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Geographical Distribution Analysis of Field Hospitals Along the Frontline: 2SFCA method-based approach

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Abstract

The purpose of this article is to develop mathematical-geographical model to study the accessibility of fields hospitals along a frontline based on 2SFCA methodology. Invented P2SFCA model compares destinations proportionally and customizes the distance decay function for the needs of wounded soldiers. It is empirically shown that P2SFCA model distributes the same amount of accessibility as 2SFCA model but allocates it differently. Obtained model could be further used in decision making processes to better ensure the safety of wounded soldiers.

KEY WORDS: *2SFCA; field hospitals; spatial accessibility; frontline; proportional distances; minimal distance decay function.*

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1. Introduction

When it comes to health care availability we can monitor multiple parameters to monitor the situation in a given location. Among the most basic ones are hospital capacity, which measures how many patients can particular hospital treat in a predetermined amount of time, and patient's demand, which describes how many patients will visit given hospital in a specific amount of time.

Measuring hospital capacity can be achieved by different means, for example, by calculating the number of hospital beds, hospital physicians or hospital size. On the other hand, it is more difficult to estimate patient's demand as it involves unknown variables. For example, only a portion of ill patients will go to a hospital. Furthermore, patients can usually choose between several hospitals and will decide which one to visit based on variable criteria. However, even when patients decide between multiple hospitals, they can visit only one hospital at a given time.

For this reason, mathematical-geographical models were developed to estimate patient's demand (where groups of patients are considered instead of individual patients) in a simplified manner. Furthermore, 2SFCA models aggregate ratios of hospital capacities to patients' groups demand to measure health care availability in an investigated area. Special meaning is assigned to the distance between hospitals and patient groups.

2SFCA models were used under different settings to address various civilian needs. However, it seems that these models are yet to be deployed for military use. Nevertheless, there is a clear difference between civilian patients and military patients. This article then investigates a theoretical background for a potential application, where 2SFCA models are utilized in a military environment. As a consequence, a new modified 2SFCA model (named P2SFCA) was obtained and it analyses geographical distribution of field hospital along a frontline.

Primary objective of P2SFCA model is to introduce dynamical definition of the search radius by proportional comparison of distances. Its main advantage is that it better mirrors the real-world situation and offers more precise results. Additionally, distance decay function that generally appears in 2SFCA model is customized to better suit the military needs.

Modern warfare utilizes modern technology, bombardment and swift tactical attacks to deal with an opponent as is illustrated, for example, by Gulf War (see the official US government site [1]).

However, stalled progress of Ukrainian recently showed, that even in modern conflicts can prolonged frontline appear. Therefore, analyzing deployment of field hospitals along a front line still has its place in modern military preparedness. Improved effectiveness of field hospital distribution could then lead to saved lives. P2SFCA model could be later introduce into multi-criteria decision-making processes that compare multiple factors such as accessibility, costs, terrain and others.

2. Literary review

Original simple 2SFCA model was developed in [2] based on previous research and it geographically compares supply (hospital capacities) and demand (patients' demand) in two steps. Studied area is subdivided into smaller regions and the method works in two steps. First, supply/demand ratios are calculated for each hospital based on the localized demand, i.e. based on the regions that fall into hospital's scope. Next, for each region are considered hospitals that are sufficiently close and their supply/demand ratios are aggregated to calculated the accessibility index for that region.

In [3] weights were introduced to represent friction of distance into the model, i.e. regions that are closer to the hospital put higher demand on the hospital than regions that are farther away. This is nowadays called distance decay function and article [3] works with stepwise functions. Article [4] introduced continuous Gaussian distance decay function. At present, by 2SFCA models we usually refer to the models introduced in [3] and [4] (that is also the terminology that we will use). However, in literature we sometimes find these models under the name E2SFCA (that is the original terminology proposed by [3]).

These models were originally used to measure healthcare accessibility (see also [5-9]), however, in the last ten years they were used to investigate other scenarios such as earthquake shelter distribution [10] (see also [11] as well), fire stations distribution [12], supermarket accessibility [13], and water supply accessibility [14].

Field hospitals are sometimes used in emergency situation such as natural disasters or earthquakes. Optimal allocation of such hospitals saves civilian lives and tax payer's money. Mathematical algorithms were developed to optimize the allocation in [15], [16]. Furthermore, several countries recently utilized field hospital to relief overcrowded hospitals during the pandemic. As a consequence, effective distribution of said hospitals was investigated as well, see, for example, article [17]. Following this, article [18] developed algorithm that optimizes field hospital allocation during a pandemic by minimizing 2SFCA based coefficient in the studied area.

