# Artificial Intelligence in the steel industry

Lukáš Skopár
Technická univerzita v Košiciach
Fakulta elektrotechniky a informatiky
lukas.skopar@student.tuke.sk

***Abstract*—The steel industry is undergoing a transformative phase driven by the digitalization of production processes. This shift presents significant opportunities for enhancing process reliability, product quality, and socio-economic and environmental sustainability across the production chain. However, it also poses challenges such as personnel upskilling and the need for advanced monitoring and control procedures. In response to these challenges, this study introduces an AI-based predictive maintenance tool for real-time estimation of the ageing status of ladles in steel production plants. Leveraging data collected from a real electric steelworks and operators' experience, the developed system employs machine learning models to accurately predict ladle status. The methodology encompasses data analysis, model testing, and validation to ensure reliability and effectiveness. Experimental results demonstrate the efficacy of the predictive maintenance tool in enhancing productivity and product quality by providing timely insights for proactive maintenance interventions. This paper contributes to advancing predictive maintenance practices in the steel industry and lays the groundwork for future research and implementation of AI-driven solutions.**

***Index Terms*—Steel industry, Predictive maintenance, Artificial intelligence, Machine learning, Production processes**

## I. Introduction

The industrial landscape is undergoing significant transformations driven by advancements in technology and methodologies aimed at enhancing productivity, quality, and sustainability [1]. In this context, predictive modeling and quality assessment methodologies play a crucial role in optimizing industrial processes, ensuring product integrity, and minimizing operational risks. This introduction provides an overview of various methodologies employed in industrial contexts, highlighting their significance and applications across different domains.

Predictive modeling and quality assessment methodologies encompass a diverse range of approaches tailored to address specific challenges encountered in industrial settings. These methodologies leverage advanced computational techniques, data analytics, and domain knowledge to develop effective solutions for predicting equipment aging, evaluating material resistance, forecasting concrete behaviors, and assessing process quality.

One notable approach in predictive modeling involves the development of Decision Support Systems (DSS) [3] for predicting the end-of-life (EOL) of critical equipment used in metallurgical processes. These systems integrate process information from Programmable Logic Controllers (PLCs) and additional features to support preventive maintenance strategies. Ladle status predictors, trained using data extracted from plant databases, incorporate operators' expertise to identify ladle conditions and facilitate timely maintenance interventions.

Artificial Neural Networks (ANNs) [2] have emerged as a powerful tool for evaluating material resistance in various industrial applications. Studies have demonstrated the effectiveness of ANNs in predicting the cross-section resistance of stainless steel structures exposed to fire conditions. By leveraging TensorFlow and MATLAB's ANN toolbox, researchers have developed models capable of capturing complex relationships between input parameters and material properties, thereby improving prediction accuracy and reliability.

Furthermore, ANNs have been instrumental in predicting concrete mechanical behaviors, including compressive strength (CS), flexural strength (FS), and tensile strength (TS) of fiber-reinforced concrete. These models leverage datasets comprising concrete properties and curing days to train ANNs, enabling accurate predictions of material properties crucial for structural design and performance assessment.

In addition to predictive modeling, quality assessment methodologies have been advanced through innovative approaches such as the CSBFNet model for quality-checking rating of steel scrap unloading processes. This model integrates attention mechanisms and feature fusion networks to analyze images captured at the exit of descalers, providing valuable insights into scrap quality and process efficiency.

Overall, these methodologies represent diverse approaches to address challenges in predictive modeling and quality assessment in industrial settings. By leveraging advanced computational techniques and domain-specific knowledge, researchers and practitioners can develop tailored solutions to enhance process efficiency, product quality, and overall operational performance.

## II. Methodology

In exploring predictive modeling and quality assessment methodologies in industrial contexts, various approaches have been employed across different studies. These methodologies aim to address specific challenges in predicting equipment aging, evaluating material resistance, forecasting concrete behaviors, and assessing process quality.

