Festo Plant for Discrete Manufacturing:
Simulation Models for Industrial Copilots

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ABSTRACT

The main objective is to **enhance production efficiency and decision-making** through precise simulations of forces applied on drilling tools, from which **degradation and quality** of the discrete manufacturing process can be deduced. The project **uses empirical models to estimate wear and quality** while using **LangChain to build a natural language User-Agent interface**. Through literature, datasets are acquired and feature importance techniques are used to correctly estimate the desired quantities; while for the second part, complete developed tools are implemented as part of GenAI-based pilots. Lastly, analyses are done to test different **Large Language Models, Prompt Engineering and Agentic Architecture**.

METHODOLOGY

DATASET: We use the **XAI Drilling Dataset**, a **20,000-sample** synthetic yet physics-informed dataset for explainable drilling-failure analysis. It contains **ten process and material features and four expert-defined failure categories** tied to tool wear, chip formation, and tool–material mismatch. Its **rule-based** design makes it well-suited for **interpretable prediction** methods.

WEAR TOOL

- Automatically determines the degradation state* of the cutting tool based on **vc**, **Tf** (torque x feed rate) and **material properties**.
- A **rule-based physical filter** is first applied to guarantee that only physically consistent machining conditions are evaluated.
- A monotonic domain-informed **XGBoost** model classifies the degradation state with **100% accuracy and recall** on unseen data.
- **Output** includes predicted estimated **wear** percentage, enabling immediate **decision-making during machining**.

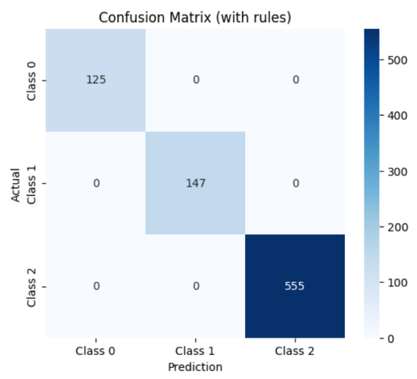


Fig. 1 and 2: Confusion matrix and predicted wear example on material N (Non-ferrous metal).

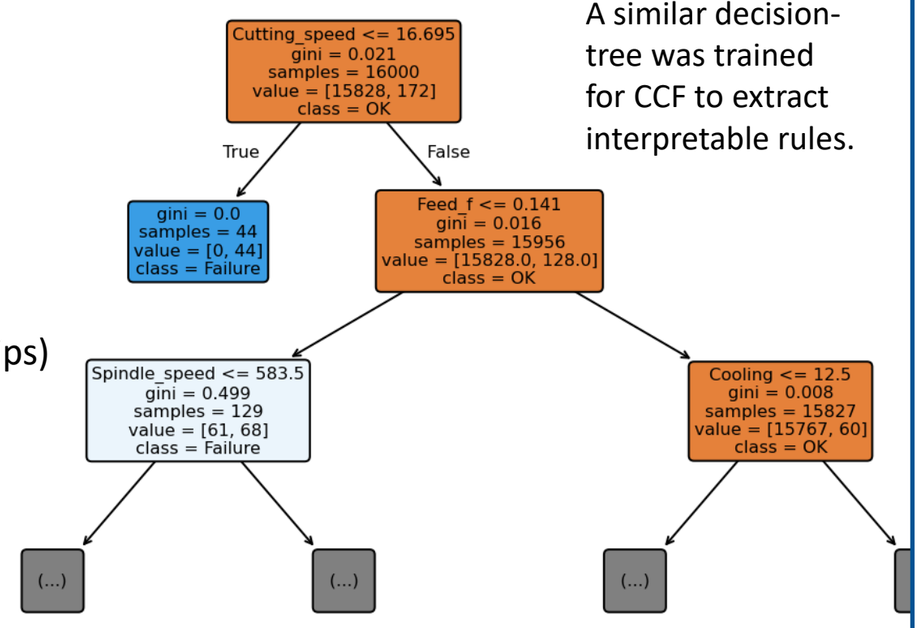
*** Class 0:** wear < 5%, **Class 1:** 5% < wear < 100%, **Class 2:** worn (100% wear).

QUALITY TOOL

- To improve process reliability and reduce tool and material use.
- **BEF** & **CCF** predictions are obtained using **decision-tree** models.
- All rules were **automatically generated** from the learned trees and then **manually refined**.

