Genetic Algorithm-based Optimization Model for Emergency Shelters Location Allocation in Public Health Emergency Situations

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ABSTRACT

Deploying emergency resources after a disaster is crucial for reducing the event's impact. A multi-objective (MO) resource allocation (RA) method is developed to achieve efficient distribution of relief items and the best choice of transportation routes, taking into account the variable and persistent nature of rescue operations. The MO Cellular Genetical Approach (MOC-GA) addresses the concept by incorporating auxiliary populations and neighborhood architecture into the cellular automaton. The comparative experiment conclusively demonstrates that MOC-GA performs favorably compared to Particle Swarm Optimisation (PSO), Ant Colony Optimisation (ACO), and Dragon Fly Optimisation (DFO) in several metrics such as the Pareto Front (PF), hypervolume, mean objective function value, and PF ratios. The findings demonstrate that MOC-GA effectively addresses the MO dynamical emergency RA approach, offering decision-makers a more comprehensive range of superior and diversified candidate rescue strategies than alternative methods. This research analyzes the existing rescue methods and proposes a theoretical rescue strategy to aid decision-makers in making scientifically informed decisions.

1. Introduction

Public health crises have escalated globally in recent decades [1]. Notable emergencies included the SARS epidemic in China in 2003 and the H1N1 flu pandemic that originated in the United States in 2009 and traveled to 214 nations and territories [2]. The H7N9 outbreak in 2013 caused widespread public fear. After the onset of these public health crises, there is typically a shortage of specialized medical facilities and hospital rooms. An illustrative instance of a significant public health crisis is the COVID-19 pandemic that emerged in late 2019 [3]. This outbreak resulted in a severe scarcity of emergency healthcare resources and presented substantial difficulties to the international public health emergency structure due to its rapid spread, wide-ranging infection, and challenging safeguarding and control measures. Hence, the issue of locating and allocating emergency amenities, known as Location-Allocation Problems (LAP), has emerged as a significant research concern in disaster management [13]. An efficient method of medical rescue following an essential public health emergency depends on promptly transporting medical materials and personnel to the affected area using advanced equipment, such as intelligently designed mobile cabin healthcare facilities attached to vehicles or portable cabin healthcare facilities that can be folded [7]. In response to the COVID-19 outbreaks, the Chinese authorities accelerated building more than 20 mobile cabin facilities in Wuhan to prevent the virus from spreading further [4]. As the virus disseminated worldwide, several nations began constructing emergency medical centers. Portable cabin facilities have demonstrated significant use throughout the quarantine period by offering accommodations, testing services, and medical care for those diagnosed or believed to have COVID-19. Timely response to this public health emergency can facilitate the swift recovery of affected individuals, thereby mitigating pandemic-related fatalities and containing the transmission of the virus. Emergencies medical facilities' location-allocation policies have garnered significant attention from education, the administration, and society [5].

Unlike typical commercial transportation, crisis Resource Allocation (RA) focuses on effectively distributing rescue materials and minimizing casualties and damages. Providing a prompt and suitable rescue plan is crucial for allocating emergency resources due to uncertainty and abrupt shifts in the rescue procedure. To prevent delays caused by road damage, it is imperative to acknowledge the unpredictability of the road's accessibility. The primary objective is to achieve the efficient distribution of relief supplies and the rational choice of delivery routes.

Critical RA has emerged as a prominent research area, with the focus shifting from marine disasters to broader large-scale calamities. Mukhopadhyay et al. introduced a methodology for allocating emergency assets in an evolving emergency resource schedule [6]. Wang et al. developed an emergency resources allocation system and distributed various resources to many simultaneous incidents [14]. Idoudi et al. developed a model for allocating resources throughout the evacuation procedure in response to traffic crises [8]. Based on the planned horizon, the study can generally be categorized as either single-period or multi-period. Single-period frameworks cannot consider the inter-temporal effects because they do not consider dynamic shifts and uncertainty accumulating over consecutive periods.

Numerous multi-period theories have been suggested as well. Gharib et al. introduced a dynamic approach for allocating emergency vehicles to be redeployed [9]. Lin et al. introduced a complex model that considers many periods and incorporates the dynamics of migration and RA for post-disaster management [10]. This research proposes a multi-period crisis RA system to address the challenges of ambiguity and tenacity in the rescue procedure.

Most studies on emergency RA consider Multi-Objective (MO) frameworks to reflect the notion of humanitarian logistics. Most researchers have devised a method of either using a single objective or combining many objectives with assigned weights to simplify the resolution of models. More research needs to be focused on optimizing many objectives concurrently. Guo et al. created a MO-based RA method to enhance rescue effectiveness [11]. This model considers cost, transit time, and allocation contentment factors. Lu et al. introduced a MO-optimizing framework that integrates RA with disaster preparedness, considering rescue effectiveness, delay expenses, and justice [12]. This work offers an MO framework for efficient emergency RA and optimal commuting road selection.