Above mentioned references illustrate an interest in investigating field hospitals, their geographical distribution and availability for civilian purposes. However, authors of this article do not know about similar scientific paper that would cover military requirements.

3. P2SFCA model

2SFCA model with Gaussian decay developed in [4] works in the following manner. Studied area is subdivided into smaller regions. Each region i is assigned its demand P_i (e.g. number of patients, number of people living in the region, …) and each hospital j is assigned its capacity S_j (e.g. number of physicians [19], number of ICU beds [20], floor area, …). Distances $d_{i,j}$ (e.g. planar distance, walking distance, mean travel time, …) between regions i and hospitals j are calculated. For each hospital j is then calculated its R_j - supply/demand ratio as

$$R_j = \frac{S_j}{\sum_{d_{i,j} \leq d_0} P_i f(d_{i,j})},$$

where d_0 is maximal radius, from which would people still consider traveling to the hospital and $f(x)$ is Gaussian distance decay given as

$$f_G(d_{i,j}) = \begin{cases} \dfrac{\mathrm{e}^{-\frac{1}{2}\left(\frac{d_{i,j}}{d_0}\right)^2} - \mathrm{e}^{-\frac{1}{2}}}{1 - \mathrm{e}^{-\frac{1}{2}}} & \text{if} \quad d_{i,j} \leq d_0\,, \\ 0 & \text{if} \quad d_{i,j} > d_0. \end{cases}$$

In the second step, A_i - accessibility index is calculated for each region i as

$$A_i = \sum_{d_{i,j} \leq d_0} R_j f(d_{i,j}).$$

Region's demand P_i is scaled in denominator of R_j with distance decay function $f(d_{i,j})$, that can be explained by the following reasoning: The portion of patients that would consider traveling to the hospital is decreasing with increasing distance. This is natural in certain scenarios as some patients with, for example, flu, would not decide to travel to far away hospital and rather stay at home. On the other hand, this means that there will be some situations where patients will not travel anywhere. However, for the purposes of this article, patients represent seriously wounded soldiers that do need medical attention. Hence, P2SFCA model utilizes modified distance decay function

$$f(d_{i,j}) = \begin{cases} 1 & \text{if} \quad d_{i,j} = \min_l (d_{i,l}), \\ \dfrac{e^{-\frac{1}{2}\left(\frac{d_{i,j}}{d_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}} & \text{if} \quad \min_l (d_{i,l}) < d_{i,j} \leq d_0, \\ 0 & \textit{otherwise}. \end{cases}$$

Here every patient considers traveling at least to the closest hospital. Hospitals, that are further away than the closest one are considered only when they are located in maximal radius d_0. Gaussian decay function is then employed for these hospitals. Additionally, P2SFCA model utilizes modified coefficients A_i and R_j given as

$$R_j = \frac{S_j}{\sum_i P_i f(d_{i,j}) H(i,j)}, \qquad A_i = \sum_j R_j f(d_{i,j}) H(i,j),$$

where

$$M_{k,i} = \left\{ d_{i,j} \middle| \frac{\min_l (d_{i,l})}{d_{i,j}} \geq 1 - \frac{1}{k} \right\} \cap N_{k,i},$$

$k_0 \geq 1$ is maximal integer that satisfies $|M_{k_0,i}| = k_0$ and $H(i,j) = \begin{cases} 1 & \text{if } d_{i,j} \in M_{k_0,i} \\ 0 & \text{if } d_{i,j} \notin M_{k_0,i} \end{cases}$. Here $|M_{k,i}|$ denotes number of elements in the set $M_{k,i}$ and $N_{k,i}$ set of k smallest distances from region i.

In this way, hospitals are filtered for the second time. Their distances are compared with the closest hospital proportionally through ratio $\frac{\min_i(d_{i,j})}{d_{i,j}}$ which has to satisfy certain condition $\geq 1 - \frac{1}{k_0}$ and only k_0 closest hospitals are taken. The condition ensures that only limited number of hospitals are considered and that if we consider more hospital then their distances have to be in smaller range.

