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Assessment of fault detection and monitoring techniques for effective digitalization

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As a result of digitalization, data is collected at every level of production as an enhancer for decision-making. However, including more sensors to collect additional information does not directly contribute to increasing the system reliability but instead raises challenges for optimal data utilization. This work presents an evaluation approach based on FMSA (Failure mode and symptoms analysis) combined with FMECA (Failure mode, effects and criticality analysis) prioritization methods. The different methods are applied to a feed-drive system to evaluate the suitability of the currently implemented detection and monitoring techniques. The recommendations derived from the evaluation can be utilized to maximize confidence in the monitoring and to minimize the sensors utilization and data collection. Since the FMEA family of assessment tools present shortcomings such as bias and uncertainty associated with their results, this work also aims at mitigating these effects in obtaining the monitoring priority numbers and their respective categorization and prioritization.

Keywords: Digitalization, monitoring, system reliability, FMSA, MPN, FMECA, Fuzzy logic

1. Introduction

Industrial digitalization aims to enhance operational efficiency and equipment reliability, which can only be obtained through proper maintenance supported by data-driven decision-making. For any system, effective monitoring techniques are vital for detecting, diagnosing, and prognosing faults and defining critical maintenance items (Murad et al. 2020). However, extensive digitalization does not co-exist with sustainability; contrariwise, it could imply increased cost and complexity and potentially lower reliability. Thus, it is crucial to uncover unleveraged monitoring potentials within the existing system capabilities or to improve them with minimal resource addition.

Among the detection and monitoring analysis tools, the FMSA was selected due to its focus on fault identification and degradation rather than occurrence. The implementation of this tool is exemplified through a case study of a feed-drive system. Additionally, the study compares different methods to calculate the MPN (Monitoring Priority Number) and its prioritization. These methods are evaluated for their ability to provide relevant information and recommendations to effectively utilize data resources, consider critical functions, and avoid unnecessary equipment deployment.

2. FMSA and FMECA assessment methods

FMSA is an extension of the FMECA, focussing on selecting the appropriate detection and monitoring techniques for different failure mode symptoms (ISO 2015). Each FM (Failure Mode) has one or multiple root causes and associated symptoms, which are detected at specific locations and frequencies. These inputs determine ratings for the likelihood of detection, diagnosis and prognosis accuracy, and the degree of severity of the FMs.

The MPN is the product of the mentioned factors. A high MPN indicates a suitable detection and monitoring for the associated FM (ISO 2015). A lower MPN may signify low severity or deficient detection, diagnosis, or prognosis. The MPN threshold is user-defined, and its ranking does not directly suggest improvement actions. This study applies various existing methods to calculate and categorize MPNs linking them to linguistically described recommended actions. These actions provide concrete improvement directions, reducing the bias associated with FMEA tools. Methods used include standard MPN calculation (ISO 2015), Pareto, Boxplot (Catelani et al. 2020), and Bluvband approach (Bluvband et al. 2004), k-means clustering, and Fuzzy-FMSA (Murad et al. 2020).

Table 1. Resulting MPN calculation, prioritization and recommended actions derived with different methods.

Methods	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10
Standard MPN	R 20	R 12	R 8	R 8	I 36	I 48	R 18	I 36	R 18	R 24
Pareto (inv. MPN)	C 20 (123)	C 12 (131)	C 8 (135)	C 8 (135)	NC 36 (107)	NC 48 (95)	C 18 (125)	NC 36 (107)	C 18 (128)	C 24 (119)
Boxplot	R 20	R 12	R 8	R 8	I 36	NC 48	R 18	I 36	R 18	I 24
Bluvband	C 20	C 12	C 8	C 8	C 36	NC 48	C 18	C 36	C 18	C 24
Clustering (3 groups)	NC N/A	I N/A	I N/A	I N/A	I N/A	I N/A	I N/A	I N/A	R N/A	R N/A
FMSA (4 out)	R 100	I 50	R 100	R 100	I 50	I 50	I 50	I 50	R 100	R 100
FMSA (6 out)	R-R 260	I-H 60	R-A 175	R-A 175	I-H 60	I-H 60	I-H 60	I-H 60	R-A 175	R-A 175

