# Application and Evaluation of Multiple Optimization Algorithms for the Fire Station Relocation Problem


1st Shota Fukuda
*Graduate School of Engineering*
*Kobe University*
1-1 Rokkodai-cho, Nada, Kobe, 657-8501, Japan
fukuda-s@es4.eedept.kobe-u.ac.jp

2nd Takuya Nakata
*Center for Mathematical and Data Sciences*
*Kobe University*
1-1 Rokkodai-cho, Nada, Kobe, 657-8501, Japan
tnakata@bear.kobe-u.ac.jp

3rd Sinan Chen
*Center for Mathematical and Data Sciences*
*Kobe University*
1-1 Rokkodai-cho, Nada, Kobe, 657-8501, Japan
chensinan@gold.kobe-u.ac.jp

4th Sachio Saiki
*School of Data and Innovation*
*Kochi University of Technology*
185 Miyanokuchi, Tosayamada, Kami, Kochi
saiki.sachio@kochi-tech.ac.jp

5th Masahide Nakamura
*Center for Mathematical and Data Sciences*
*Kobe University*
1-1 Rokkodai-cho, Nada, Kobe, 657-8501, Japan
masa-n@cmds.kobe-u.ac.jp



***Abstract*—In recent years, emergency demand in Japan has increased due to the aging population, while the number of fire incidents has declined. Under these circumstances, the demand structure for fire and emergency services is changing, and conventional fire station locations may no longer be suitable, indicating the need for their reassessment. In this study, we aim to support decision-making for fire station relocation. To achieve this, we propose a method to identify the distribution patterns of candidate relocation sites using a search algorithm. In the evaluation experiments, three search algorithms —hill climbing, simulated annealing, and a genetic algorithm— were applied and compared using real-world data from Kobe City, Hyogo Prefecture. The results indicate that the genetic algorithm consistently outperforms the other methods. Furthermore, we demonstrate that visualizing the search results as distributions provides effective decision support for stakeholders.**



***Index Terms*—Optimization problem, Search algorithms, Emergency services, Fire station location planning, Aging society**


## I. Introduction

In recent years, in Japan, demographic changes —particularly population aging— have significantly affected social structures and the demand for public services. In particular, with the increase in the elderly population, demand for emergency transportation has been rising year by year, indicating the need to reassess the sustainability and efficiency of fire and emergency services [1]. Meanwhile, the number of fire incidents has been decreasing over the long term, and the demand structure in fire services is gradually diverging from conventional patterns.

Such changes in the demand structure also affect the deployment of fire stations. Conventional fire station locations have been determined based on past population distributions and fire and emergency demands; however, they are not necessarily optimal under current and future conditions. Since relocating fire stations requires substantial cost and time, it is necessary to make rational and accountable decisions under limited resources. However, when considering relocation sites, multiple factors —including emergency demand, fire demand, population distribution, road networks, and the resources of emergency teams— must be taken into account simultaneously, making manual decision-making difficult. Recent studies (e.g., Liu et al. [2] and Rezvani et al. [3]) have emphasized not only computational rigor but also the practical usefulness of decision support based on real-world urban data.

In this study, we aim to support decision-making for fire station relocation. To achieve this goal, we formulate the fire station relocation problem as an optimization problem and propose a method to identify the distribution patterns of candidate relocation sites using search algorithms. In the proposed method, a two-stage optimization framework is adopted, consisting of an inner problem that evaluates fire station deployments and an outer problem that searches for optimal locations based on the evaluation results. The evaluation metric is defined as the weighted sum of response times to all regions, where population, the number of emergency units, and travel time are used as weights. This framework enables both quantitative evaluation and efficient exploration of fire station deployments.

Previous studies have formulated fire station location and relocation problems as facility location optimization problems, including covering and location-allocation models [9]. These approaches are effective for identifying deployments that optimize predefined objective functions, such as response time or service coverage. More recent studies have incorporated real-world urban data and advanced optimization techniques to improve practical applicability [2], [3]. However, most existing approaches focus on obtaining a single optimal or near-optimal deployment, providing limited support for exploring multiple alternative plans in practical decision-making.

The novelty of this study lies not in identifying a single optimal solution, but in proposing a method that derives and visualizes the spatial distribution patterns of solutions obtained through multiple runs of metaheuristic algorithms. This approach enables flexible, data-driven decision-making while taking into account practical constraints such as land acquisition and budget limitations.

The proposed approach in this study consists of three stages: (A1) quantitative evaluation through an inner problem, (A2) large-scale exploration through an outer problem, and (A3) visualization of the results. In the evaluation experiments, real-world data from Kobe City, Hyogo Prefecture, are used, and through a comparison of hill climbing, simulated annealing, and a genetic algorithm, we verify that the proposed method provides effective support for decision-making.

