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DEVELOPING A HYBRID CONTINUOUS-DISCRETE APPROACH FOR OPTIMIZING MEDICAL LOGISTICS THROUGH TWO-STAGE LOCATION PROBLEM SOLVING

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Optimizing logistics is essential for supply chain management, especially in healthcare. It efficiently distributes medical products efficiently and ensures public health and quick response during crises. Technologies and algorithms, like genetic algorithms for two-stage location problems, improve medical logistics by optimizing facility distribution. This enhances decision-making, speeding up operations and making them more cost-effective.

Metaheuristic algorithms are widely used in research on problems akin to those encountered in medical logistics. In [1], the researchers applied a genetic algorithm to analyze a two-stage transportation issue, focusing on a fixed route cost and the movement of goods. Paper [2] aims to improve spatial planning for public health services through location-allocation and accessibility models. The study seeks to determine the best sites for hospitals and healthcare facilities by considering population needs, accessibility, and closeness to other medical centers. Using Lisbon, Portugal's healthcare system as a case study, the research showed that applying these techniques greatly enhanced the quality and cost-effectiveness of healthcare. Study [3] explores optimizing resource allocation for natural disasters featuring several secondary hazards. It introduces a two-stage stochastic optimization model to replicate scenarios with unpredictable timing and intensity of disasters. More detailed literature review for two-stage location and transportation problems can be found in [4].

During crises, the swift delivery of critical medical supplies (drugs and equipment) to affected populations is crucial. Regions are equipped with subregional centers (SRCs) serving as initial distribution hubs. However, logistical limitations and resource scarcity necessitate the selective activation of these SRCs by authorities. The activated SRCs then forward the supplies to various local distribution centers (DCs), ensuring the populace within their service zones receives the necessary medical items. The primary challenge lies in identifying the optimal SRCs, positioning DCs effectively, and devising an efficient transport plan. This involves minimizing transportation costs while considering factors such as expenses, distance, and capacity constraints at every distribution level.

The illustration for this problem statement is shown in Fig. 1.

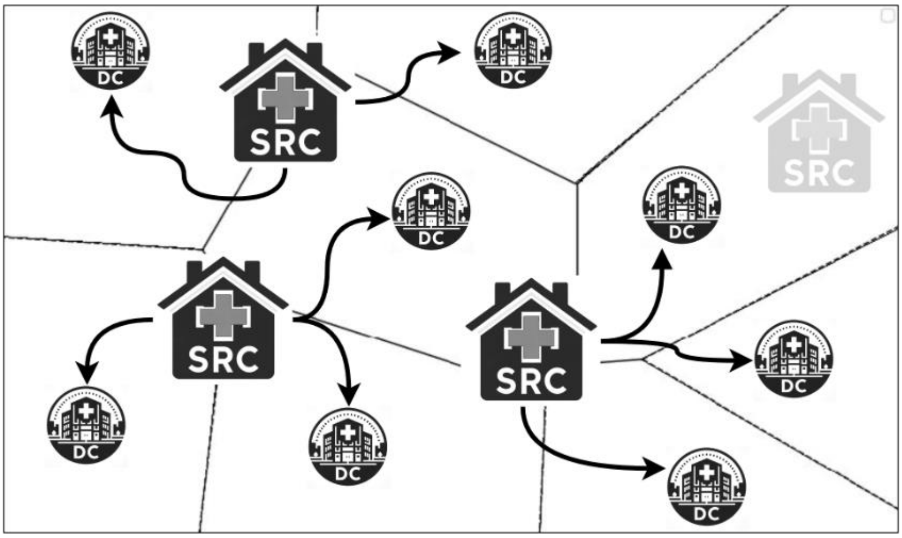

Figure 1 – Visualization of the problem statement

To tackle this problem, we suggest employing a blend of genetic algorithm techniques and optimal set partitioning theory. This approach allows us to segment the resolution of the mentioned problem into two distinct stages.

In the initial stage, we locate distribution centers and define their service areas by solving an optimal set partitioning problem (1) – (3). This stage focuses on initializing the optimization domain, setting up initial conditions like grid and step sizes, and covering the domain with a grid for discrete calculations.

Minimize

$$\sum_{i=1}^{N}\int_{\Omega_i} c_i^I\left(x,\tau_i^I\right)\rho\left(x\right)dx\,, \tag{1}$$

under the following constraints:

$$\bigcup_{i=1}^{N}\Omega_i=\Omega, \tag{2}$$

$$\Omega_i\cap\Omega_j=0, i\neq j, i,j=\overline{1,N}, \tag{3}$$

where Ω – the area of final second-stage consumers; N, M – number of distribution and subregional centers, respectfully; c – transportation fees for a unit of weights (where an additional index corresponds to the specific stage); $\tau_i^r=\left(\tau_{i1}^r,\tau_{i2}^r\right)$ - centers coordinates of different stages; $\rho\left(x\right)$ - known demands.

In the second stage, we address a discrete location problem (4) – (8):

$$\sum_{j=1}^{M}A_j\lambda_j+\sum_{i=1}^{N}\sum_{j=1}^{M}c(\tau_i^I,\tau_j^{II})\lambda_j v_{ij}^I\rightarrow\min\,, \tag{4}$$

under the following constraints:

$$\sum_{j=1}^{M}v_{ij}^I\lambda_j=b_i^*, i=\overline{1,N}\,, \tag{5}$$

$$\sum_{i=1}^{N}v_{ij}^I\leq\lambda_j b_j,\ j=\overline{1,M}, \tag{6}$$

$$\sum_{j=1}^{M}\lambda_j\leq L, \tag{7}$$

$$v_{ij}^I\geq 0,\lambda_j\in\left\{0;1\right\}, i=\overline{1,N}, j=\overline{1,M}, \tag{8}$$

where A – SRCs operation costs; L – limit on maximum SRCs that can be activated; $\tau^I=\left(\tau_1^I,\tau_2^I\ldots\tau_N^I\right)$, $\tau^I\in\Omega^N$ – locations of the DCs obtained as a result of the first stage; b_i^* – determined capacity of DCs: $b_i^*=\int_{\Omega_i}\rho\left(x\right)dx, i=\overline{1,N}$.

Additionally, there is a solvability condition:

$$\int_{\Omega}\rho\left(x\right)dx\leq\sum_{j=1}^{M}b_j\lambda_j\,.$$

We propose a more detailed description of the model in [5]. The algorithm, software implementation and model task are considered in [5] as well.

Conclusion. As a result of the research, we consider problem statements in cases of emergency such as crises, pandemics, and wars. The medical system plays a vital role during those situations. At the first stage, we need to locate distribution centers by solving the optimal set partition problem. At the second stage, we activate subregional centers by solving discrete optimization problem using a modified approach based on genetic theory. We propose a model of the problem, its descriptive problem statement, and a strategy for the solution. On top of that, we developed an algorithm for solving two-stage continuous-discrete location problem and illustrate via model task. The results can be used to enhance the medical logistics system in emergency situations.

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