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Enhancing the Resilience of Combat System-Of-Systems Under Certainty and Uncertainty: Two-Phase Resilience Optimization Model and Deep Reinforcement Learning-Based Recovery Optimization Method

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Abstract : A combat system-of-systems (CSoS) comprises various types of functional combat entities that interact to meet corresponding task requirements in the present and future. Enhancing the resilience of CSoS holds significant military value in optimizing the operational planning process, improving military survivability, and ensuring the successful completion of operational tasks. Accordingly, this research proposes an integrated framework called CSoS resilience enhancement (CSoSRE) to enhance the resilience of CSoS from a recovery perspective. Specifically, this research presents a two-phase resilience optimization model to define a resilience optimization objective for CSoS. This model considers not only task baseline, recovery cost, and recovery time limit but also the characteristics of emergency recovery and comprehensive recovery. Moreover, the research extends it from the deterministic case to the stochastic case to describe the uncertainty in the recovery process. Based on this, a resilience-oriented recovery optimization method based on deep reinforcement learning (RRODRL) is proposed to determine a set of entities requiring restoration and their recovery sequence, thereby enhancing the resilience of CSoS. This method improves the deep Q-learning algorithm by designing a discount factor that adapts to changes in CSoS state at different phases, simultaneously considering the network's structural and functional characteristics within CSoS. Finally, extensive experiments are conducted to test the feasibility, effectiveness and superiority of the proposed framework. The obtained results offer useful insights for guiding operational recovery activity and designing a more resilient CSoS.

Keywords : combat system-of-systems, resilience optimization model, recovery optimization method, deep reinforcement learning, certainty and uncertainty
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