## II. Preparation

### A. Background

In recent years, Japan has been facing the chronic challenge of a declining birthrate and an aging population. According to the Cabinet Office's White Paper on the Aging Society [4], as of 2024, the population aged 65 and over is 36.24 million, accounting for 29.3% of the total population. These trends are expected to continue, and it is projected that by 2070, the population aged 65 and over will reach approximately 35.00 million, resulting in a society in which one in every 2.6 people is aged 65 or older.

The effects of aging population are observed across various sectors, and emergency transportation services provided by fire departments are one such example. According to the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications [5], the number of emergency dispatches in 2024 reached 7,720,740, representing an increase of 79,753 cases compared to the previous year. Furthermore, as shown in Fig. 1, which presents the composition ratio of transported patients by age group, the proportion of elderly individuals has been increasing, while that of other age groups has been decreasing. These findings suggest that aging population has contributed to the increase in emergency transportation cases, and this trend is expected to continue in the future.

Meanwhile, the number of fire incidents has been on a declining trend. In 2024, the number of fire incidents was 37,141 (a decrease of 1,531 cases, or 4.0%, compared to the previous year). Compared with 43,741 cases in 2014, this represents a decrease to 84.9% [6].

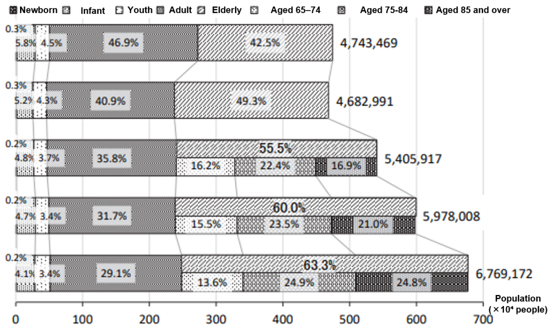


Fig. 1. Trends in proportion of transported patients by age in Japan. [5]

From the above, it can be observed that in Japan, emergency demand is increasing with the progression of population aging, while the number of fire incidents is on a declining trend, indicating that the demand structure for fire and emergency services is changing. Such changes in demand suggest that conventional fire station deployments may not necessarily be optimal under current and future conditions.

### B. Research Objectives

Properly deploying fire stations is crucial, as it directly contributes to reducing emergency response times and mitigating fire damage. However, as discussed in the previous section, ongoing changes in the demand structure—such as increasing emergency demand and decreasing fire demand—suggest that existing fire station deployments may not necessarily be optimal. In fact, the Amagasaki City Fire Department [7] has been reviewing the deployment of fire stations, as well as vehicles and units, in response to changes in demand structure, including a decrease in fire incidents and an increase in rescue cases, with the aim of strengthening firefighting capabilities in the future. Thus, revising fire station deployments is of great importance.

On the other hand, when considering relocation sites for fire stations, it is necessary to take into account multiple factors simultaneously, such as emergency demand, fire demand, geographical conditions, and road networks, as well as guidelines for fire service deployment [8], making the decision-making process highly complex. In addition, once a deployment is determined, it is not easy to modify, and since such changes involve large-scale projects, it is necessary to compare and evaluate multiple deployment plans in advance. However, methods to support such decision-making processes have not yet been sufficiently established.

In this study, we focus on the problem of how to support decision-making in fire station relocation.

### C. Fire Station Relocation Problem

Based on the issues discussed in the previous section, this study defines the problem of determining the relocation sites for an arbitrary number of $n$ fire stations as the Fire Station Relocation Problem, with the aim of supporting decision-making. This problem aims to identify more desirable fire station deployments by evaluating and comparing configurations while taking into account geographical information, population distribution, and road networks. Here, a desirable deployment is defined as one that minimizes the total response time to all regions.

### D. Limitations of Conventional Methods

Various mathematical models have been proposed for the fire station relocation problem [9]. Most of these studies formulate the problem as a facility location optimization problem and seek a deployment that minimizes response time or maximizes service coverage under predefined constraints. However, as discussed in Section Ⅱ.B, real-world relocation planning involves complex interactions among economic constraints such as land acquisition and budget limitations, as well as political, legal, and spatial considerations. Therefore, computationally optimal solutions do not necessarily guarantee practical feasibility. This suggests that pursuing mathematically rigorous optimal solutions does not always directly lead to practically viable decisions. In fact, Marianov et al. pointed out that "political feasibility" is a crucial factor in facility location planning [9]. From the above, conventional mathematical optimization approaches that derive a single solution have limitations in sufficiently supporting flexible decision-making in practice. Such a perspective aligns with recent studies (e.g., Liu et al. [2] and Rezvani et al. [3]), which emphasize the importance of not only computational rigor but also practical decision support based on real-world urban data.