This can be explained on a following example. When the closest hospital is 10 kilometers away then we consider n hospitals only when the farthest hospital satisfies that its distance is $d_{i,j} \leq \frac{10n}{n-1}$. Meaning that if we consider $n = 3$ hospitals then the farthest one can be at most 15 kilometers away (12.5 kilometers for $n = 5$ and 11.7 kilometers for $n = 7, \dots$). On the other hand, if the closest hospital is 100 kilometers away, then we consider $n = 3$ hospitals when the farthest one is at most 150 kilometers away. In a sense, this condition scales the number of hospitals considered dynamically. In fact, this is supposed to better represent humans' decision process where values are compared between each other and not with respect to a theoretical maximal distance.

Proposed P2SFCA model can be mathematically described in the following fashion as well. Let D be a matrix created from distances $d_{i,j}$. Furthermore, assume that $\tilde{D}$ is another matrix, containing ordered rows of D that are increasing from left to right and let us denote its elements as $\tilde{d}_{i,j}$. Finally, let $\sigma_i(j)$ be a system of bijections such that $d_{i,j} = \tilde{d}_{i,\sigma_i(j)}$ for all i and let there be a function

$$H(\tilde{d}_{i,j}) = \begin{cases} \tilde{d}_{i,j} & \text{if} \quad \dfrac{\tilde{d}_{i,1}}{\tilde{d}_{i,j}} \geq 1 - \dfrac{1}{j}, \\ 0 & \text{otherwise.} \end{cases}$$

Then we can calculate coefficients A_i and R_j for P2SFCA model as

$$R_j = \frac{S_j}{\sum_i P_i f\left(H(\tilde{d}_{i,\sigma_i(j)})\right)}, \qquad A_i = \sum_j R_j f\left(H(\tilde{d}_{i,\sigma_i(j)})\right).$$

4. Methodology

Classic 2SFCA model is compared with newly established P2SFCA model on two datasets. Strictly theoretical data were generated based on the system proposed in [9], where model's performance is tested on various small case scenarios and both models are compared. Two classes of nodes are generated, one representing hospitals and another representing groups of patients. Distances between nodes, hospitals' capacities and patients' groups demands are then generated and varied to obtain several scenarios. Finally, it is observed how scenario's parameters impact each model.

Another set of simulated data was utilized as well. A segment of Ukrainian frontline (roughly 160 km long measured from one endpoint to another, whereas the curved path measures twice that long; segment is depicting the situation at the end of January 2024, see [21]) was taken and locations for field hospitals and military units were simulated. Military units were represented by their position centroids with the distance to the closest unit ranging from 3 to 7 kilometers. Overall, 57 units and 6 hospitals were generated. Each hospital was assigned semi randomized capacity (from 10 to 25 for each hospital with overall capacity 105) and similarly each military unit was assigned semi randomized number of seriously wounded soldiers representing patients' demand (from 0 to 4 with the total number being 75). Distances between hospitals and military units were calculated in ArcGIS pro software. Finally, accessibility indices A_i for both 2SFCA and P2SFCA are compared in map and statistically with maximal radius d_0 taken as 50 kilometers.

Wilcoxon Signed Rank (WSR) Test [22] is applied in MATLAB software (function *signrank*) to statistically compare accessibility indices A_i for both models. WSR Test is non-parametric test with the null hypothesis that two random samples have the same median against the alternative that their medians are different.

5. Model evaluation

This section presents models' analysis where we compare both models on strictly theoretical data and on simulated data.

5.1. Theoretical data

Three scenarios are considered and they schematics are visualized on Figure 1 a), b) and c). Here circles represent demand points (military units) and squares represent supply points (field hospitals). As was already mentioned, P_i represents number of wounded soldiers in group *i* and S_j capacity of hospital *j*. These values are taken as fixed in Figure 1 a), b) and for Figure 1 c) they are summarized in Table 3. Distances $d_{i,j}$ between nodes P_i and S_j are taken as fixed for Figure 1 b), where they are written next to the edges. Distances $d_{i,j}$ for Figure 1 a), b) are summarized in Table 1 and 3. Maximal (cut off) distance was taken as $d_0 = 1$ for all scenarios.

Scenario a) is the same as in [9], [23] and it was considered for historical continuity. Scenario b) is similar to the scenario considered in [9] and illustrates possible issues with P2SFCA model that occurs if the number of supply points (field hospitals) is bigger that the number of demand points (military units). This is expected to be an unrealistic but theoretical situation. Scenario c) illustrates how indices A_i depend on distances $d_{i,j}$ across different settings.

