IOSR Journal of Business and Management (IOSR-JBM)
e-ISSN: 2278-487X, p-ISSN: 2319-7668. Volume 22, Issue 2. Ser. I (February. 2020), PP 06-11
www.iosrjournals.org

Hierarchical Location of Urban Emergency Shelters under Multi-Flow Pattern

Xiang-Jun Zhang, Ying-Ying Liu*
(School of Management, Shanghai University, Shanghai 200444, China)
(School of Management, Shanghai University, Shanghai 200444, China)
**Corresponding Author: Ying-Ying Liu*

Abstract:*According to the typical hierarchical structure of urban emergency shelters as well as the pattern of population transfer among these shelters, ahierarchical location model for urban emergency shelters under multi-flow pattern is formulated in this paper. Differing from the single-flow pattern, in which the affected population must be transferredfrom low-level to high-levelshelters step by step to obtain the corresponding services, the multi-flow pattern allows the affected population to get low-level services directly from high-level shelters. The proposed model is an extension of the traditional single-flow hierarchical location model, and it is more in line with the realistic situation of emergency shelters location. Moreover, it illustrated by theoretical and case analysis that the location solution obtained under multi-flow pattern not only ensures the effect of asylum but also saves resources and costs.*

Keywords: *emergencyshelter,hierarchicalstructure,multi-flow pattern,hierarchical location*

Date of Submission: 21-01-2020 Date of Acceptance: 11-02-2020

I. Introduction

Along with the social development and urbanization, the scale and population of many cities are continuously expanding, and meanwhile, the risk of suffering from various disasters are also increasingly magnified. It has become an urgent task in urban management to reinforce urban disaster management and strengthen the ability of disaster resistance and emergency rescue. The construction of emergency evacuation sites as well as practicing the notion of disaster prevention and mitigationbecomes an effective measure to strengthen the urban disaster management.

The planning and location of emergency shelters have attracted great attention during the last few decades. For instance, Liu et al.[1]analyzed the principle of emergency shelter selection comprehensively based on the Wenchuan earthquake. Li et al.[2] took the earthquake as an example, and built a two-stage optimization model considering the number of victims after the earthquake. Hallak et al.[3] considered various humanitarian factorscomprehensively based on Syrian crisis in 2011, and built a mixed integer weighted goal planning model finally. Kınay et al.[4] formulated a chance constrained model for the shelter site location problem. Recently, Ozbay e et al.[5] constructed a three-stage stochastic mixed integer programming model based on a variety of disaster situations when considering the uncertainty of the people seeking refuge. Besides the studies on emergency shelters for earthquake, the location of other emergency facilities (e.g., fire station[6, 7] and emergency medical service[8, 9]) as well as the recently developed new methods for location analysis[10, 11] also provide sound theoretical basis for the emergency shelter planning.

Although the location and layout of emergency evacuation sites have been studied by scholars more and more in-depth, these studies mainly analyze the location problem at the same level, and the hierarchy in the entire emergency system as well as the population mobility between different evacuation facilities and collaborative management is not fully considered. In a typical hierarchical service facility structure[12, 13], higher-level service facilities can mostly cover the services provided by lower-level facilities, and every facility needs to be effectively connected and coordinated. For urban emergency shelters, Chen et al.[14, 15] proposed three levels of emergency shelters through the analysis of the level of emergency shelter demand, and constructed a three-level location model under the single flow mode from temporary to short-term to medium and long-term emergency shelters.

According to the pattern of population transfer among these shelters, it can be divided into single-flow pattern and multi-flow pattern[16]. In the single-flow pattern, residents can only choose temporary shelters when disaster occurs and then move upwards layer by layer. However, it usually is not appropriate with the actual situation. In the hierarchical emergency system, since the higher-level facility services can cover the services provided by lower-level facilities, all shelters will be open to the public to provide emergency evacuation services when an emergency occurs. Residents will also choose nearby shelters, and then they will be transferred according to the subsequent needs instead of strictly moving from low-level to high-level of single-pattern, which forms the so-called multi-flow pattern.

