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Multi-scale, Multi-criteria Decision Making for Retrofitting Prioritization of Lifeline Networks

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The complexity of lifeline networks makes it a challenging task to determine which component should be retrofitted with preferences. This is because such decision making problems typically involve multiple conflicting criteria in comparing the preferences for retrofitting network components, which can be termed as "multi-criteria decision making problem." In addition, the complicated network topology makes a decision making process more difficult because the importance of a component varies with its relative location in the network system. Moreover, the importance of one component may not be the same as the other component even though both of them have the same preferences from the component level perspective. Even though a prioritization list is set, the prioritization list could be significantly changed after conducting the retrofitting project for a component with higher preference because of the re-retrofitting effects on the network performance. This is a so-called "network level problem." In this paper, in order to overcome the limitations of existing approaches developed to overcome the aforementioned challenges, a new multi-scale multi-criteria decision making approach for lifeline networks is developed by incorporating the component-level multi-criteria utility theory into the analytical network reliability methods presented in the previous research by the authors. As for the component level, the conflicting criteria such as vulnerability, retrofitting effects, traffic congestion costs and retrofitting costs are synthesized into a "stand-alone" utility for each component by using the multi-criteria utility function. The stand-alone utility for each component is then used for developing another utility by using the network reliability analysis methodology, which is called the CPIM (Component Probability based Importance Measure) utility with consideration of the component's connectivity or importance in the network topology. The selective recursive decomposition algorithm (S-RDA; Lim and Song, 2012) and the clustering-based multi-scale analysis approach (Lim et al., In print) are used to calculate the CPIM utilities of components. A binary integer programming subject to a budgetary constraint is applied to select a set of retrofitting project candidates, which maximizes the summation of their CPIM utilities under the budgetary constraint. Next, the single project with the most CPIM utility among them should be chosen and the process should then be repeated using the updated CPIM utilities with a new stand-alone utility for the selected component (i.e., set to zero because of the lowest preference for retrofitting) until the available budget is exhausted because of the re-retrofitting effects, i.e., a retrofitted component may affect the preferences of the other components in the network. The accuracy and efficiency of the proposed approach are demonstrated by numerical examples of a hypothetical network, the gas transmission pipeline network of Shelby County in Tennessee, USA, and the main water transmission pipeline network of Shelby County in Tennessee, USA, and Sejong city in South Korea for assumed earthquake hazard scenarios.

Keywords: Decision making, lifeline network, multi-scale analysis, network reliability, retrofitting prioritization, utility theory.

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