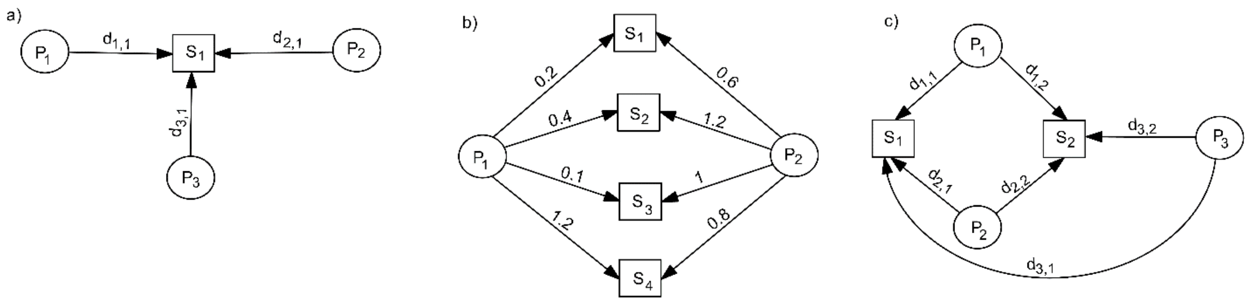

Fig. 1. Three scenarios a), b), c) and their schematic representation.

Scenario a) assumes that $P_1 = P_2 = P_3 = 100$ and $S_1 = 20$. This is the same as with the analogous scenario in [9]. In the scenario, there is only one supply point and its supply/demand ration R_1 is given in Table 1, where spatial accessibility indices A_i are calculated as well. In situation a) I there are $d_{1,1} = d_{2,1} = d_{3,1} = 0.8$ which mathematically ensures for both models that all accessibility indices A_i are equal. Furthermore, when there is just one supply point S_1then P2FCA model has $f(d_{1,1}) = f(d_{2,1}) = f(d_{3,1}) = 1$ and consequently indices A_i(P2SFCA) are mathematically equal for situation a) II as well. Finally, means of A_i are mathematically equal for all situations a) I, a) II and all models 2SFCA, P2SFCA. Moreover, this is true even when A_i(2SFCA) are different in situation a) II.

Table 1.

Accessibility indices A_i and parameters for scenario a).

		$d_{1,1}$	$d_{2,1}$	$d_{3,1}$	R_1	A_1	A_2	A_3	mean(A_i)
I	2SFCA	0.8	0.8	0.8	0.219	0.067	0.067	0.067	0.067
	P2SFCA				0.067	0.067	0.067	0.067	0.067
II	2SFCA	0.8	0.1	0.6	0.107	0.033	0.105	0.062	0.067
	P2SFCA				0.067	0.067	0.067	0.067	0.067

Scenario b) assumes that $P_2 = 100$ a $S_1 = S_2 = S_3 = S_4 = 20$ and its indices R_j, A_i are summarized in Table 2. Here it has to be emphasized that $R_2 = 0$, which is a theoretical consequence of hospital S_2 being too far from all demand points. As a consequence, hospital S_2 is not considered by any demand point and therefore $H(1,2) = H(2,2) = 0$, which results in division by zero in the process of evaluating R_2. However, this can happen with 2SFCA model as well and the situation is avoided by setting $R_2 = 0$.

Scenario b) highlights a theoretical difference between 2SFCA and P2SFCA models. Model 2SFCA considers unlimited number of supply points S_j if they are inside of maximal radius. On the other hand, P2SFCA model works with only a limited number of closest supply points that have sufficiently similar distances. Therefore, in scenario b) are sets $M_{k_0,i}$ given as $M_{k_0,1} = \{d_{1,1}, d_{1,3}\}$, $M_{k_0,2} = \{d_{2,1}, d_{2,4}\}$. Furthermore, P2SFCA model gives more weight to the closes node, which in scenario b) results in $f(d_{2,1}) = 1 > 0.581 = f_G(d_{2,1})$. This disparity grows remarkably when the distance of the closest node tends to d_0.

Table 2.

Accessibility indices A_i and parameters for scenario b).