Therefore, based on the typical hierarchical structure characteristics of urban emergency shelters and the actual flow pattern of the disaster-stricken population at the time of the disaster, this paper built a multi-level model of urban emergency shelters under multi-flow pattern. Because of the multi-flow pattern allows the affected people to obtain low-level functional services from high-level shelters directly which including the special case ofsingle-flowpattern, this model is a general extension of the hierarchical location model under the traditional single-flowpattern, and also more suitable for the layout requirements of the actual emergency shelter location. The effectiveness of the proposed model in our paper is proved through theoretical and case analysis. Meanwhile, we compare the location model of emergency shelters of the single-flow pattern and multi-flow pattern, the result shows that the multi-flow location scheme can not only ensure the effect of refuge, but also save resources and costs.

The rest of this paper is organized as follows. First, the problem description is given in Section II. Then, the problem is formulated as a mathematical programming in Section III. Subsequently, Section IV presents a Case analysis. Finally, conclusion is given in Section V.

II. Problem description

According to China's national standard "earthquake emergency shelter: site and supporting facilities" (gb21734-2008) as well as local standards and construction specifications of provinces and cities, the urban emergency shelter is generally divided into three levels: temporary emergency shelter (level III), short-term shelter (level II) and middle-long-term shelter (level I). Furthermore, the functions and services provided by the high-level emergency shelters contain those provided by low-level shelters. Based on this, this paper studies the three-level structure of the emergency shelter. The residents' demand for shelter and the corresponding hierarchical relationship of the emergency shelter are shown in Figure 1.

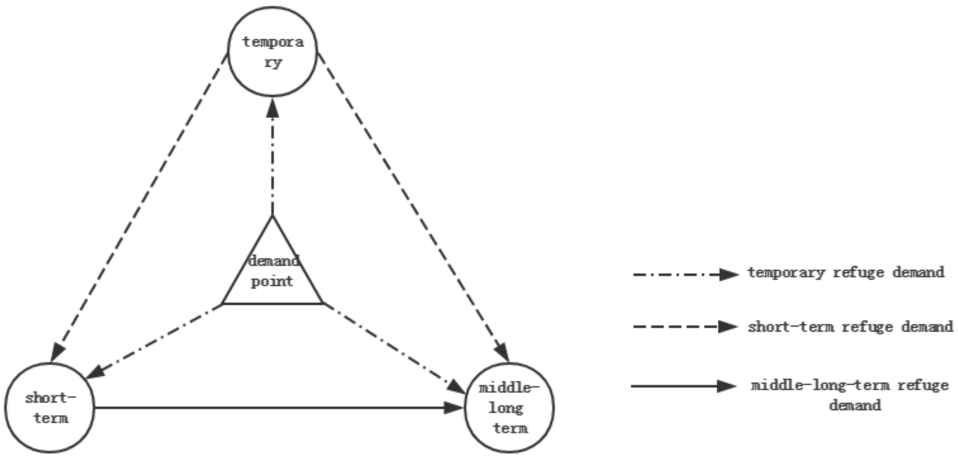

Figure 1. The relationship between refuge demands and emergency shelters

The multi-flow pattern of the affected population between different shelters allows the affected population to obtain the low-level functional services directly from the high-level shelters, that is,after the disaster, the affected people first obtain the temporary shelter services in any adjacent shelters, and then the affected people in the temporary shelters transfer to the short-term or middle-long-term shelters according to the needs of the shelters to obtain the corresponding services.At last, the people in the short-term shelters will transfer to the middle-long-term shelters according to their needs to obtain higher-level services. The flow relationship is shown in Figure 2.