Methods	FM11	FM12	FM13	FM14	FM15	FM16	FM17	FM18	FM19	FM20	# C modes	C modes threshold	# NC modes	Review region
Standard MPN	I 36	I 32	R 18	NC 135	R 18	R 24	R 24	I 48	I 54	NC 90	7	[80-25]	2	Yes
Pareto (inv. MPN)	NC 36 (107)	C 32 (111)	C 18 (125)	NC 135 (8)	C 18 (125)	C 24 (119)	C 24 (119)	NC 48 (95)	NC 54 (89)	NC 90 (53)	12	<36 (>107)	8	No
Boxplot	I 36	I 32	R 18	NC 135	R 18	I 24	I 24	NC 48	NC 54	NC 90	7	[45-24]	5	Yes
Bluvband	C 36	C 32	C 18	NC 135	C 18	C 24	C 24	NC 48	NC 54	NC 90	15	<48	5	No
Clustering (3 groups)	R N/A	I N/A	I N/A	NC N/A	R N/A	R N/A	R N/A	I N/A	R N/A	NC N/A	10	N/A	3	No
FMSA (4 out)	I 50	I 50	I 50	NC 327	R 100	R 100	R 100	I 50	I 50	R 100	10	Memb. [20-80]	1	Yes
FMSA (6 out)	I-H 60	I-H 60	I-H 60	NC 413	R-A 175	R-A 175	R-A 175	I-H 60	I-L 110	R-R 260	10	Memb. [20-150]	1	Yes

Code	I	R	C	NC	I-H	I-L	R-A	R-R
Description of the recommended action	Improve	Review	Critical	Non-critical (Satisfactory monitoring)	Improve monitoring high priority	Improve monitoring low priority	Review monitoring (consider adding monitoring level)	Review monitoring (consider reducing monitoring level)

3. Case study: Results and discussion

Figure 1 displays the feed-drive system analyzed. Positioning accuracy, response time and load-carrying capacity are considered as the system's key performance indicators (KPI). The system has a current sensor and a rotational encoder for functional (control) and monitoring (detection) purposes.

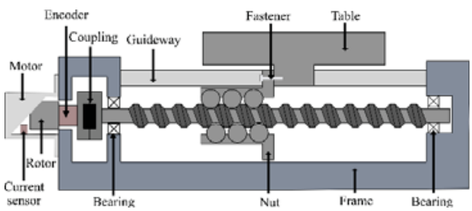

Figure 1. Schematic of a feed-drive system.

Initially, functional analysis (VDI 1996) helped establish the system's functions. Then, FMs for each function were detailed, and the FMSA criteria were graded by panel of experts. MPNs, their prioritization, and recommendations are presented in Table 1.

The first four methods (rows 1-4 in Table 1) used the standard MPN calculation, testing various FM prioritization methods derived for FMECA.

Three prioritization categories with associated improvement recommendations were found using defined thresholds and the boxplot method. The former results in case-dependent FM prioritization categories, while the latter is generalizable but underestimates FMs requiring improvement.

Pareto and Bluvband methods classify 60% and 75% of FMs as critical but lack information on monitoring improvement actions. Clustering results in three categories and an average of FMs needing monitoring improvement. However, the association between prioritization groups and the selection of the number of groups can be ambiguous.

Integrating expert knowledge into prioritization-recommendation through fuzzy logic yields four and six output categories, depending on recommendation specificity and discretization of edge categories to minimize algorithm bias. This approach aims to reduce uncertainty in FM prioritization by providing a clear directive for improvement. The case study's results highlight the need for monitoring improvements in FMs related to position estimation and mechanical coupling. For instance, adding a linear encoder and accelerometer can enhance system monitoring and contribute to achieving KPIs. The assumption in action-oriented FMSA is that once the rule base is created it is used in multiple systems. Further evaluation in industrial cases will determine the suitability of the approach for effective digitalization.

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