

Abstract

Ensuring the reliable operation of Automated Guided Vehicles (AGVs) is a significant challenge in Warehouse 4.0 environments, where equipment failures may lead to disruptions in material flows, reduced system efficiency, and increased maintenance costs. Traditional maintenance strategies based on corrective or fixed maintenance schedules are often insufficient in highly automated intralogistics systems characterized by variable operating conditions and the coexistence of multiple factors affecting vehicle performance.

This dissertation develops and validates the Fuzzy Proactive Maintenance Decision Framework (FPMDF), a decision-support model for proactive maintenance management of AGV fleets. The proposed framework integrates technical, operational, environmental, and historical factors affecting AGV operation through a Mamdani fuzzy inference system. By combining information originating from different areas of AGV operation, the model enables the assessment of vehicle technical condition and supports maintenance decision-making under conditions of uncertainty.

The development of the framework was based on a structured procedure comprising research problem exploration, identification of degradation factors using the Ishikawa diagram, selection of key variables through Pareto–Lorenz analysis, conceptualisation of the framework structure, and formalisation of the decision-making process using fuzzy logic. As a result, a solution was developed that transforms operational and diagnostic information into maintenance assessments supporting the final evaluation of vehicle technical condition and maintenance-related decision-making.

The framework was implemented in MATLAB and subjected to a multi-stage verification and validation procedure, including structural verification, expert scenario validation, sensitivity analysis, robustness testing against input data disturbances, and evaluation using operational performance indicators. The obtained results confirmed the logical consistency of the developed solution, its stability under varying input conditions, and its usefulness as a decision-support tool for proactive maintenance management in Warehouse 4.0 environments.

The main contribution of this dissertation is the development of the Fuzzy Proactive Maintenance Decision Framework (FPMDF), a decision-support model integrating technical, operational, environmental, and historical factors into the maintenance decision-making process for AGV fleets. The proposed framework generates interpretable maintenance recommendations under conditions of uncertainty and provides a structured approach to supporting maintenance decisions in Warehouse 4.0 environments.

Keywords: Automated Guided Vehicles (AGVs), proactive maintenance, fuzzy logic, Industry 4.0, Warehouse 4.0, maintenance management.