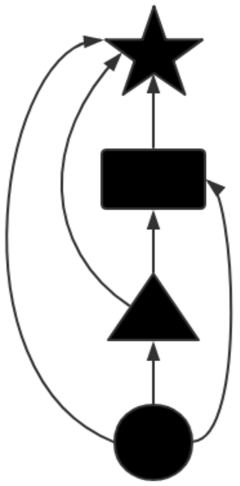

Figure 2. Multi-flow pattern

In order to ensure that urban residents can evacuate in time and safely when disaster occurs, the city should plan and build corresponding emergency shelters reasonably. At the same time, the construction, maintenance and operation of emergency shelters also require a lot of resources,so it is necessary to balance the relationship between the social benefit and the economic cost of emergency shelter to reduce the waste of resources caused by excessive construction.Consequently, our paper aims to minimize the total construction costs while ensuring emergency requirements.

III. Model formulation

To formulate the problem, the relevant parameters and variables are defined as follows:

$I = \{i|i = 1,2, \dots, n\}$: Set of demand points;

$A = \{j|j = 1,2, \dots, m\}$: Set of potential sites of emergency shelters;

$T = \{t|t = 1,2,3\}$: The service level that emergency sheltercan provide;and 1, 2, 3 represent temporary refuge services, short-term refuge services, middle-long-term refuge services respectively;

c_i: The number of affected populationin demand point i (all of them require temporaryemergency evacuation);

α: Proportion of the affected population that require short-term refuge services;

β: Proportion of short-term suffering population that requiremiddle-long-term refuge services;

d: Radiation radius of the temporary emergency evacuation service, that is, each demand pointmust be serviced(temporary emergency evacuation service) by the emergency shelter within this distance;

g_t: Minimum area per capita provided by t-level shelters;

u^t: Unit construction cost of t-level shelters;

w_j: Effective area of potentialemergency shelters;

x_{ij}: Decision variable. If demand point i receives temporary refuge service at potentialsitej,$x_{ij} = 1$; otherwise $x_{ij} = 0$.

x_{jk}: Decision variables, the populationthat received short-term refuge services from short-term shelters k in temporary shelters j;

x_{kl} : Decision variable, the population that received middle-long-term refuge services frommiddle-long-term shelters lin short-term sheltersk.

x_{jl}: Decision variable, the population that received middle-long-term refuge servicesfrom middle-long-term shelters l in temporary shelters j;

y_j: Decision variable. If potential site j is selected as a t-level shelter, $y_j = 1$, otherwise $y_j = 0$, $t \in T$.

Based on the above analysis, a three-level location model of emergency shelters that minimizes total construction costs under the multi-flow pattern as follows:

$$\text{Min} \quad \sum_{j \in A} y_j^1 u^1 + \sum_{j \in A} y_j^2 u^2 + \sum_{j \in A} y_j^3 u^3 \quad (1)$$

S.t.

$$\sum_{j\in A/d_{ij}\leq d} x_{ij}^1 = 1, \forall i \in I \qquad (2)$$

$$\alpha y_j^1 \sum_{i\in I} c_i x_{ij}^1 = \sum_{k\in A} y_k^2 x_{jk}^2 + \sum_{k\in A} y_l^3 x_{jl}^4 \ , \forall j \in A(3)$$

$$\alpha\beta y_k^2 \sum_{i\in I} c_i x_{ik}^1 + \beta y_k^2 \sum_{j\in A} x_{jk}^2 = \sum_{l\in A} y_l^3 x_{kl}^3 \ , k \in \forall(4)$$

$$\sum_{i\in I} x_{ij}^1 \cdot c_i \leq \frac{w_j}{g_1}\left(y_j^1 + y_j^2 + y_j^3\right), \forall j \in A(5)$$

$$(y_k^2 + y_k^3)\left[\alpha \sum_{i\in I} c_i x_{ik}^1 + \sum_{k\in A} x_{jk}^2\right] \leq \frac{w_k}{g_2}(y_k^2 + y_k^3), \quad \forall k \in A \ (6)$$