One notable approach involves the development of Decision Support Systems (DSS) for predicting the end-of-life (EOL) of ladles used in metallurgical processes. In this study, the

DSS integrates process information from Programmable Logic Controllers (PLCs) and additional features to support a preventive maintenance approach. Ladle status predictors are trained using data extracted from plant databases, incorporating operators' expertise to identify ladle conditions. Different classifiers, such as Decision Trees (DT) and Random Forests (RF), are tested to predict ladle statuses based on process conditions, with hyper-parameter tuning to optimize performance.

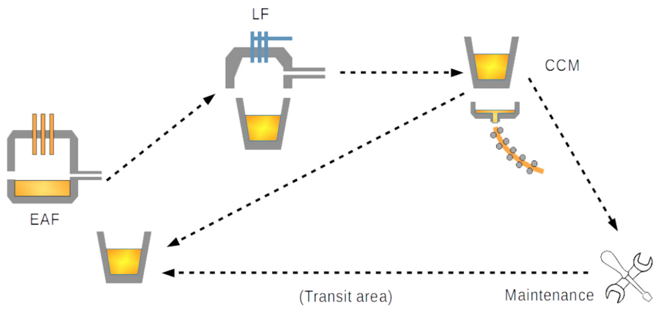


Fig. 1. Schematic representation of the considered steelworks highlighting the different routes of the ladle.

In other studies, Artificial Neural Networks (ANNs) have been utilized to evaluate material resistance, such as the cross-section resistance of stainless steel I-sections in fire. Here, ANNs are trained using TensorFlow with a dataset split into training and testing sets. Multiple networks are adopted for different steel types and loading conditions, with specific architectures designed to capture the complex relationship between input parameters and material resistance. Mean Square Error (MSE) is employed as the loss function, and cross-validation is conducted to optimize the model and prevent overfitting.

Furthermore, ANNs have been employed in predicting concrete mechanical behaviors, including compressive strength (CS), flexural strength (FS), and tensile strength (TS) of Ultra-High-Performance Fiber-Reinforced Concrete (UHSFRC). In this study, the ANNs model is developed using MATLAB's ANN toolbox, with input variables related to concrete properties and curing days. The training process involves data preprocessing, neural network creation, training, testing, and performance evaluation.

Additionally, a novel approach called CSBFNet model has been introduced for quality-checking rating of the steel scrap unloading process [5]. This methodology integrates attention mechanisms and related technologies such as Cross Stage Partial Networks (CSP), Squeeze-Excitation (SE), and EfficientDet. The model framework integrates feature extraction, attention mechanisms, and multi-scale feature fusion to assess scrap quality based on image analysis.

Overall, these methodologies represent diverse approaches to address challenges in predictive modeling and quality assessment in industrial settings. Each approach offers unique insights and solutions tailored to the specific requirements of the respective domains.

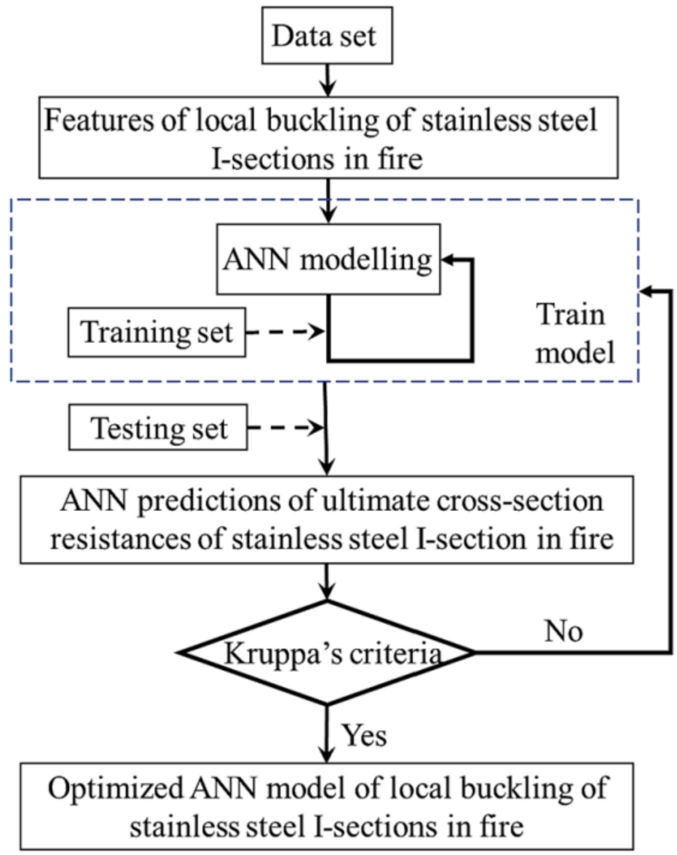


Fig. 2. Flow chart of ANN model development.

