MarTREC
Maritime Transportation Research & Education Center

BIL MarTREC Tier 1 UTC Project Request Form
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Submission Date: May 15, 2024
Lead Recipient/Grant Number: University of Arkansas / 69A3552348331
Principal Investigator Institution: Jackson State University
Center Name: Maritime Transportation Research and Education Center
USDOT Research Priority: Preserving the Existing Transportation System
Primary USDOT Strategic Goal (*select drop down*): Economic Strength and Global Competitiveness
Principal Investigator(s) with ORCID(s) and Contact Information: Dr. Wei Zheng, https://orcid.org/0000-0002-2808-3237, wei.zheng@jsums.edu
Project Partners: *Provide full name of any partner organization(s) who will actively engage in the project*
Project Type (*select drop down*): Advanced Research
Project Research Topic Type (*select drop down*): Maritime Sustainable and Resilient Infrastructure
Transportation Modes Involved (*check all that apply*): ☒Waterway ☒Road ☒Rail ☐Pipeline ☐Other
Research Project Funding: Federal funding amount of $55,000. Non-Federal funding amount: $27,500 Total amount: $82,500.
Project Start and End Dates: 01/30/2025 to 01/30/2026
Project Title: AI-Driven Preventive Maintenance for Coastal Bridges in Marine Environments
Project Abstract (Brief Description): **Project objectives** are: (1) to develop a proof-of-concept AI model for optimal maintenance of coastal bridges in harsh marine environments, aimed at achieving the required performance and safety with the minimized overall maintenance cost; and (2) to pioneer a novel AI lifelong learning framework that incorporates historical records, domain knowledge, expert insights, and in-situ sensor data to transform maintenance practices across transportation systems. **Problem Statement:** Bridges along coastlines are inevitably subject to accelerated, corrosion-induced deterioration caused by sea salt and humidity. The maintenance of these bridges presents unique challenges but has received limited research focus. Preventive maintenance involves planned strategies of cost-effective treatments that retard deterioration and maintain or improve the function of these structures. The USDOT mandates a systematic approach to the preventive maintenance of bridges. Current maintenance often relies on engineers' judgment, which may not always maximize benefits or minimize costs. Optimized preventive maintenance can theoretically be addressed through reinforcement learning (RL). However, traditional data sources are currently insufficient for training AI models. Additionally, traditional RL struggles with handling uncertainty due to environmental variability. Recently, AI advancements, particularly in natural language processing and probabilistic deep RL, have provided new ways to address these challenges. This project will innovatively explore the use of historical textual data from bridge annual inspection reports, maintenance logs, construction documents, and national weather databases, as well as relevant research publications - data that have not previously been utilized with RL for preventive maintenance. It will also pioneer the use of probabilistic deep RL and a brand-new class of neural networks, GFlowNets, which have not yet been explored in preventive maintenance with limited and noisy datasets. **Proposed Method:** The method encompasses the following perspectives: (1) It involves collecting historical documents, including bridge annual inspection reports, maintenance records, construction documents, and relevant research publications related to deterioration in marine environments. This data will be utilized to fine-tune a large language model (LLM), such as BERT, to incorporate domain-specific knowledge, enabling the LLM to accurately represent text concerning deterioration and maintenance actions from relevant documents. The fine-tuned LLM can be used to generate text tokens for identifying and representing units of text clusters related to deterioration conditions, maintenance actions, costs, and the condition after maintenance from documents, exploring

different text pooling and transforming methods to develop features that describe varying conditions, actions, costs, and consequences of actions across different sequences from historical documents in a similar way as the Named Entity Recognition. (2) The transformer-based AI, in a similar way to BERT, will be developed and trained to predict the masked conditions or consequences in a manner similar to how an LLM predicts the masked words in sentences, using sequences of text clusters in historical documents. This training allows the AI model to understand the underlying rules of deterioration and maintenance processes, akin to the language of natural laws, enabling it to generate simulated data for various conditions and maintenance scenarios. For instance, given a specific condition, if a certain maintenance action is taken, the model can probabilistically determine the cost of the action and the resulting condition of the bridge based on rules implied in the historical documents. (3) This simulated data will be employed to further train RL agents through probabilistic reinforcement learning (RL) or GFlowNets. The developed model will offer not just a single policy but a range of policy options whose probability distribution aligns with the cost function, allowing decision-makers to evaluate various actions and understand the associated costs and the renewed conditions. (4) The data will be continuously collected and utilized to refine the AI model further, incorporating Reinforcement learning from human feedback to include expert input within the loop, enabling it to operate in a lifelong learning mode as more data is gathered, thus enhancing the reliability of decision-making. This innovative approach will empower AI agents to make optimized decisions based on domain knowledge, historical data, current sensor data, and expert insights while accounting for uncertainty. (References will be provided upon request.)

USDOT Priorities: The project aligns with USDOT's strategic goals of enhancing economic strength and competitiveness by reducing maintenance costs and improving infrastructure resilience. It also supports climate and sustainability goals by promoting resource-efficient maintenance practices.

Outputs (results of the work performed) Outputs will include (1) A proof-of-concept AI model for predictive maintenance with the ability to continuously learn and adapt to ensure it remains effective as new data and technologies emerge; (2) Comprehensive data collecting strategies and test data .sets for combining historical and ongoing data to training and updating the AI agent; (3) New data collection protocol and methodologies for integrating AI in structural health monitoring for optimal preventive maintenance; and (4) Publications and presentations at relevant conferences.

Outcomes/Impacts: The application of this project's outputs will enhance infrastructure management through the partnership of AI and human experts, leading to improved safety, reliability, and cost-efficiency in transportation systems. Long-term benefits include extended asset life spans and reduced environmental impact due to optimized maintenance interventions. The impacts of this project will profoundly contribute to enhancing the safety, reliability, and cost-efficiency of maintenance of transportation systems in marine environments, thereby extending the lifespan of these vital infrastructures. This advancement will not only align with the USDOT's strategic goals of boosting economic strength and global competitiveness but also has the potential to be adapted for maintenance practices across various systems. Furthermore, the project is set to contribute significantly to climate and sustainability objectives by fostering the adoption of more resource-efficient maintenance practices, setting a new standard in infrastructure management.

Technology Transfer Activities: Planned activities include workshops with industry stakeholders, publications in peer-reviewed journals, and presentations at international conferences. Additionally, a web portal will be developed to share project findings with the broader transportation community.

Final Research Report: Upon completion of the project, a URL link to final report will be provided

Project Deliverables: ☒ PI agrees to submit all deliverables within 4 weeks after the project end date.

Data Management Plan (DMP): ☒ PI has reviewed and agrees to adhere to MarTREC DMP. Proposed project DMP must be attached to the submission email along with this form.

Center Director Approval Signature and Date:  07.15.24