$$y_l^3 \left[\alpha\beta \sum_{i\in I} x_{il}^1 \cdot c_i + \sum_{k\in A} x_{kl}^3 + \beta \cdot \sum_{j\in A} x_{jl}^4\right] \leq \frac{w_l}{g_3} \cdot y_l^3, \quad \forall l \in A \quad (7)$$

$$y_j^1 + y_j^2 + y_j^3 \leq 1, \forall j \in A \qquad (8)$$

$$x_{jk}^2, x_{kl}^3, x_{jl}^4 \geq 0, \forall j,k,l \in A(9)$$

$$y_j^1, y_j^2, y_j^3, y_k^2, y_l^3, x_{ij}^1, x_{ik}^1, x_{il}^1 \in \{0,1\}, \forall j,k,l \in A(10)$$

The objective function (1) minimizes the total construction cost of building a three-level shelters. Constraint(2) shows that within the specified service radius, every demand point i can obtain temporary refuge services; Constraints (3) and (4) are flow constraints.(3) indicates that a part of the population (proportion of which is α) receiving temporary services from temporary sheltersjneeds to be transferred from temporary sheltersj to short-term sheltersk or middle-long-term sheltersl require to receive short-term refuge services while (4) shows that a part of the population (proportion of which is β) receiving short-term services from short-term shelters k needs to be transferred from short-term shelters k to middle-long-term shelters l to attain middle-long-term refuge services; In addition,constraints (5), (6), and (7) are capacity constraints of the shelters, indicating that the number of people arriving at each shelter cannot exceed the maximum capacity of the site (determined by the effective area of the potential site and the level of service provided); Moreover,constraint (8) ensures that the a candidate can only has a service level;Finally constraint (9) representsnon-negativity of variables and constraint (10) indicates 0-1 variable constraint.

Obviously, the single-flowpattern is a special case of the multi-flow pattern, in other words, the single-flowpattern and its corresponding location scheme is a subset of the feasible domain defined by the hierarchical location model in the multi-flowpattern.Consequently,the model is a general extension of the hierarchical location model in the traditional single-flowpattern, and the objective function value in the multi-flowpattern cannot higher than that in the single-flowpattern.

In order to further compare with the location selection scheme of the multi-flow pattern in the subsequent example analysis, the constraints (5) and (6) in the location model of the above multi flow pattern are replaced by the following constraints (11) and (12) respectively,and setting$x_{jk} = 0$, then the multi-level location model under the restriction of single-flow pattern can be obtained.

$$\sum_{i\in I} x_{ij}^1 \cdot c_i \leq \frac{w_j}{g_1} y_j^1, \forall j \in A \ (11)$$

$$y_k^2\left(\alpha \sum_{i\in I} c_i x_{ik}^1 + \sum_{k\in A} x_{jk}^2\right) \leq \frac{w_k}{g_2} y_k^2, \forall k \in A(12)$$

IV. Case Analysis

Assume that there are 10 demand points and 8 potential emergency shelters in an area. The construction standards of emergency shelters aboutdifferent levels are shown in Table 1 and the distance from the demand point to the emergency shelter is shown in Table 2. The radiation radius of the temporary emergency refuge service is 500 meters ($d = 0.5$). The number of affected people at each demand point is shown in Table 3. The rate parameters are set as $\alpha = 0.6$, $\beta = 0.4$.

