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Multiple-Objective Analysis of Integrated Relief Distribution and Network Restoration in Post-Disaster Humanitarian Logistics – Hazus-based South Carolina (SC) Case Study

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1. ABSTRACT
While several works exist in the pre-disaster operations, there is a clear need for research in post-disaster operations. The poster shows the Multiple-Objective Integrated Response and Recovery (MOIRR) model, which provides an equity- or fairness-based solution for constrained capacity, budget, and resource problems in post-disaster logistics management. Further, a designed experiment for this NP-hard problem is conducted to analyze important aspects of the integrated problem for both small- and large-sized networks: full vs. partial restoration and pooled vs. separate budgeting approaches. Further, the model is applied to a Hazus-based regional case study in South Carolina (SC) based on an earthquake scenario and efficient Pareto frontiers are generated to understand the trade-offs between the objectives of interest.

2. INTRODUCTION
The humanitarian logistics literature can be categorized into the four phases of the disaster management: pre- and post-disaster operations: 1) Mitigation, 2) Preparedness, 3) Response, and 4) Recovery.

According to the World Disaster Report (2012), 6925 disasters took place between 2002 and 2011. More than 1.2 million casualties, over 2.6 billion affected people, and an estimated $1.46 trillion in economic damage are reported. These significant losses motivate the need for humanitarian logistics management.

3. MOIRR MODEL AND COMPLEXITY CLASS
We model the multiple-objective, mixed integer linear programming (MILP) model, which is intended to provide decision-makers with a set of strategic restoration plans for disrupted nodes and areas in a network such that relief items can be equitably supplied to those in need.

Objective functions (1), (3), and (4) can be normalized using a linear normalization technique to allow inter-criteria comparison. This technique converts objectives to a range between 0 and 1 based on ideal and anti-ideal solutions. Then, the weighted objective (non-preemptive) method can be applied.

We can use a reduction technique to show that the MOIRR model reduces to the maximum concurrent flow problem (MCFP) and the multi-commodity integral flow problem (MIFP), which is known to be NP-complete.

4. EXPERIMENTATION

- In order to gain managerial insights into significant model factors, we conduct a full factorial experimental design on three factors at two levels each: restoration type (full and partial), budget spending approach (pooled and separate) and network size (small and large).
- The MOIRR model is modeled in AMPL and analyzed using CPLEX solver.
- 50 test data-sets with different levels of disruption are randomly generated to verify and validate model functionality.

5. INITIAL RESULTS

- Small-sized disrupted network: The percent of satisfied demand (fairness) fluctuates across these data-sets due to the randomness of network disruption. In terms of computation time, partial restoration-based models (scenarios 4 and 6) require higher computational time. Intuitively, this trade-off exists as more variables are required in the partial restoration scenarios.

- Large-sized disrupted network: It is clear that scenarios 3 and 7 that use pooled budgeting provide a much higher percent demand satisfaction than do scenarios 1 and 6 that employ separate budgeting. The pooled budget approach provides flexibility across organizations, given that budget parameters are limited. Further, computation time increases with problem size as expected due to the NP-hard complexity of the MOIRR model.

6. HAZUS METHODOLOGY
The Federal Emergency Management Agency (FEMA) developed the Hazards US Multi-Hazard (Hazus) tool; a geographic information system (GIS)-based natural hazard loss estimation software package that can estimate potential building and infrastructure losses resulting from catastrophic events.

- Given a 5.5 magnitude earthquake in the Columbia, SC metropolitan area, Hazus calculates its output in a risk evaluation module and the resulting Hazus loss data are then used as input to the MOIRR model.
- Six major SC airports are chosen as relief supply points: (a) Charleston, (b) Columbia, (c) Florence, (d) Greenville, (e) Hilton Head, and (f) Myrtle Beach.
- One disrupted relief supply point, 16 disrupted warehouses and 143 demand census tracts were affected by the earthquake.

7. HAZUS RESULTS

- The Figure shows MOIRR results for post-restoration and supply flow decisions.
- (a) five existing and one restored relief port, as well as 31 existing, fully restored and four partially-restored relief warehouses.
- (b) example of flow decisions from the restored Columbus supply port to its relief warehouses.
- (c) example of flow decisions to associated demand points.

8. EFFICIENT (PARETO) FRONTIER ANALYSIS

- Solution trade-offs are developed for two different pairs of objectives: (a) Pair 1 (fairness vs. cost) and (b) Pair 2 (unmet demand vs. cost).
- (a) when more weight is given to the fairness (e.g., w1:w3 = 0.7:0.3), the objective values for fairness and total cost are 72.5% and $1.25 billion, respectively.
- (b) Pair 2 study can be interpreted in a similar way.

9. CONCLUSION AND FUTURE WORK

- We develop a multiple-objective model that integrates the supply distribution problem (response) with the restoration problem (recovery) operations.
- As performance measures in relief operations are not only cost-based, we also consider an equity- or fairness-based solution approach.
- It is clear that partial restoration under pooled (coordinated) budgeting approach provides flexibility when budgets are limited in a highly disrupted network.
- The MOIRR model was applied to a South Carolina-based case study using loss data estimated from FEMA’s GIS-based loss estimation software, Hazus.
- The efficient frontiers are developed to understand the trade-offs between the different objectives of interest.
- Future work includes a goal programming (GP) approach that yields a compromise solution and a multiple objective metaheuristic approach that provides practical, effective solutions to this NP-hard problem in a timely manner.

10. REFERENCE