Therefore, unlike conventional approaches that seek a single optimal deployment, this study emphasizes an approach that aggregates multiple high-quality solutions obtained during the search process and visualizes their spatial distribution patterns. By presenting clusters of promising relocation sites rather than a single recommendation, the proposed method enables decision-makers to compare multiple alternatives while considering practical constraints that are difficult to formulate mathematically.

## III. Proposed Method

In this study, we aim to support manual decision-making by computationally deriving candidate relocation sites for fire stations that minimize the total response time to all regions. To achieve this objective, the fire station relocation problem is formulated as an optimization problem, and multiple search algorithms are applied.

The proposed method adopts a two-stage optimization framework consisting of an inner problem that evaluates fire station configurations and an outer problem that searches for relocation sites based on the evaluation results. In the inner problem, given a fire station configuration, the response time for assigned regions is quantitatively calculated, and the total travel time is used as the evaluation score. In the outer problem, using this evaluation score as the objective function,

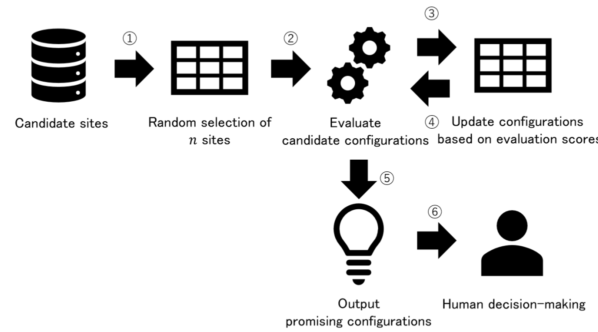


Fig. 2. Overview of the proposed method

the relocation configuration of fire stations that minimizes the total response time is explored using metaheuristic algorithms. The detailed approach is described below, and the overall flow is illustrated in Fig. 2.

- A1: Formulation of the inner problem
  Given a fire station configuration, a mathematical model is constructed to calculate the total response time for all regions by solving the assignment relationship between regions and fire stations as a combinatorial optimization problem.
- A2: Application of search algorithms to the outer problem
  Using the evaluation score obtained in A1, search algorithms are applied to explore better fire station configurations.
- A3: Visualization of results and decision support
  The obtained candidate relocation sites and their evaluation results are visualized to support final decision-making by human operators.

### A. A1: Formulation of the inner problem

In this section, we formulate the inner problem for evaluating fire station configurations. This is because, when treating the fire station relocation problem as an optimization problem, it is necessary to define an evaluation function that quantitatively measures the quality of a given configuration. In this study, the inner problem is formulated as a combinatorial optimization problem. A combinatorial optimization problem is defined as the problem of finding a solution that minimizes (or maximizes) an objective function while satisfying given constraints from a large set of discrete candidates [10].

Specifically, given a fire station configuration, we consider the problem of assigning a responsible fire station to each region. Here, the assignment is determined by optimizing the total response time for all regions, where population, the number of emergency teams, and travel time are incorporated as weights. The resulting minimum value is defined as the **optimal evaluation score** for the given fire station configuration.

The detailed formulation of the inner problem is described below. First, the variables are defined as follows.

- $x_{ij} \in \{0, 1\}$: a binary decision variable indicating whether region $i$ is assigned to fire station $j$ (0: not assigned, 1: assigned)

- $P_i \in \mathbb{N}$: the population of region $i$
- $T_{ij} \in \mathbb{R}$: the travel time between region $i$ and fire station $j$
- $R_j \in \mathbb{N}$: the number of emergency teams at fire station $j$
- $C \in \mathbb{N}$: the population capacity that a single emergency team can handle

Here, $P_i$ is defined under the assumption that emergency demand in each region is proportional to its population. On the other hand, the capacity $C$ of fire station $j$ is calculated by multiplying the maximum number of emergency transports handled by its teams by the ratio of the total number of emergency transports to the total population of the city.

Next, the objective function is defined as in Eq. (1), which minimizes the total response time for all regions. In this study, the value of this objective function is used as an evaluation score representing the quality of a fire station configuration in the outer problem.

$$\min \sum_i \sum_j P_i \, T_{ij} \, x_{ij} \tag{1}$$

Finally, the following two constraints are imposed.

- Each region is assigned to exactly one fire station.
- Each fire station can be assigned regions only within the limits of its available resources.

