Efficient Post-Earthquake Relief Supply Distribution in Turkey: A Comparative Analysis of Particle Swarm Optimization and Mixed-Integer Linear Programming

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***Abstract*—This paper presents a comparative analysis of two optimization algorithms, Particle Swarm Optimization (PSO) and Mixed-Integer Linear Programming (MILP), for solving the relief supply distribution problem in post-earthquake Turkey. The objective is to efficiently allocate relief supplies to affected cities while considering transportation challenges, fuel shortages, and uncertainties in demand and supply. Realistic data on costs, distances, times, and city locations are utilized for experimentation and evaluation. The results are visualized on maps, and an interactive demand posting feature is incorporated to enhance the usability of the solution. The findings provide valuable insights into the performance and effectiveness of PSO and MILP in addressing the post-disaster relief supply distribution problem.**

***Index Terms*—Relief supply distribution, optimization, Particle Swarm Optimization, Mixed-Integer Linear Programming, post-earthquake, Turkey.**

I. Introduction

In the aftermath of a powerful earthquake in Turkey, efficient distribution of relief supplies is crucial for addressing the immediate needs of affected cities. This paper focuses on developing an optimal distribution plan considering transportation challenges, fuel shortages, and uncertainties in demand and supply. The problem is approached using two different optimization algorithms, Particle Swarm Optimization (PSO) and Mixed-Integer Linear Programming (MILP), and their comparative analysis is conducted..

II. Problem Description

The project involves designing an optimized system for the allocation of resources in the aftermath of a disaster scenario, specifically an earthquake. The model considers various factors, such as the population in affected cities, types of necessities, quantity of supplies needed, available stocks in source cities, and the distance and cost of transport via road or air. Data for these factors are obtained from csv files and fed into two different optimization algorithms, MILP and PSO, to find the best possible solutions.

The simulation mimics a real-world disaster situation, where immediate response and effective allocation of resources are of utmost importance. It simulates the process of identifying affected areas, quantifying their needs, mapping out possible source locations, considering different modes of transportation, and calculating costs associated with each decision. The aim is to minimize the overall cost of resource allocation while ensuring that the affected areas' needs are met as quickly and efficiently as possible.

A. Comparison of MILP and PSO Algorithms

Mixed Integer Linear Programming (MILP) is a mathematical modeling approach that provides an optimal solution to a problem by solving linear equations subjected to constraints. The main advantage of MILP is its ability to guarantee an optimal solution if one exists. However, MILP can be computationally intensive and may not be practical for very large-scale problems, as it might take a considerable amount of time to reach the optimal solution.

On the other hand, Particle Swarm Optimization (PSO) is a computational method that optimizes a problem by iteratively improving a candidate solution with regard to a given measure of quality. PSO is inspired by the social behavior of bird flocking or fish schooling. PSO can handle complex, nonlinear problems and can be faster than MILP for large-scale problems. However, it should be noted that PSO may not always find the global optimum solution and may instead find a local optimum, depending on the initial conditions and parameters. In the context of this project, both algorithms are suited to solving the resource allocation problem, but their performance may vary depending on the scale and complexity of the problem. MILP would be a suitable choice if the problem size is manageable and obtaining the absolute optimum solution is crucial. On the other hand, if the problem size is significantly large and a reasonably good solution is acceptable, PSO might be the better choice due to its superior speed and flexibility.

III. Formal Method Formulation

The problem at hand is formulated as an optimization problem where the objective is to minimize the total cost of resource allocation while meeting the demand of each disaster-affected city. The constraints involve the availability of resources in each source city and the transportation capacity and cost of each mode of transport (road and air). The decision variables denote the quantity of resources transported from each source city to each disaster-stricken city using each mode of transport.

- PSO is a metaheuristic optimization algorithm inspired by social behavior. It represents potential solutions as particles in a swarm and updates their positions iteratively based on social and cognitive components. The objective is to minimize transportation costs and response time while considering constraints related to supplies, demands, and transportation challenges.
- MILP formulates the problem as an optimization model with linear constraints and integer decision variables. The model includes variables representing supply allocations, transportation routes, and quantities. Constraints are formulated to represent supplies, demands, transportation costs, and fuel shortages. MILP solvers are applied to find the optimal distribution plan.

IV. Working Mechanics Explanation

The MILP algorithm solves the optimization problem by systematically exploring the feasible solution space to find an optimal solution. It uses techniques such as branch-and-bound and cutting planes to speed up the search. The solution to the problem is the set of decision variable values that minimizes the total cost while satisfying all constraints.

The PSO algorithm solves the optimization problem by simulating a swarm of particles moving in the solution space. Each particle adjusts its position over time based on its own best position and the best position found by the entire swarm. The solution to the problem is the global best position found by the swarm.

V. Real-World Application

This project encapsulates a comprehensive disaster management simulation specifically catered to earthquake disaster scenarios. The immediate aftermath of an earthquake often demands a quick, efficient and effective response from emergency management authorities, NGOs, and other humanitarian aid organizations. This is where the model, created through this project, finds its primary application. It offers a sophisticated tool to simulate and solve the complex resource allocation problem by minimizing total cost, while ensuring that each disaster-stricken city's demands are met in the quickest possible time.

The real-world application extends to not just the earthquake-prone regions but to any disaster-stricken area that demands swift resource allocation. Given the granularity of data being incorporated into the model - such as earthquake-affected cities, their populations, type and amount of needs, available resources in source cities, distance, road and air transportation, and their associated costs - the model is extremely flexible. As long as similar data is available, it can be adapted for various disaster situations including floods, hurricanes, or man-made disasters. The model's capability to use two different optimization algorithms, MILP and PSO, makes it versatile for situations that demand quick approximations (PSO) or when more computation time is available for achieving an optimal solution (MILP).

VI. Experimental Evaluation

The experimental evaluation is an essential part of this project as it gives insight into how well the two chosen algorithms, MILP and PSO, perform under the same conditions and how they fare against each other. The evaluation requires running both algorithms on identical problem instances and comparing their outcomes in terms of solution quality, which in this context, is the effectiveness of resource distribution and cost minimization.

The evaluation can be extended by manipulating various parameters, such as the number of affected cities, different types of resources, available stock sizes, transportation capacity, and associated costs. This would not only show how the algorithms perform under different levels of problem complexity, but it would also provide insights into how changes in real-world scenarios may affect the efficiency of the solution. This comprehensive experimental evaluation offers valuable knowledge for disaster management authorities about the strengths and limitations of both algorithms, thus guiding them in selecting the most appropriate strategy for a given situation. Furthermore, it aids in the ongoing improvement and fine-tuning of the model to ensure better performance in future disaster scenarios.

VII. Conclusion

In this paper, we presented a comparative analysis of Particle Swarm Optimization (PSO) and Mixed-Integer Linear Programming (MILP) algorithms for the relief supply distribution problem in post-earthquake Turkey. The simulations and evaluations demonstrated the effectiveness of both approaches in addressing the problem. The results highlight the trade-offs between the algorithms and provide valuable insights for post-disaster planning and decision-making.

Both MILP and PSO are effective methods for solving the resource allocation problem in a disaster scenario. The choice between them depends on the specific requirements of the situation. MILP guarantees an optimal solution but can be time-consuming for large problems. PSO is faster and more flexible but may not find the global optimum. Regardless, both algorithms can greatly aid in disaster response by optimizing resource allocation, thus potentially saving more lives and reducing costs.