Optimal Control Policies for the Recovery of Socio-physical Systems

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Abstract

Disasters often cause significant damage to infrastructure systems and result in displacement of communities. Recovery after such events becomes complicated due to the presence of various interdependencies. For example, there are dependencies that are present between various types of infrastructure systems. Similarly, a displaced social group may decide to return after a disaster only when a sufficiently large number of groups in its social network return and certain infrastructure components in its neighborhood are repaired. In addition, there could be constraints on the availability of resources and manpower for recovery after disasters. The recovery decisions in such resource-constrained scenarios are often guided by practitioner knowledge, experience, and convention. Therefore, it is important to develop policies that can be efficiently implemented for optimal recovery of such systems.

In this dissertation, a mathematical abstraction of the above recovery problem is considered. Since the number of possible recovery strategies under such scenarios grows exponentially fast as the number of damaged infrastructure components increases, it is intractable to enumerate all possible solutions to find the optimal strategy. In addition, existing computational frameworks like integer programming and dynamic programming become computationally burdensome as the size of the problem increases. Therefore, this dissertation focuses on rigorously characterizing optimal and near-optimal policies for the recovery of socio-physical systems. First, we focus on the recovery of infrastructure components that face accelerated deterioration after disasters due to processes such as floods and corrosion. For the scenario when there is a single repair agency, it is proved that the optimal policy is to target the healthiest component at each time-step when the deterioration rate is larger than the repair rate whereas the optimal policy is to target the least healthy component at each time-step when the repair rate is sufficiently larger than deterioration rate. Next, various extensions of this problem involving heterogeneity in the deterioration and repair rates as well as weights across components, dependencies between components, and multiple repair agencies are considered. It is shown that the characterized policies depend on the relationship between the deterioration and repair rates for all these cases. After that, the problem of maximizing the number of displaced social groups that return, while addressing the repair of infrastructure components, is considered. Optimal and near-optimal policies are characterized for various cases of this problem as well.

Finally, we provide greedy heuristics (motivated by the above optimal policies) and other computational methods to solve cases of the problem for which optimal policies are not currently known.