## III. Results and Analysis

The results and analysis from various studies shed light on the effectiveness and applicability of different methodologies in addressing specific research questions. In one study, the performance of classifiers, specifically decision trees (DT) and random forests (RF), was evaluated through a comprehensive test campaign. The classifiers were assessed based on various key performance indicators (KPIs) such as recall and precision. The results indicated satisfactory performance, particularly in detecting critical conditions in ladles, despite the challenging nature of the classification task due to imbalanced data and variable durations of ladle aging status. While both DT and RF classifiers performed well, DT showed better performance in detecting end-of-life (EOL) situations with higher precision. Visual representations of the DT predictor's outcomes further validated its effectiveness in predicting critical situations during ladle operations.

Another study compared artificial neural network (ANN) models with existing design rules for stainless steel cross-sections in fire conditions. Design methods outlined in EN 1993-1-2 and the recommendations by Xing et al. were evaluated alongside optimized ANN models. The results revealed that traditional design methods often underestimated cross-section resistance predictions due to their failure to account for plastic behavior in certain conditions. In contrast, opti-

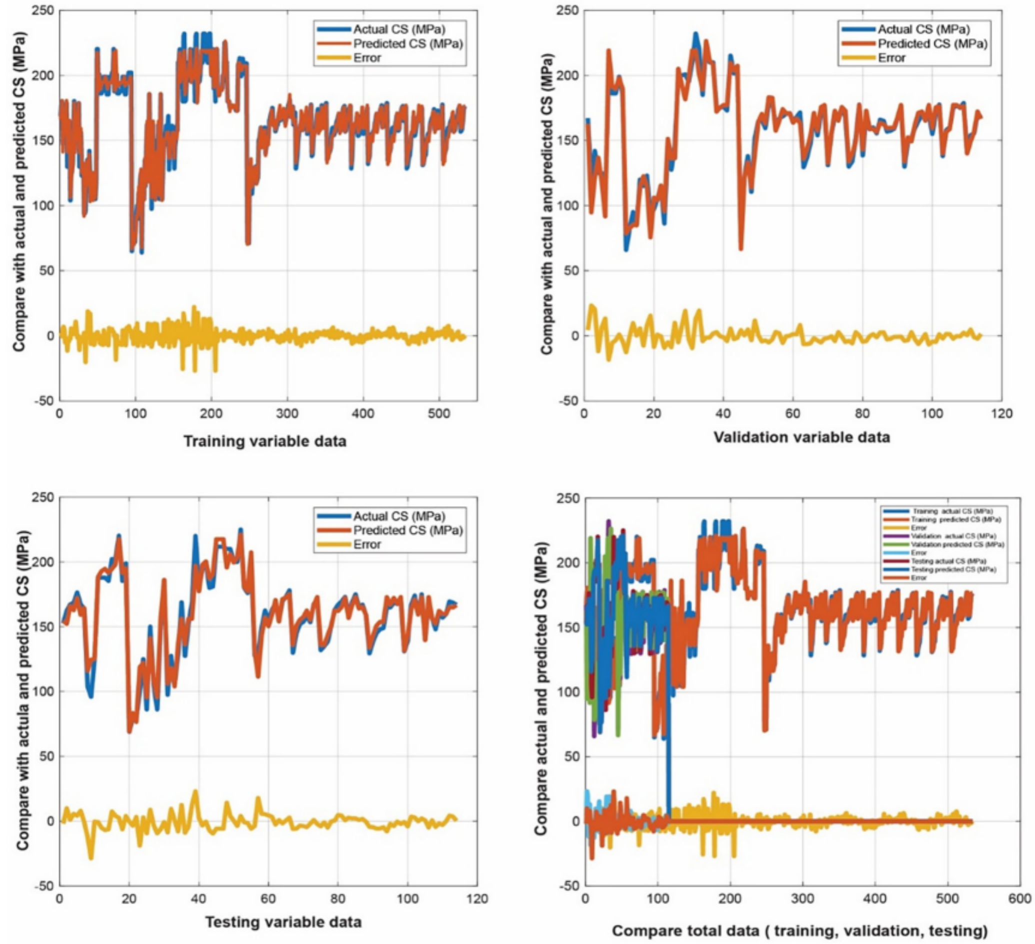


Fig. 3. Compare actual and predicted CS with errors.

mized ANN models demonstrated more accurate predictions, especially in scenarios where traditional methods fell short. The reliability of the methods was assessed based on specific criteria, with ANN models proving to be more consistent and reliable compared to traditional design rules.

Furthermore, the evaluation method employed in a different study involved mean square error (MSE) and root mean square error (RMSE) for assessing the accuracy of machine learning algorithms. The study utilized a substantial dataset from various sources and trained ANNs to predict compressive strength (CS) of ultra-high-strength fiber-reinforced concrete (UHSFRC). The ANNs were trained, validated, and tested using different subsets of the dataset, and their performance was evaluated based on error values and correlation coefficients. The results demonstrated high accuracy and consistency of the ANNs model compared to previous studies, highlighting the effectiveness of using ANNs for predicting CS in UHSFRC.

Moreover, a comparison experiment conducted in another study evaluated the CSBFNet model against classical target detection algorithms for identifying and categorizing steel scrap. The results showed that the CSBFNet model outperformed other models in terms of detection precision, despite having lower computational complexity. Ablation experiments further validated the effectiveness of incorporating attention mechanisms and feature fusion networks into the CSBFNet model, resulting in improved detection accuracy and efficiency.