The former constraint, expressed in Eq. (2), ensures that each region is assigned to exactly one fire station, thereby preventing assignment to multiple stations or to none. The latter constraint, expressed in Eq. (3), is introduced to prevent excessive load concentration on specific fire stations. Specifically, the total population assigned to fire station $j$ is constrained to be less than or equal to the capacity determined by the number of emergency teams at that station.

$$\sum_j x_{ij} = 1 \quad (\forall i) \tag{2}$$

$$\sum_i P_i \, x_{ij} \leq C \, R_j \quad (\forall j) \tag{3}$$

*B. A2: Application of search algorithms to the outer problem*

In this section, we describe the outer problem, which explores optimal fire station configurations using the evaluation score obtained in A1. Metaheuristic methods are employed for the search, for two main reasons.

First, the problem is a discrete combinatorial optimization problem with a vast search space, and it is necessary to obtain solutions within a practically acceptable computation time. Second, this approach allows us to consider the "political feasibility" emphasized in this study. Rather than pursuing a single exact solution as in existing studies, we aim to explore a wide range of sufficiently good solutions, thereby providing flexible options that can accommodate real-world constraints.

As metaheuristic approaches, three methods—hill climbing, simulated annealing, and a genetic algorithm—are applied, each aiming to minimize the evaluation function. The reasons for selecting these methods are as follows.

- Hill climbing: It has extremely low computational cost and enables rapid identification of local improvement trends.
- Simulated annealing: By allowing probabilistic transitions in the early stage of the search, it avoids being trapped in local optima and enables exploration of a broader range of promising solutions.
- Genetic algorithm: By exploring multiple candidate configurations in parallel and inheriting and exchanging information from high-quality solutions, it demonstrates strong capability in finding stable solutions even under complex constraints.

In the search algorithms used in this study, only the configurations of the fire stations subject to relocation are treated as decision variables. On the other hand, in the inner problem defined in A1, the evaluation considers the entire fire station configuration, including those that are not relocated. This enables a comprehensive evaluation of the overall fire station system.

*1) Application of Hill Climbing:* Hill climbing is a representative local search method and has been widely applied to discrete optimization problems [11]. The basic idea is to iteratively explore neighboring solutions of the current solution and update the solution only when an improvement in the evaluation score is observed, thereby progressively obtaining better solutions.

In this study, the hill climbing method is applied to the problem of placing $n$ fire stations according to the following procedure.

- **Initialization**: An initial configuration is generated by selecting $n$ locations from the set of candidate relocation sites.
- **Generation of neighboring solutions**: A neighboring solution is generated by randomly replacing one location in the current configuration with a nearby candidate site. Here, "neighboring" refers to locations that are geographically close within the predefined set of candidate relocation sites.
- **Solution update**: The current solution and the neighboring solution are evaluated using the objective function defined in A1, and the solution with the smaller evaluation score is adopted as the new solution.
- **Iteration**: The above steps are repeated for a predetermined number of iterations.

Fig. 3 illustrates a conceptual diagram of the hill climbing search for the case of $n = 6$.

*2) Application of Simulated Annealing:* Simulated annealing is a search algorithm that introduces a probabilistic strategy to escape from local optima [12]. Unlike hill climbing, which updates the solution only when an improvement in the evaluation score is observed, simulated annealing accepts worse solutions with a certain probability. This mechanism maintains diversity in the search process and aims to obtain globally good solutions.


Fig. 3. Hill Climbing ($n = 6$). ①:Initialization ②:Generation of neighboring solutions ③:Solution update by selecting the better one ④:Iteration

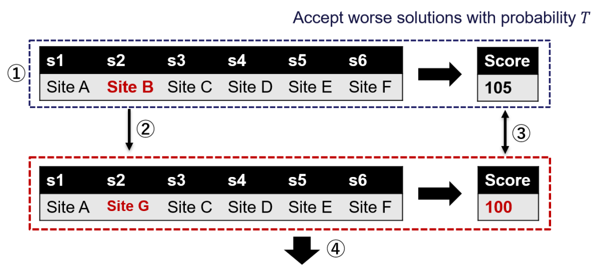


Fig. 4. Simulated Annealing($n = 6$) ①:Initialization ②:Generation of neighboring solutions ③:Solution update: A better solution is always accepted, while a worse solution is accepted with a certain probability ④:Iteration

In this study, the same neighborhood structure as in hill climbing is used, and simulated annealing is applied according to the following procedure.