Proposed Multi-Objective Cellular Genetical Approach

While numerous MO methods exist, certain ones need help to compromise solution accuracy and diversity effectively. The MO cellular Genetic Algorithm (GA) efficiently adjusts the trade-off between global exploration and local refinement by integrating domain architecture and evolutionary operations. The optimizing process considers both the quality and variety of the ideal solution set. Although the proposed MOC-GA has demonstrated exceptional optimization capabilities, its application in emergency RA issues is uncommon. Thus, to assess the efficacy of MOC-GA in addressing MO crisis RA issues and offering decision-makers a more comprehensive range of superior and varied rescue strategies, this study utilizes and adapts the MOC-GA algorithm.

The MOC-GA algorithm is modified to address the MO crisis RA scenario. MOC-GA defines a solitary cell as an autonomous entity, equips it with the ability to learn independently, and applies evolutionary operations within the local framework of the cellular automata system. To safeguard the survival of the more advanced individuals, MOC-GA utilizes the present-day elite as a supplementary population to produce offspring with their parents.

Fitness computation

The choice variable in the suggested framework $R_{x,y,h,p}$ represents real numbers and signifies the number of emergency resources sent from the Secondary Particle (SP) to the Auxiliary Particle (AP) during period p. It is logical to utilize actual coding to depict the movement of resources during the rescue operation. Every person symbolizes a specific rescue plan involving transporting supplies from SPs to APs at varied time intervals. Every element in MOC-GA appears as $C = \{E_1^1, E_2^1, \cdots, E_h^p, \cdots, E_H^P\}$. The set C is partitioned into H × P sections based on the RA category periods. Each component, $E_h^p = \{r_{1,1,h,p}, r_{1,2,h,p}, \cdots, r_{x,y,h,p}\}$. The formed population is subjected to a quick, non-dominated sorting process to maximize the many objectives. The fitness is assessed based on the hierarchical position of people inside the layers. Due to the dominance of people in the bottom tier over those in the upper layer, they are assigned a more excellent fitness score (F(C)) and are deemed superior beings.

Selection model

To carry out the evolutionary process, persons are chosen independently from the offspring and the AP group. The selection procedure for parenting involves dividing individuals into two-dimensional matrices. The action is then performed within the set S, which consists of the core cell $C_{x,y}$ and its surrounding neighborhood architecture. The chosen probability is denoted as $L_{x,y} = \frac{F(C_{x,y})}{\sum F(C_{x,y})}$. The roulette wheel technique, similar to conventional GA, is used in this case. There is a distinction in that the individuals participating in the roulette are restricted to a set S. The two-dimensional geographic structure of the surrounding area provides population variety.

Sorting model

To maintain a constant population size and identify the best individuals in each successive iteration, selecting the new population of parents and children is essential. The fitness and overcrowding proximity determine the sorting process. Thus, the initial step in the population is to do a fitness assessment operation. The people with the highest fitness reflect the best RA strategies for crisis resources. As individuals within the same stratum are assigned equal fitness values, crowding separation removes similar people and preserves a varied population. The crowding distance is calculated for each group of individuals on different layers. The Pareto Fronts (PF) crowding length is set to 0. The crowding separation for people at the extreme ends of a single level is considered infinite due to their most significantt or lowest functional value. The crowding distance, denoted as $C_x = \sum_{n=0}^{N-1}\{f_n^{x+1} - f_n^{x-1}\}$, is calculated as the sum of the differences across adjacent objective function values for individuals located across both ends of the identical floor. The value of N denotes the total amount of objective processes, and f_n^x , which indicates the nth objective functional value of individual x. The sorting process promotes the selection of superior and distinct persons as parents for the generation, enhancing the overall fitness of all people.

Limited Optimisation Model

The research limits the search range during population initiation to enhance the efficiency of producing viable solutions. This ensures that the first population generated adheres to the given limitations. The research proceeds to formulate a decision-making process concerning limitations. If the persons formed satisfy the limitations, they are brought back as new people; alternatively, they are substituted by the existing ones.

Simulation Outcomes and Findings

The rescue procedure is separated into two phases, with the first phase being dedicated to the heavily affected disaster area. The anticipated inventory requirements and market needs for each period, as well as the distances and potential hazards associated with transit within the network. The variable settings include a cell space size of 12 × 15, a population dimension of 150, 200 repetitions, and a rise from 0.0 to 1.0. The mean hypervolume for every variable is calculated using six separate runs.

