Optimization of temporary and demountable flood protection strategies for resilient infrastructure systems

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Abstract

Infrastructure systems deliver critical services. Extreme weather events, particularly flooding, can severely disrupt these services. Temporary and demountable flood protection (TDFP) offers a flexible way to safeguard individual infrastructure assets, especially where permanent defenses are impractical. Due to budget constraints, TDFP are typically stored centrally and deployed to multiple infrastructure assets, making warehouse location a critical factor in minimizing costs and maximizing coverage. To address this complex spatial challenge, a Spatial Resource Allocation Optimization (SRAO) framework using a Genetic Algorithm has been developed and tested in the Humber Estuary, UK. The SRAO identifies optimal deployment strategies across various scenarios, achieving up to 50% cost savings and significantly reducing deployment times. It also highlights eight robust "hotspot" warehouse locations that perform consistently well despite model uncertainties. This approach offers immediate value to local authorities, infrastructure operators, and emergency planners—enhancing flood resilience while reducing financial burdens for the communities they serve.

Keywords: spatial optimization; emergency management; resilient infrastructure; temporary flood protection

Introduction

Infrastructure networks—such as power, telecoms, transport, water, finance, and emergency services—are vital to society (Dawson et al., 2018). Flood management often prioritises protecting people, yet damage to infrastructure can disrupt essential services for hundreds of thousands beyond the flood zone (Arrighi et al., 2021; and Merz et al., 2021). Resilient systems anticipate shocks and improve recovery, making investments in resilience more cost-effective and sustainable (Baral and Shahandashti, 2022).

Permanent flood protection for all assets is rarely feasible. Temporary and demountable flood protection (TDFP) offers a flexible, lower-cost alternative (Booth and Gleed, 2024), but presents logistical challenges: it requires advance warning, is bulky to store and transport, and infrastructure assets are widely dispersed with access routes prone to flooding. These constraints create trade-offs for decision-makers, who must balance cost, coverage, and deployment speed to minimise disruption. Strategic planning is essential to optimise resilience and ensure critical services remain operational during flood events.

Spatial Resource Allocation Optimization

To address this combinatorial problem, a Spatial Resource Allocation Optimization (SRAO) framework has been developed. Initially applied to optimize health resources (Lopane et al., 2023) it has been adapted for infrastructure resilience.

The SRAO comprises six key components: (1) The algorithm first processes input data and generate an initial population of potential solutions. The Iterator (2) includes three components: (2a) Three genetic mechanisms of selection, crossover, and mutation to efficiently explore and evaluate the parameter space; (2b) Problem-specific limitations and rules that ensure only feasible solutions are retained; and, (2c) at each iteration the set of non-dominated solutions, the Multi-Objective Pareto Optimal (MOPO) set is updated and stored. In the final phase (3) the SRAO returns a set of optimal solutions as the result of the search process.

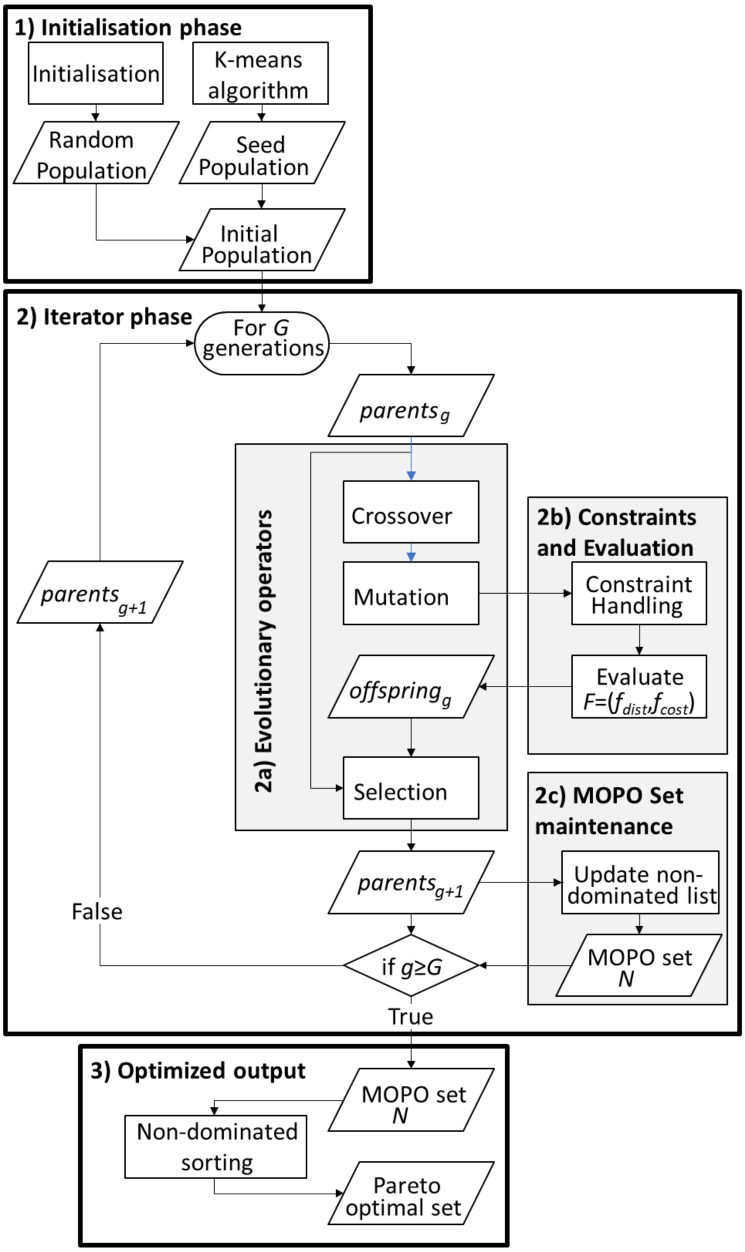

Figure 1. Overview of the Spatial Resource Allocation Optimization framework.