- **Initialization**: An initial configuration is generated by selecting $n$ locations from the set of candidate relocation sites.
- **Generation of neighboring solutions**: A neighboring solution is generated by randomly replacing one location in the current configuration with a nearby candidate site.
- **Solution update**: The current solution and the neighboring solution are evaluated using the objective function defined in A1. If the evaluation score of the neighboring solution is smaller than that of the current solution, it is always accepted. Otherwise, the neighboring solution is accepted with a probability $T$, even if the evaluation score is worse.
- **Update of probability**: The probability $T$ is updated by multiplying it by a decay rate $\alpha$ $(0 < \alpha < 1)$.
- **Iteration**: The above steps are repeated for a predetermined number of iterations or until the probability $T$ becomes sufficiently small.

Fig. 4 illustrates a conceptual diagram of the simulated annealing search for the case of $n = 6$.

*3) Application of Genetic Algorithm:* Genetic algorithms are characterized by maintaining multiple candidate solutions simultaneously and performing the search through operations such as crossover and mutation [13].

The application procedure of the genetic algorithm in this study is described below. Each individual represents a fire station configuration, and the evaluation score obtained from the inner problem defined in A1 is used as the fitness score.

- **Initialization**: $m$ configurations $S$ are generated as the initial population by randomly selecting $n$ locations from the set of candidate relocation sites $A$ $(m > 3)$. For each configuration, a score $r_m$ is calculated using the evaluation function defined in A1.
- **Selection of parent individuals**: Three individuals are randomly selected from the current population, and the one with the best evaluation score is chosen as the parent individual $p_1$. The second parent individual $p_2$ is selected in the same manner.
- **Crossover**: A crossover operation is applied to the parent individuals $p_1$ and $p_2$ to generate two offspring: $c_1$, which consists of the first half of $p_1$ and the second half of $p_2$, and $c_2$, which consists of the second half of $p_1$ and the first half of $p_2$.
- **Mutation**: For each offspring $c_1$ and $c_2$, one element is randomly selected with probability $T$ and replaced with another candidate site. This operation ensures diversity in the search.
- **Generation of offspring**: By repeating the processes of selection, crossover, and mutation, a total of $m$ new candidate configurations are generated.
- **Generation update**: The generated $m$ configurations are used as the next generation population $S$.

By repeating the above procedure for a predetermined number of generations, configurations with lower evaluation scores—i.e., shorter total response times—are obtained. If duplication or deficiency occurs due to crossover or mutation, corrections are made by randomly selecting locations from the candidate set to ensure that each configuration always consists of $n$ locations.

Fig. 5 illustrates a conceptual diagram of the genetic algorithm search for the case of $n = 6$.

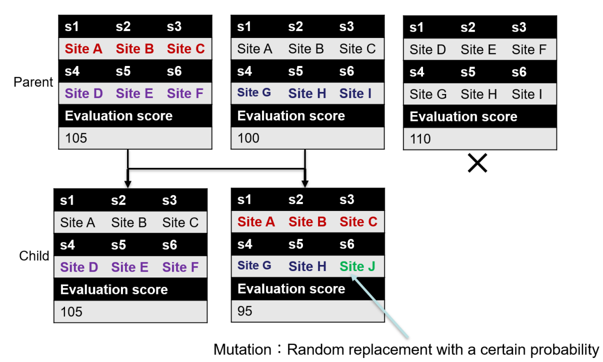


Fig. 5. Genetic Algorithm($n = 6$) Child are generated by combining two high-scoring parent configurations, and mutation is applied by randomly replacing one element with a certain probability.

### C. A3:Visualization and Decision Support

In this section, we describe how decision-making is supported based on the results of fire station configuration searches obtained in Steps A1 and A2.

As discussed in Section Ⅱ.C, this study aims to output the overall trends of promising configurations rather than a single optimal solution. To this end, the search process described in Phase A2 is executed $m$ times.

By aggregating and visualizing the multiple search results obtained, we analyze the selection frequency and spatial distribution of candidate relocation sites, thereby supporting decision-making for fire station configuration.

## IV. Experiments

To evaluate the effectiveness of the proposed method, experiments were conducted using real-world data from Kobe City, Hyogo Prefecture. The research question (RQ) of this study is defined as follows. **Which of the multiple optimization algorithms is most suitable for supporting decision-making regarding fire station placement?**

### A. Experimental Conditions

*1) Target Facilities for Relocation:* The facilities selected for relocation are shown in Fig. 6, which were sampled from the 31 fire stations operated by the Kobe City Fire Department. These six fire stations have relatively aged facilities and are therefore considered likely candidates for reconstruction within a similar time frame. Each point is labeled B1–B6.