Table 1. The construction standards of emergency shelters about different levels

Type	Effective area /m2	Minimum per capita area/ m2	Unit construction cost/104
Middle-long-term	20000	2	2000
Short-term	10000	1	500
Temporary-term	2000	0.5	10

Table 2. The distance from the demand point to the emergency shelter (unit: km)

j \ *i*	1	2	3	4	5	6	7	8
1	0.2	0.5	0.8	1.2	2.6	3.6	6.1	5.6
2	0.5	0.4	0.3	0.8	4.4	3.6	2.2	6.5
3	1.3	0.8	1.2	1.5	1.4	2.5	0.4	7.1
4	2.1	3.5	2.3	3.8	2.5	0.2	0.6	5.1
5	3.2	1.2	2.9	8.6	1.4	0.4	3.9	0.5
6	5.6	0.4	1.7	6.3	2.3	1.2	0.5	3.8
7	7.8	2.5	6.2	3.2	1.6	2.6	0.4	0.5
8	2.7	1.4	0.5	2.3	1.5	5.5	2.7	2.7
9	3.5	2.5	0.2	1.8	1.5	2.3	3.5	0.5
10	5.9	4.2	1.3	3.3	1.2	0.7	0.5	1.8

Table 3. The number of people with refuge requirement at each demand point (unit: 1000)

Demand point	1	2	3	4	5	6	7	8	9	10
Population	1.5	1	1	2	2.3	2.3	1.5	1.2	1	1.4

We utilize Lingo to solve the model under multi-flow pattern by using the above data, the optimal location scheme and corresponding population transfer route are shownin Table 4 and Figure 3 respectively. There are 5 emergency shelters needed to be constructed, including 4 temporary shelters as well as a middle-long-term shelter, and the total construction cost is 20.4 million yuan.

Table 4. Optimal location scheme under multi-flow pattern

Alternative sites	1	2	3	4	5	6	7	8
Type	—	Middle-long term	temporary	—	—	temporary	temporary	temporary

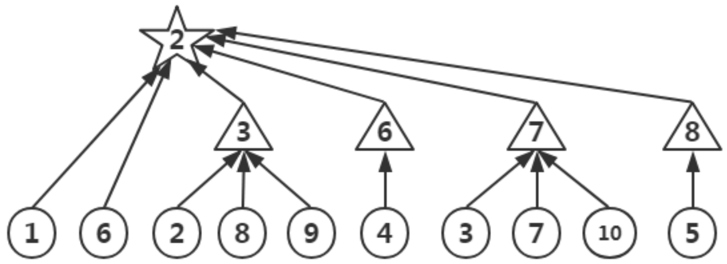

Figure 3. The population transfer routeunder the multi-flow pattern

The optimal location scheme and corresponding population transfer route under the restriction of the single-flow pattern are shown in Table 5 and Figure 4. There are 8 emergency shelters should be constructed, including 6 temporary shelters, 1 short-term shelter, and 1 middle-long-term shelter, the total construction cost is 25.6 million yuan.

Table 5. Optimal location scheme under single-flow mode

Alternative sites	1	2	3	4	5	6	7	8
Type	temporary	temporary	temporary	Short-term	Middle-long term	temporary	temporary	temporary

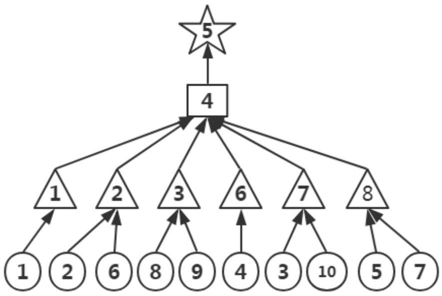

Figure 4. The population transfer route under the single-flow pattern

It can be seen from the comparison that under the single-flow pattern, the affected population must obtain the corresponding level of services in the way of gradual transfer from the low-level shelters to the high-level shelters, so more shelters need to be built to provide services. Under the multi-flow pattern, the emergency shelter location scheme can save more resources and costs on the premise of meeting the same refuge requirements.