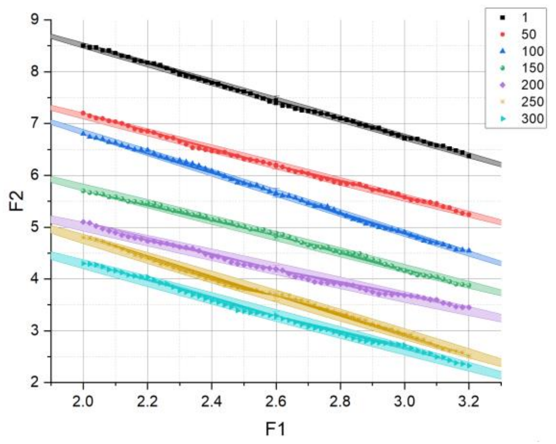

Figure 1. PF analysis of the different models

Figure 1 displays the PFs of MOC-GA at various generations. The findings indicate that the early PFs primarily comprise the optimum PFs. The proposed scheme exhibits an 11% decrease in the mean value of F1, a 30% decrease in the mean value of F2, and a 140% increase in the hypervolume relative to the initial designs. The enhanced optimal strategies have significantly addressed the problem of allocating emergency resources. This demonstrates that the improved RA achieved through MOC-GA enhances emergency rescue capabilities and reduces losses after an emergency.

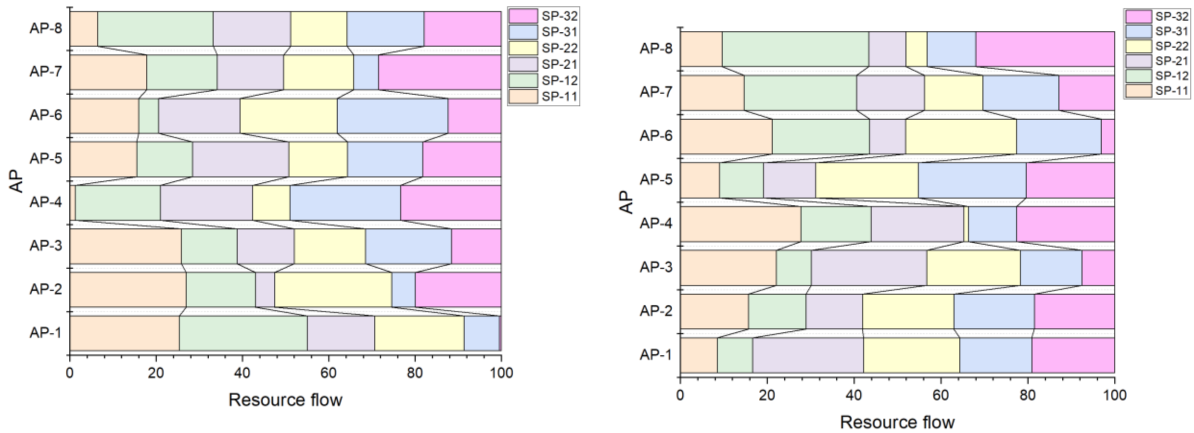

Figure 2. RA analysis of different times (a). T1 (b). T2

The second component is offering instructive perspectives on the most effective rescue strategies. The rescue strategies with F1 values ranging from 2.1 to 2.9 × 110 have been chosen for analysis. Figure 2 displays the statistical data regarding the distribution of emergency supplies from each SP during each period. Findings suggest that during the initial phase, the allocation of resources from SPs is mainly focused on the heavily affected disaster area.

The primary rescue objectives across SPs vary. The SP applies to the heavily affected and general disaster regions. The RA outflows from SPs are more intricate. The flows of various resource kinds from the same service provider vary.

2. Conclusion and future scope

The practical and RA strategies for emergency resources are crucial for the post-disaster recovery procedure. This research develops an MO and multi-period crisis RA framework by considering natural rescue processes' uncertain and persistent nature. The suggested model minimizes disaster losses and evacuation hazards throughout the rescue operation. It achieves this by effectively allocating relief supplies and making sensible choices for transportation paths. The MO cellular genetic code is created to maximize competing MO variables simultaneously. The MOC-GA balances regional and global optimization and generates a set of RA methods that exhibit excellent variation.

The comparison studies show that the proposed model outperforms PSO, ACO, and DFO when dealing with the MO crisis RA scenario. The proposed model exhibits superior reliability and efficiency during the search procedure. The proposed model can offer decision-makers more effective rescue strategies. The sensitivity assessment demonstrates that the supplementary population and the sorting method are crucial components of the proposed model. They not only guarantee the selection of exceptional individuals but maintain the variety of the population during the recruitment procedure. In the future, the research shall consider primary and secondary disasters.

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