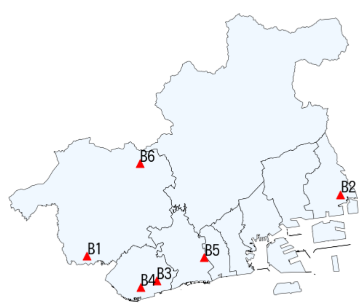


Fig. 6. Locations of the selected fire stations for relocation in Kobe City. Each point is labeled B1–B6.

*2) Definition of Variables:* Region $i$ is defined as one of the 163 elementary school districts in Kobe City. This definition is adopted for the following two reasons.

First, it reduces computational cost and enables the derivation of solutions within a practically acceptable time. It is well known that the computational complexity of the assignment optimization problem defined in A1 increases rapidly as the number of regions grows.

Second, elementary school districts are based on areas within walking distance for children and are therefore considered suitable as decision-making units in disaster prevention and administrative planning.

On the other hand, for candidate relocation sites of fire stations, a more fine-grained spatial analysis is required. Therefore, 789 town-level locations are considered as candidates.

In addition, the population capacity $C$ that a single emergency team can handle is set to 60,000. This value is calculated by multiplying the maximum number of transports that an emergency team can handle by the ratio of the actual number of emergency transports to the total population in Kobe City.

*3) Parameter Settings:* For each search algorithm used in A2, the number of iterations was set such that the evaluation function defined in A1 was executed a total of 500 times. In Simulated Annealing, the initial temperature was set to $T = 100$, and a geometric cooling schedule with $\alpha = 0.98$ was employed.

In addition, for the visualization and analysis described in A3, the search process was executed $m = 10$ times, and the results were aggregated.

### B. Dataset and Implementation Environment

Python was used as the implementation language, and NumPy and PuLP were used as the main libraries. The travel time $T_{ij}$ between region $i$ and fire station $j$ was calculated using the *Google Routes API*. Population data were obtained from the 2023 Kobe City dataset of population by elementary school district.

### C. Results

The three methods—hill climbing, simulated annealing, and the genetic algorithm—were compared from the perspective of which is most suitable for supporting decision-making on fire station relocation. Fig. 7 shows the distribution of solution scores obtained by each method.

From Fig. 7, it can be observed that the genetic algorithm is less likely to output poor solutions (i.e., solutions with high scores) compared to the other methods, and its performance is relatively stable. This implies that the risk of presenting extremely inappropriate solutions as candidates can be reduced in the decision-making process, which is considered a desirable property for decision support.

On the other hand, although simulated annealing has the potential to obtain the best solution, its solution distribution is unstable, which may pose a risk for decision-makers when making confident choices.

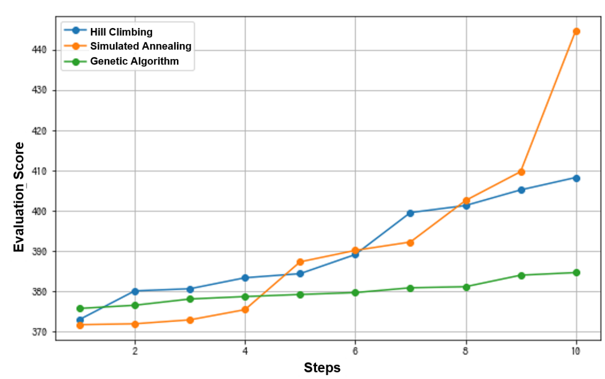


Fig. 7. Comparison of scores for each method. The horizontal axis shows the iteration index, and the vertical axis represents the total response time for all regions. Lower values indicate better solutions.

Next, the results of plotting the coordinates of candidate relocation sites obtained by each search algorithm on a map are shown in Fig. 8, Fig. 9, and Fig. 10, respectively.

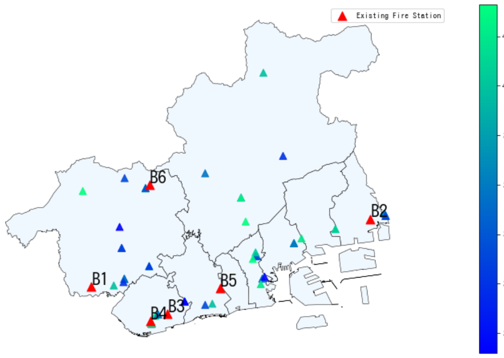


Fig. 8. Results of candidate relocation sites obtained by hill climbing. Each point represents a candidate location, and the color indicates the evaluation score. Red points represent existing fire stations.

