ABSTRACT

The recent rise in the applications of advanced technologies in the sustainable design and construction of transportation infrastructure demands an appropriate medium for their integration and utilization. A relatively new concept of Civil Integrated Management (CIM) is such a medium, which enhances the development of digital twins for the infrastructure and embodies various practices and tools, including the collection, organization, and data management techniques of digital data for transportation infrastructure projects. As transportation projects grow in complexity throughout their lifespan, particularly in terms of inspection and rehabilitation needs, the implementation of various CIM tools and functions can help assets sustain their performance levels by leveraging information collected in earlier stages. Therefore, CIM methods and tools have the potential to improve the performance and predictability of a project, from early stages such as scoping, and surveying, through design and construction, to the latest stages such as operations and maintenance. Asset management for transportation infrastructure refers to the systematic process of cost-effectively maintaining, upgrading, and operating physical assets. This process encompasses the planning, design, construction, maintenance, and rehabilitation of infrastructure assets such as roadways and bridges. The literature review revealed the need for a geospatial model-based asset management system for transportation infrastructures. It further highlights the importance of integrating IoT technologies with modeling techniques to create a digital twin framework, which is a dynamic, interactive model that represents the physical and functional characteristics of infrastructure assets throughout their lifecycle. Despite challenges such as modeling complexity, technology investment, and data privacy, the integration of GIS, BIM, and Artificial Intelligence within asset management systems holds the potential to improve infrastructure's structural integrity and long-term performance through automated monitoring, analysis, and predictive maintenance during its lifespan.

The objective of an effective asset management practice is to ensure that these assets deliver their intended service levels over their lifecycle while minimizing costs and maximizing performance, safety, and reliability. This process involves data collection, condition assessment, performance monitoring, and the implementation of strategies to optimize the allocation of resources for maintenance and rehabilitation activities. The high associated costs with asset management-related tasks for highways paved the way for the arrival of modern predictive pavement performance forecasting pavement deterioration. Through mathematical or machine learning methods, performance modeling involves relating pavement conditions such as surface distress to various predictors, including material and structural properties, traffic loading, and environmental factors. However, developing an effective predictive model for pavement performance is challenging due to the numerous critical predictors and their complex interrelationships. To overcome these challenges, this dissertation explores various machine learning algorithms, specifically ensemble learning models such as Random Forest, Extra Trees, and Extreme Gradient Boosting, as well as deep learning models including Artificial Neural Networks and Physics-Informed Neural Networks. These advanced models are developed to identify the most significant factors influencing AC wheel path cracking and to determine the age at which cracking initiates in a pavement section. The required features for a machine learning-based pavement deterioration model have been collected from the Long-Term Pavement Performance database provided by the Federal Highway Association. The open-access database comprises valuable information including wheel path cracking, material type and properties, environmental factors, traffic, design, and construction specifications, and more importantly maintenance and rehabilitation changes. Additionally, a GeoBIM framework was developed that replaces the existing milepost strategy of DOTs by employing a smaller segmentation using linear referencing to store digital information concerning asset performance as well as construction and material specifications. Moreover, this study found that the quality of construction and rehabilitation changes, captured through material testing, were amongst the most important features affecting pavement performance. This study illustrates the practical application of the developed models in forecasting wheel path cracking for the U.S. 1 highway, demonstrating their potential as powerful tools for infrastructure asset management.

Building on the methodology outlined, the dissertation presents an extensive exploration into the development implementation of CIM workflow, emphasizing the integration of collected information across various phases. By integrating life cycle information gathered from various phases of an asset, this research has demonstrated that existing infrastructure performance models can be improved considerably to assess its performance.

Keywords: Civil Integrated Management; CIM; Machine Learning; Transportation Infrastructure; Asset Management; Physics-Informed; Artificial Intelligence