V. Conclusion

The construction of urban emergency shelters is a livelihood project. Strengthening the scientific planning and construction of emergency shelters is of great significance to improve the urban safety risk management system and enhance the city's ability to respond to sudden disasters. The construction of urban emergency shelters must consider not only social benefits but also economic costs. Based on the summary of the local and overseas research results, this paper analyzes the characteristics of the hierarchical, nested structure and multi-flow pattern of emergency shelters, and builds a hierarchical location model of emergency shelters under the multi-flow pattern. The location scheme obtained by the model can minimize the total construction cost on the premise of meeting the emergency refuge needs of the affected people. Compared with the location scheme under the traditional single-flow pattern, the resource utilization efficiency is higher, which has certain guiding significance for the scientific and reasonable planning of the urban emergency shelter.

References

[1]. Liu, Q., Ruan, X., & Shi, P., Selection of emergency shelter sites for seismic disasters in mountainous regions: Lessons from the 2008 WenchuanMs 8.0 Earthquake, China. Journal of Asian Earth Sciences,2011, 40(4): 926–934.
[2]. Li, H., Zhao, L., &Huang, R., Hierarchical earthquake shelter planning in urban areas: A case for Shanghai in China. International journal of disaster risk reduction, 2017, 22: 431-446.
[3]. Hallak, J., Koyuncu, M., &Miç, P., Determining shelter locations in conflict areas by multiobjective modeling: A case study in northern Syria. International Journal of Disaster Risk Reduction, 2019: 101202.
[4]. Kınay, Ö. B., Kara, B. Y., &Saldanha-da-Gama, F., Modeling the shelter site location problem using chance constraints: A case study for Istanbu. European Journal of Operational Research, 2018, 270(1): 132-145.
[5]. Ozbay, E., Çavuş, Ö.,& Kara, B. Y., Shelter site location under multi-hazard scenarios. Computers & Operations Research, 2019, 106: 102-118.
[6]. Zhou, J., Li, Z., & Wang, K., A multi-objective model for fire station location under uncertainty. Advances in Information Sciences and Service Sciences, 2013, 5(7): 1184-1191.
[7]. Wang, K., Li, Z., & Zhou, J., Two decision-making approaches to fire station location in a fuzzy environment. Journal of Information and Computational Science, 2014, 11(13): 4779-4793.
[8]. Garner, A. A., & van den Berg, P. L., Locating helicopter emergency medical service bases to optimise population coverage versus average response time. BMC emergency medicine, 2017, 17(1), 31.
[9]. D'Souza, I., Ma, W., &Notobartolo, C., Real-time location systems for hospital emergency response. IT Professional, 2011, 13(2): 37-43.
[10]. An, H. C., Singh, M., &Svensson, O., LP-based algorithms for capacitated facility location. SIAM Journal on Computing, 2017, 46(1): 272-306.
[11]. Yang, Y., Zhou, J., Wang, K., &Pantelous, A. A., A new solution approach to two-stage fuzzy location problems with risk control. Computers & Industrial Engineering, 2019, 131: 157-171.
[12]. Moore, G.,&Revelle, C., The hierarchical service location problem. Management Science, 1982, 28:755-780.
[13]. Wang, K., & Yang, Q., Hierarchical facility location for the reverse logistics network design under uncertainty. Journal of Uncertain Systems, 2014, 8(4): 255-270.
[14]. Chen, Z., Gu, L., Chen, J., & Li, Q.,Study on hierarchical location of urban emergency shelters (I): hierarchy analysis. Journal of Natural Disasters (in Chinese), 2010,19(3): 151-155.
[15]. Chen, Z., Li, Q., & Chen, J., Study on hierarchical location of urban emergency shelters (II):Three-hierarchical location models. Journal of Natural Disasters (in Chinese), 2010,19(5):13-19.
[16]. Sahin, G. and Sural, H., A review of hierarchical facility location models, Computers & Operations Research, 2007, 34(8): 2310-2331.

Ying-Ying Liu, etal. "Hierarchical Location of Urban Emergency Shelters under Multi-Flow Pattern." *IOSR Journal of Business and Management (IOSR-JBM)*, 22(2), 2020, pp. 06-11.