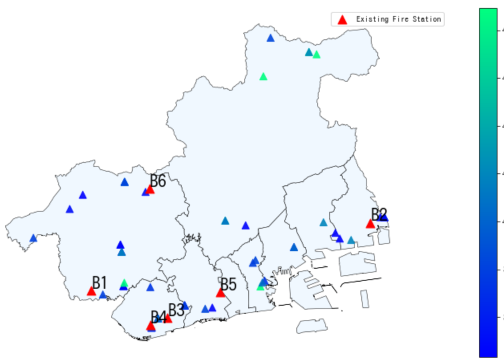


Fig. 9. Results of candidate relocation sites obtained by simulated annealing. Each point represents a candidate location, and the color indicates the evaluation score. Red points represent existing fire stations.

From Fig. 8 and Fig. 9, it can be confirmed that the candidate relocation sites obtained by hill climbing and simulated annealing are distributed over a relatively wide area. This suggests that, due to the characteristics of their search processes, these methods tend to generate geographically dispersed candidate solutions.

In contrast, the results of the genetic algorithm shown in Fig. 10 indicate that the candidate relocation sites are concentrated in specific regions, exhibiting a clear spatial distribution pattern compared to the other methods. Such distribution patterns provide useful insights for identifying promising areas for relocation and can serve as valuable information for decision-making support.

For example, the results suggest that B1, B2, B3, B4, and B6 do not necessarily require relocation to distant locations, whereas B5 tends to be relocated toward the eastern.

From these results, it can be concluded that the genetic algorithm not only provides stable numerical performance but also clearly reveals the spatial distribution patterns of candidate relocation sites. By visualizing such distributions, it becomes possible to present multiple promising regions for relocation rather than a single optimal solution, suggesting its effectiveness in supporting decision-makers.

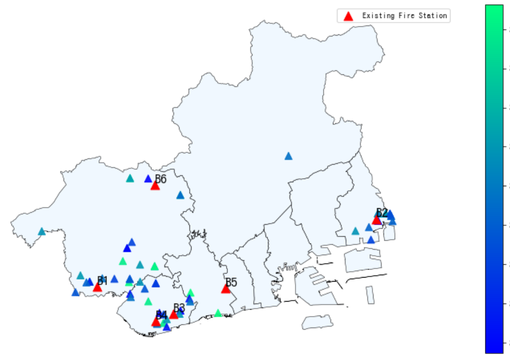


Fig. 10. Results of candidate relocation sites obtained by genetic algorithm. Each point represents a candidate location, and the color indicates the evaluation score. Red points represent existing fire stations.

## V. Discussion

### A. *Advantages of the Proposed Method*

From the results of the evaluation experiments, it was confirmed that the proposed method can support human decision-making by computationally deriving candidate relocation sites for fire stations using the total response time across all regions as the evaluation metric.

In particular, the genetic algorithm consistently obtains high-quality solutions compared to the other search methods. Furthermore, when the results of multiple runs are visualized, clear spatial distribution patterns of candidate relocation sites emerge. These patterns provide useful insights for decision-makers and enhance the interpretability of the results as a decision support tool.

For example, the results suggest that several facilities (B1, B2, B3, B4, and B6) do not necessarily require relocation to distant locations, whereas B5 shows a tendency to shift toward the eastern area. Such location-specific tendencies enable decision-makers to distinguish between facilities that require significant relocation and those that can remain near their current positions, thereby supporting more practical and context-aware decision-making.

Furthermore, unlike conventional facility location approaches that provide only a single recommended deployment, the proposed framework visualizes the spatial distribution of multiple high-quality candidate solutions. Therefore, even if a particular candidate location is found to be impractical due to factors that are difficult to incorporate into the optimization model, such as land availability, legal restrictions, budget limitations, or political considerations, nearby alternatives within the same promising region can still be considered. This flexibility is particularly valuable in real-world relocation planning, where many practical constraints are difficult to formulate mathematically, and enables decision-makers to explore multiple feasible alternatives rather than relying on a single solution.

In this study, population data from 2023 were used; however, the method can be extended to future-oriented planning by incorporating projected population data or demand forecasts. Recent studies have explored long-term forecasting of emergency demand using real-world urban data, including applications to Kobe City (e.g., Kaneda et al. [14]). These approaches suggest that the proposed method can be further extended by incorporating such predictive information.

Therefore, the proposed method can be regarded as an effective approach for supporting evidence-based decision-making in fire station relocation planning.

### B. Limitations of the Proposed Method

The proposed method in this study has several limitations.

First, there are issues related to the representation of emergency demand. In this study, the evaluation is based on the residential (nighttime) population of each region; however, in reality, population distribution varies between daytime and nighttime due to commuting and schooling (daytime population). This discrepancy may not accurately reflect the spatio-temporal dynamics of true emergency demand.

