure detection algorithm can be identified for each examined failure condition.

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Outline of the results

- This study involved developing a method for data-mining compatible **digitalisation** of CCPSs for an analytical use case
- Subsequently, **pitting** and **insufficient lubrication** were identified as high-priority faults for the carriage, whereas pitting and **installation errors** were prioritised for the guide rail.
- The analysis results indicated that **vibration** was a **suitable measurement variable** for detecting pitting and inadequate lubrication.
- Further experiments were conducted to identify suitable **measurement locations** on the system.

- With a focus on the organisation of maintenance activities, data-driven FMEA combines the revealed correlation from past maintenance events with the experience of employees and provides support during the planning of maintenance and repair.

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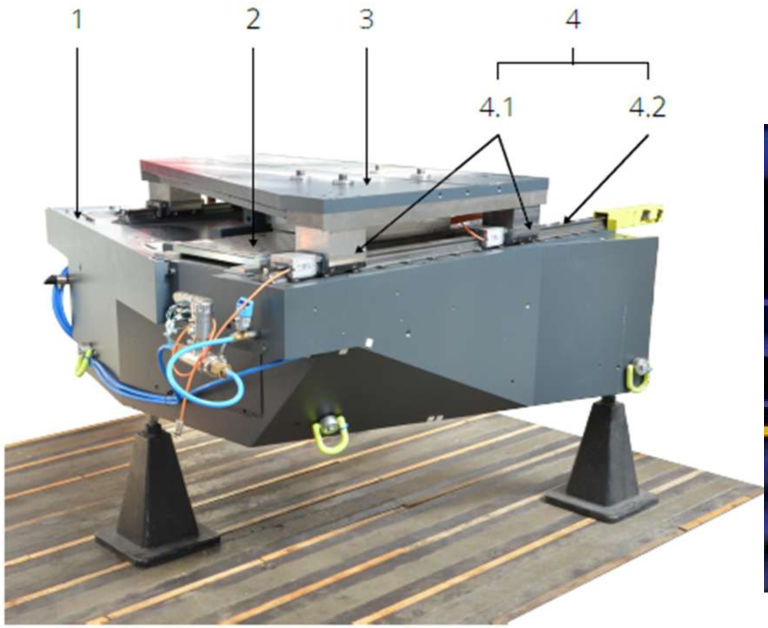
Digitization Stock-Fotos, lizenzfreie Bilder, Vektorgrafiken und Videos

Use Case; Challenges

Test stand

The initial objective of the case study was to analyse the system, determine the necessary data sources, measurement points, and sensors to be chosen,.



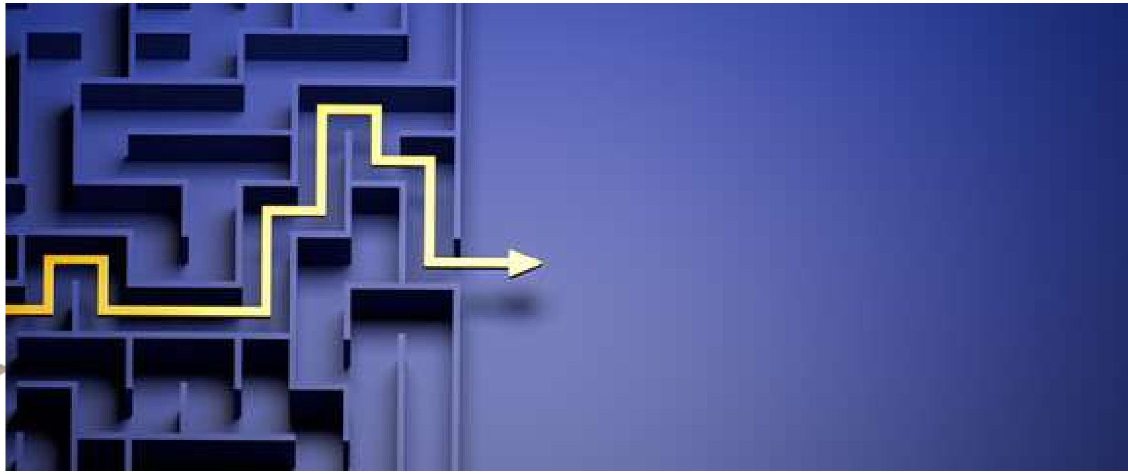


Figure 2: Figure presenting the "Intelligent Machine Bed" test stand.

