ABSTRACT

Compound crises, such as a major hurricane unfolding amid a contagious disease outbreak, force emergency managers to pursue two imperatives that usually pull in opposite directions: clear the threatened area as fast as possible and keep evacuees sufficiently dispersed to suppress pathogen transmission. Traditional "fastest-clearance" plans overload critical corridors and pack shelters, while purely health-protective strategies impose distancing rules that lengthen travel times and can leave late-departing households exposed to wind, surge, or debris. The absence of decision tools that can reconcile these conflicts has been amplified by the COVID-19 experience, especially in coastal counties where shelter stock is limited, and vulnerable residents constitute a large share of the population. This dissertation responds by designing, analyzing, and testing two optimization frameworks that embed pandemic constraints directly into large-scale evacuation logistics.

The first contribution is the Emergency Evacuation Planning Under Pandemic Situation (EEPPS) model, a mixed-integer bi-objective formulation that jointly (I) minimizes total person-hours spent on the network and (II) minimizes virus-exposure risk, proxied by the aggregate deviation of individual shelter occupancies from the system mean. Both objectives are enforced through time-dependent road capacities, shelter-specific infection-risk weights, and adjustable occupancy ceilings, producing a model that remains faithful to public-health guidelines without discarding the engineering goal of rapid clearance. Because exact ε-constraint methods struggle once evacuee numbers, route choices, and shelter options exceed modest thresholds, a tailor-made Decomposition-based ε-Constraint (DECON) algorithm is devised. DECON sorts evacuees by unit travel time, partitions them into priority groups, and applies an inner ECON routine to each group while dynamically updating residual capacities. Computational experiments on 17 scenarios for Palm Beach County, Florida, ranging from 1 000 to 9 000 evacuees, show that DECON can construct well-distributed nine-point Pareto fronts in under 100 minutes on a desktop workstation; the recommended configuration (Pareto-front size = 9, group size = 350) achieves the best balance between solution density and run time. Sensitivity tests reveal that Pareto-front size, rather than group size, is the dominant driver of computational cost: increasing the front from 5 to 15 points raises average CPU effort by 69 % with negligible gain in trade-off resolution.

The second methodological strand recasts evacuation as a bi-level leader–follower game. At the upper level, planners assign “general-population” vehicles to departure windows, corridors, and either general-purpose or special-needs shelters to minimize system-wide clearance time; at the lower level, medically vulnerable evacuees react by selecting routes and special-needs shelters that minimize perceived infection risk, feeding the resulting capacity adjustments back to the leader. The resulting Bilevel Emergency Planning under Pandemic Conditions (BEPPC) model captures behavioral feedback that single-level formulations overlook. A sequential solution algorithm reaches near-equilibrium for Manatee County test cases of up to 6 000 evacuees in less than seven minutes, with 60 % of solving time consumed by the upper-level assignment stage. Comparative analysis against a fastest-clearance baseline demonstrates that incorporating lower-level behavior can cut shelter-overcrowding deviations while allowing median clearance time.

Across both modelling paradigms, managerial insights are extracted to guide practitioners. For the EEPPS framework, balanced allocations generated without pushing travel times. The preferred group size of 350 individuals, roughly the capacity of a high-school gymnasium, also aligns with typical bus convoys, simplifying field implementation. For the BEPPC game, stable corridor, shelter pairs emerge that absorb demand over a wide range of event severities; reinforcing these “backbone” facilities yields the greatest marginal benefit in joint speed-and-safety objectives. Together, the results provide a quantitative basis for phased departure orders, dynamic shelter opening sequences, and resource pre-positioning strategies tailored to compound hurricane–pandemic contexts.

The dissertation’s broader contributions are threefold. Methodologically, it demonstrates how multi-objective and hierarchical formulations, coupled with problem-specific decomposition, can make previously intractable pandemic-aware evacuation models solvable within operational time frames. Practically, it delivers tested algorithms, benchmark data sets, and parameter recommendations (e.g., ε-step counts, solver tolerances) that local agencies can adopt with minimal adaptation. Conceptually, it reframes evacuation as a public-health supply-chain problem whose ethical dimension, protection of the most medically vulnerable, must be internalized rather than treated as an afterthought.

Although the study focuses on Florida, the frameworks are readily extensible. The optimization engines accept stochastic demand inputs, alternative hazard footprints, and multimodal transport layers; their modular design permits replacement of the inner solver by goal-programming or metaheuristic modules for mega-region instances.