Case Study

The SRAO framework is applied to the Humber Estuary, on the East coast of England. Over 400,000 people live in the region, which also contains 133 strategic infrastructure assets.

The objective of deploying TDFP is to maximise the speed with which it can be deployed at the lowest cost. Here this is achieved through two fitness functions, f, which seek to minimise the time of travel from the storage site(s) to the infrastructure asset(s), f_{dist}, and to minimise the cost of the TDFP storage, f_{cost}. Travel time, f_{dist}, is calculated on the basis of the time taken to travel along the route between the warehouse and infrastructure asset, and the number of lorries available to each warehouse. Travel time therefore increases with fewer warehouses or fewer lorries. The cost, f_{cost}, incorporates the cost of building and operating a warehouse, including personnel costs, fleet costs, and maintenance costs (Ramos, 2017, Mishra, 2021).

A large number of scenarios and assumptions have been tested. These include varying the number of warehouses across the region; the availability of land for development; the number of lorries available at each warehouse to transport TDFP to infrastructure sites; prioritizing infrastructure on the basis of customers served; budget constraints.

Key findings

Figure 2 shows an indicative set of results for a scenario. Analysis of a wide range of scenarios and strategies shows that TDFP offers flexible flood defence for infrastructure assets, especially where permanent solutions or on-site storage are impractical. Shared storage sites that protect multiple infrastructure locations reduce costs but increase deployment time and risk greater disruption from flooding.

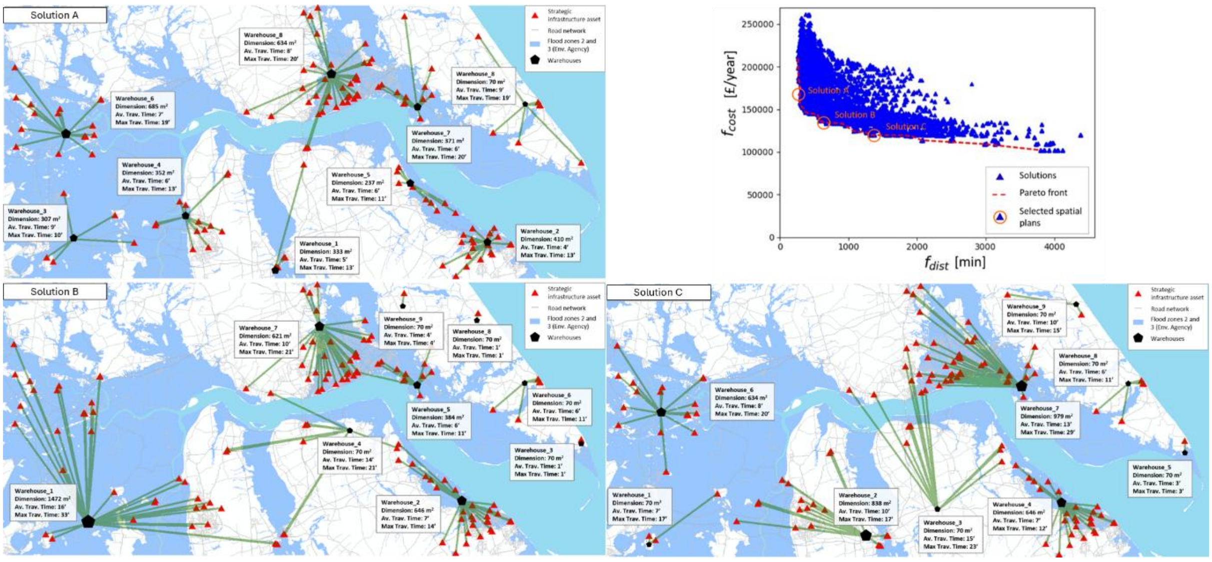

Figure 2. Indicative result for a scenario where each warehouse has one lorry available to it, and all infrastructure sites are weighted with equal importance. Three solutions from the pareto front are visualized showing proposed warehouse sites, their size and assets they cover.

The SRAO identifies strategies that halve costs and cut deployment time tenfold. For scenarios where budgets are critically constrained, limiting the number of assets that can be protected, between 20–37% of people remain susceptible to infrastructure disruption. Analysis of all scenarios demonstrated that eight warehouse locations consistently performed well, demonstrating the ability to identify strategies that are robust to a wide range of assumptions and future conditions.

Future improvements to the SRAO will consider the implications of differential hazards, the dynamics of transport behavior (e.g. using Pregnolato et al., 2016), and incorporation of other costs, impacts and scenarios. Moreover, as decisions on the allocation of flood protection are often taken at national scale further work will also increase the spatial scale of the study.

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