Test bed Stock-Fotos, lizenzfreie Bilder, Vektorgrafiken und Videos
Challenges Stock-Fotos, lizenzfreie Bilder, Vektorgrafiken und Videos

Use Case; Challenges

Anticipating the difficulties

The Bosch XDK platform , designed <u>for vibration detection</u>, is firmly attached to the measurement location, ensuring the integrated <u>acceleration sensor </u>is positioned precisely where the vibration is to be measured.

Figure 1: Figure presenting a pitting damage to a ball rolling element at LWM.

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3. Implementation details

Contribution

TABLE I. DIAGRAM PRESENTING AN OVERVIEW OF THE SOLUTION CONCEPT. HIGHEST PRIORITISED FAILURE CASES ACCORDING TO FMEA.

		Possible failure effects							
System	**Failure type**	**Local effect**	**Final effect**	**Severity**	**Possible cause of failure**	**Failure mechanism**	**Occurrence**	**Detection**	**RPN**
Guide rail	Pitting	Poorer running behaviour, Loss of accuracy, Abrasion	Significant reduction in service life, failure	8	Excessive continuous load	Material fatigue	4	4	128
Guide rail	Installation error	Higher displacement forces depending on the slide position	Reduction in service life	4	Design errors, Assembly errors	Additional tensioning, Friction	5	8	160
Guide carriage	Inadequate lubrication	Higher displacement forces, Increased friction	Wear of the rolling elements	7	Maintenance errors, Damages	Insufficient maintenance intervals	5	5	175

Contribution

TABLE II. DIAGRAM PRESENTING AN OVERVIEW OF THE SOLUTION CONCEPT. FAILURES WITH THE HIGHEST FMSA MPN.

		Possible failure effects					
System	Failure type	Failure symptoms	Failure effect	Failure description	Detection	Diagnosis	MPN
Guide rail	Pitting	Vibration	Vibration excitation, Higher amplitude	Certain damage rollover frequency when travelling over the damage	5	4	20
Guide rail	Pitting	Optical changes	Change in image information	Material breakouts are visually recognisable as part of image recognition due to changes in the raceway	5	4	20
Guide rail	Installation error	Motor current	Higher motor current depending on the carriage position	An installation error results in additional tension, which causes a higher displacement force	3	4	12
Guide carriage	Inadequate lubrication	Motor current	Continuously increased motor current	Insufficient lubrication leads to an increase in the coefficient of friction μ_R over the entire rail	3	4	12

4. Summary and outlook

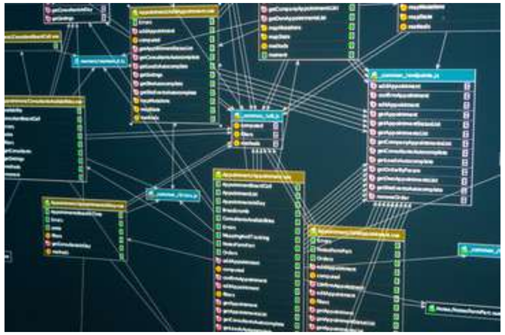
Conclusion and Future Work

- This study further develops and validates a **data-driven FMEA/FMSA methodology** to digitise machinery, thereby enhancing production facilities and enabling advanced data analysis.

- The initial setup for the components of FMEA/FMSA may be by best estimates of the team members, but over time as data accumulates, **components** of FMEA/FMSA are **improved by** using AI technologies on historical or current data).
- To ensure accurate failure prognosis and/or correct failure type diagnosis, **suitable sensors** should be selected and detection/forecasting/diagnostic algorithms should be established.

- There exists an opportunity to create an automated FMEA/FMSA system that continuously updates the risk/monitoring priority numbers

- the **development a knowledge data base** for failure scenarios, sensors, detection and forecasting algorithms is essential for a data-driven FMSA



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Paradigm change

The proposed data-driven methodology advocates a paradigm shift in the manufacturing sector, transitioning from subjectively designed individualistic concepts traditionally employed in addressing FMEA/FMSA frameworks towards objectively established, harmonised solutions.

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