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Resilience-Based Emergency Bridge Inspection Routing and Repair Scheduling under Uncertainty

Authors : Zhenyu Zhang, Hsi-Hsien Wei

Abstract : Highway network systems play a vital role in disaster response for disaster-damaged areas. Damaged bridges in such network systems can impede disaster response by disrupting transportation of rescue teams or humanitarian supplies. Therefore, emergency inspection and repair of bridges to quickly collect damage information of bridges and recover the functionality of highway networks is of paramount importance to disaster response. A widely used measure of a network's capability to recover from disasters is resilience. To enhance highway network resilience, plenty of studies have developed various repair scheduling methods for the prioritization of bridge-repair tasks. These methods assume that repair activities are performed after the damage to a highway network is fully understood via inspection, although inspecting all bridges in a regional highway network may take days, leading to the significant delay in repairing bridges. In reality, emergency repair activities can be commenced as soon as the damage data of some bridges that are crucial to emergency response are obtained. Given that emergency bridge inspection and repair (EBIR) activities are executed simultaneously in the response phase, the real-time interactions between these activities can occur – the blockage of highways due to repair activities can affect inspection routes which in turn have an impact on emergency repair scheduling by providing real-time information on bridge damages. However, the impact of such interactions on the optimal emergency inspection routes (EIR) and emergency repair schedules (ERS) has not been discussed in prior studies. To overcome the aforementioned deficiencies, this study develops a routing and scheduling model for EBIR while accounting for real-time inspection-repair interactions to maximize highway network resilience. A stochastic, time-dependent integer program is proposed for the complex and real-time interacting EBIR problem given multiple inspection and repair teams at locations as set post-disaster. A hybrid genetic algorithm that integrates a heuristic approach into a traditional genetic algorithm to accelerate the evolution process is developed. Computational tests are performed using data from the 2008 Wenchuan earthquake, based on a regional highway network in Sichuan, China, consisting of 168 highway bridges on 36 highways connecting 25 cities/towns. The results show that the simultaneous implementation of bridge inspection and repair activities can significantly improve the highway network resilience. Moreover, the deployment of inspection and repair teams should match each other, and the network resilience will not be improved once the unilateral increase in inspection teams or repair teams exceeds a certain level. This study contributes to both knowledge and practice. First, the developed mathematical model makes it possible for capturing the impact of real-time inspection-repair interactions on inspection routing and repair scheduling and efficiently deriving optimal EIR and ERS on a large and complex highway network. Moreover, this study contributes to the organizational dimension of highway network resilience by providing optimal strategies for highway bridge management. With the decision support tool, disaster managers are able to identify the most critical bridges for disaster management and make decisions on proper inspection and repair strategies to improve highway network resilience.

Keywords : disaster management, emergency bridge inspection and repair, highway network, resilience, uncertainty
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