BEF
(Built-up Edge)
4 rules
Precision : 0.977
Recall : 1.000

CCF
(Compression Chips)
8 rules
Precision : 0.958
Recall : 1.000

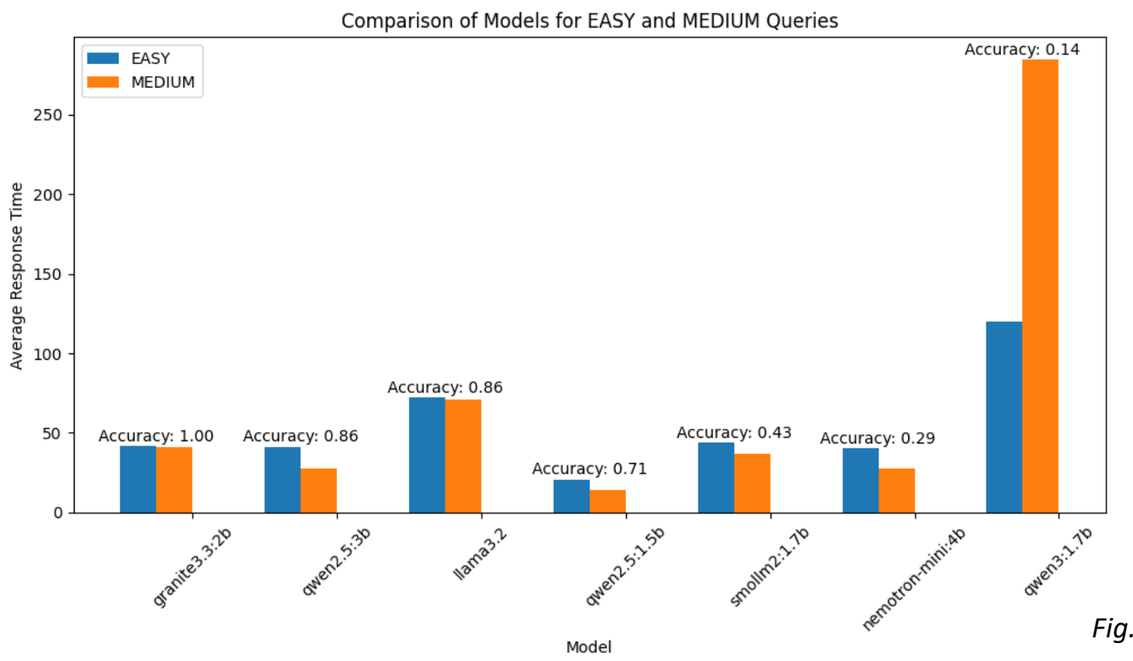


A similar decision-tree was trained for CCF to extract interpretable rules.

Fig. 3 BEF Decision Tree (Simplified)

AGENTIC SYSTEM

- **Analysis of different LLMs** performances for different levels of difficulty for user's queries.
- Comparison between **Multi-Agent and Single-Agent** systems.
- **Prompt Engineering** led to **Chain-of-Thought and Plan and Solve** as best strategies for prompting.



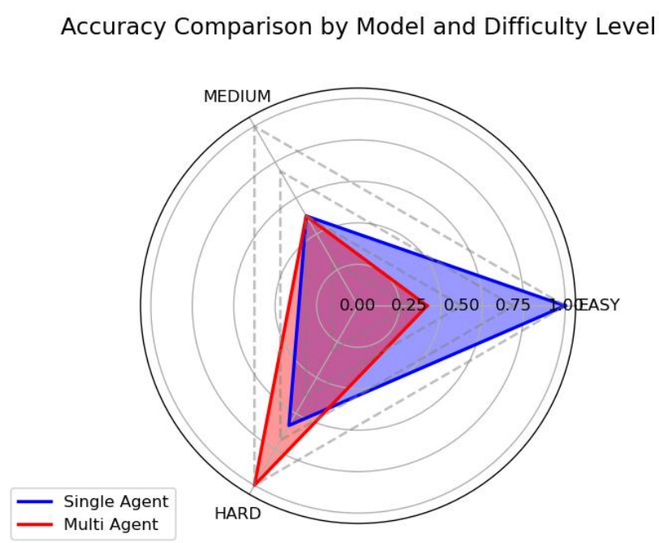


Fig. 4 and 5: Analysis on LLMs and System Architecture

RESULTS & OUTLOOK

- The agentic system evaluation showed that **multi-agent** architectures consistently **outperform** single-agent LLMs, especially **on medium and hard queries,** while **tools** reached **100% recall**, ensuring that all failure cases are detected with **no false negatives**.
- Integrate both wear and quality tools into a **unified real-time decision-support system** for CNC operators.
- Extend the methodology to **real sensor data** and additional machining failure modes to reinforce industrial applicability.

References

[1] H. Metin and C. Oysu, "Degradation model for cutting tools with explainable wear estimation," 2004, DOI:10.1016/j.mechatronics.2003.10.005 .
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[3] R. Wallsberger, "XAI Drilling Dataset," Kaggle, 2022. [Online]. Available: https://www.kaggle.com/datasets/raphaelwallsberger/xai-drilling-dataset