Second, the actual number of emergency dispatches is not directly considered. For example, the probability of emergency incidents is generally higher among elderly populations than younger populations, which may lead to discrepancies between population size and actual emergency demand. Therefore, incorporating an emergency demand model that considers age distribution and historical transport records is an important direction for future work.

## VI. Conclusion

This study focused on how to support decision-making in fire station relocation required by changes in emergency demand and proposed a method to derive the distribution patterns of candidate relocation sites using search algorithms.

Through evaluation experiments using real-world data from Kobe City, multiple search algorithms were compared, and it was shown that the genetic algorithm can stably obtain good solutions for this problem. Furthermore, by visualizing the search results as distributions, it was confirmed that effective decision support for stakeholders can be achieved.

On the other hand, this study has limitations in that it does not sufficiently consider demand population and actual emergency transport data. In the future, by incorporating factors such as age distribution, historical transport records, and demand forecasting, the method can be further developed into a more realistic and practical decision support framework.

In conclusion, the proposed method can serve as an effective approach for supporting decision-making in complex fire station relocation problems and is expected to contribute to the improvement of emergency services in the future.


## Acknowledgment

This research was partially supported by JSPS KAKENHI Grant Numbers JP25H01167, JP25K02946, JP25K24389, JP24K02765, JP24K02774, JP23K17006, JP23K28091, JP23K28383. This research was conducted as part of a collaborative research project with the Kobe City Fire Department.


## References


[1] Fire and Disaster Management Agency, "Report of the Study Group on the Future of Emergency Services in Fiscal Year 2024," 2024. [Online]. Available: https://www.fdma.go.jp/singi_kento/kento/items/post-151/02/houkokusyo.pdf

[2] X. Liu, Y. Chen, and L. Wang, "Optimising Fire Station Layouts to Improve Fire Service Efficiency: A Spatial Machine Learning and Genetic Algorithm Approach," in *Proc. 34th Annual GIS Research UK Conference (GISRUK 2026)*, Apr. 2026.

[3] M. J. Rezvani et al., "Optimizing Emergency Response Efficiency in Urban Road Networks: A Data-Driven Approach for Fire Station Placement and Resource Allocation," *Systems*, vol. 5, no. 3, p. 123, Sep. 2024.

[4] Cabinet Office, "Annual Report on the Aging Society 2025," 2025. [Online]. Available: https://www8.cao.go.jp/kourei/whitepaper/w-2025/zenbun/pdf/1s1s_01.pdf

[5] Fire and Disaster Management Agency, "Current Status of Emergency and Rescue Services 2025," 2025. [Online]. Available: https://www.fdma.go.jp/publication/rescue/items/kkkg_r07_01_kyukyu.pdf

[6] Fire and Disaster Management Agency, "Fire Defense White Paper 2025," 2025. [Online]. Available: https://www.fdma.go.jp/publication/hakusho/r7/items/r7_d1-d6.pdf

[7] Amagasaki Fire Department, "Fire Station Deployment Plan of Amagasaki City," 2025. [Online]. Available: https://www.city.amagasaki.hyogo.jp/_res/projects/default_project/_page_/001/034/481/keikaku.pdf

[8] Fire and Disaster Management Agency, "Guidelines for the Development of Firefighting Capacity," 2008. [Online]. Available: https://www.fdma.go.jp/singi_kento/kento/items/kento134_12_shiryo_09.pdf

[9] V. Marianov and C. ReVelle, "Siting emergency services," in *Facility Location: A Survey of Applications and Methods*, Springer, 1995, pp. 199–223.

[10] S. Tanaka, "Combinatorial Optimization Problems and Scheduling," *Systems, Control and Information*, vol. 64, no. 6, pp. 200–205, 2020, doi:10.11509/isciesci.64.6_200.

[11] A. W. Johnson, "Generalized Hill Climbing Algorithms for Discrete Optimization Problems," Ph.D. dissertation, Virginia Tech, 1996.

[12] J. E. Orosz and S. H. Jacobson, "Analysis of Static Simulated Annealing Algorithms," *Journal of Optimization Theory and Applications*, vol. 115, no. 1, pp. 165–182, 2002.

[13] M. Mitchell, *An Introduction to Genetic Algorithms*. MIT Press, 1998.

[14] Masaki Kaneda,Sinan Chen,Sachio Saiki,Masahide Nakamura, "Long-Term Fine-grained Forecasts of Emergency Demand Using EMS Big Data and Regional Mesh Population Estimates,"In Proceedings of 22nd IEEE/ACIS International Conference on Software pp.212-217, July 2024.