In summary, the results and analysis from these studies emphasize the importance of choosing appropriate methodologies tailored to specific research objectives. Whether it's evaluating classifiers for ladle condition monitoring, comparing design methods for stainless steel structures, predicting material properties using machine learning algorithms, or optimizing neural network models for object detection, each study offers valuable insights into the strengths and limitations of different approaches in addressing complex engineering challenges.

## IV. Conclusion

The rapid evolution of technology continues to reshape the industrial landscape, driving the need for advanced methodologies to enhance productivity, quality, and sustainability. The exploration of predictive modeling and quality assessment methodologies presented in this research paper underscores their critical role in optimizing industrial processes, ensuring product integrity, and minimizing operational risks. [4]

Through the utilization of diverse approaches such as Decision Support Systems (DSS), Artificial Neural Networks (ANNs), and innovative models like CSBFNet, researchers and practitioners have been able to address complex challenges across various domains within the industrial sector.

The development of Decision Support Systems for predicting equipment aging exemplifies the fusion of domain knowledge and advanced computational techniques to support preventive maintenance strategies. Similarly, the application of Artificial Neural Networks has revolutionized material resistance evaluation and concrete mechanical behavior prediction, offering superior accuracy and reliability compared to traditional methods.

Moreover, the introduction of novel models like CSBFNet demonstrates the continuous innovation in quality assessment methodologies, leveraging attention mechanisms and feature fusion networks to enhance process efficiency and product quality.

The results and analysis presented in this paper highlight the effectiveness and applicability of these methodologies in addressing specific research questions, ranging from ladle condition monitoring to steel scrap quality assessment. Whether it's through evaluating classifiers, comparing design methods, predicting material properties, or optimizing neural network models, each study contributes valuable insights into the advancement of industrial processes.

As technology continues to evolve, future research in this field should focus on further refining these methodologies, integrating emerging technologies such as Internet of Things (IoT) and advanced analytics for enhanced predictive capabilities and real-time monitoring. By embracing innovation and collaboration, the industrial sector can continue to leverage predictive modeling and quality assessment methodologies to drive efficiency, quality, and sustainability in manufacturing processes.

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