	R_1	R_2	R_3	R_4	A_1	A_2	$\text{mean}(A_i)$
2SFCA	0.131	0.249	0.203	0.660	0.524	0.276	0.400
P2SFCA	0.103	0.000	0.200	0.660	0.298	0.303	0.301

Scenario c) illustrates more complex situation with varied parameters for three versions of distances and two versions of supply and demand. Scenarios assume that $P_2 = 100$, $S_1 = 20$, $d_{3,1} = 0.8, d_{3,2} = 0.3$ and choices for other parameters are summarized in Table 3 together with their R_j and A_i.

Table 3.

Accessibility indices A_i and parameters for scenario c).

<table>
<tr><th>Scenarios</th><th></th><th>$d_{1,1}$</th><th>$d_{1,2}$</th><th>$d_{2,1}$</th><th>$d_{2,2}$</th><th>P_1</th><th>P_3</th><th>S_2</th><th>R_1</th><th>R_2</th><th>A_1</th><th>A_2</th><th>A_3</th><th>$\text{mean}(A_i)$</th></tr>
<tr><td rowspan="2">I</td><td>2SFCA</td><td rowspan="4">0.2</td><td rowspan="4">0.4</td><td rowspan="4">0.5</td><td rowspan="4">0.3</td><td>100</td><td>100</td><td>20</td><td>0.103</td><td>0.078</td><td>0.160</td><td>0.141</td><td>0.100</td><td>0.134</td></tr>
<tr><td>P2SFCA</td><td>100</td><td>100</td><td>20</td><td>0.118</td><td>0.071</td><td>0.176</td><td>0.154</td><td>0.071</td><td>0.134</td></tr>
<tr><td rowspan="2">II</td><td>2SFCA</td><td>150</td><td>50</td><td>80</td><td>0.088</td><td>0.315</td><td>0.338</td><td>0.342</td><td>0.307</td><td>0.329</td></tr>
<tr><td>P2SFCA</td><td>150</td><td>50</td><td>80</td><td>0.091</td><td>0.295</td><td>0.328</td><td>0.359</td><td>0.295</td><td>0.327</td></tr>
<tr><td rowspan="2">III</td><td>2SFCA</td><td rowspan="4">0.4</td><td rowspan="4">0.8</td><td rowspan="4">0.6</td><td rowspan="4">0.9</td><td>100</td><td>100</td><td>20</td><td>0.118</td><td>0.148</td><td>0.140</td><td>0.091</td><td>0.167</td><td>0.133</td></tr>
<tr><td>P2SFCA</td><td>100</td><td>100</td><td>20</td><td>0.174</td><td>0.087</td><td>0.200</td><td>0.114</td><td>0.087</td><td>0.134</td></tr>
<tr><td rowspan="2">IV</td><td>2SFCA</td><td>150</td><td>50</td><td>80</td><td>0.103</td><td>0.762</td><td>0.315</td><td>0.177</td><td>0.708</td><td>0.400</td></tr>
<tr><td>P2SFCA</td><td>150</td><td>50</td><td>80</td><td>0.121</td><td>0.408</td><td>0.245</td><td>0.427</td><td>0.408</td><td>0.360</td></tr>
<tr><td rowspan="2">V</td><td>2SFCA</td><td rowspan="4">0.2</td><td rowspan="4">0.5</td><td rowspan="4">0.5</td><td rowspan="4">0.2</td><td>100</td><td>100</td><td>20</td><td>0.079</td><td>0.103</td><td>0.147</td><td>0.153</td><td>0.101</td><td>0.134</td></tr>
<tr><td>P2SFCA</td><td>100</td><td>100</td><td>20</td><td>0.1</td><td>0.2</td><td>0.1</td><td>0.2</td><td>0.1</td><td>0.133</td></tr>
<tr><td rowspan="2">VI</td><td>2SFCA</td><td>150</td><td>50</td><td>80</td><td>0.078</td><td>0.372</td><td>0.335</td><td>0.408</td><td>0.182</td><td>0.308</td></tr>
<tr><td>P2SFCA</td><td>150</td><td>50</td><td>80</td><td>0.1</td><td>0.8</td><td>0.1</td><td>0.8</td><td>0.1</td><td>0.333</td></tr>
</table>

Scenarios c) I and c) II describe the situation where the distances are mostly smaller (as compared to the maximal distance) and it can be seen that both R_j, A_i as well as means of A_i have similar values (with differences from 1 to 3%). In both of these scenarios there are $M_{k_0,1} = \{d_{1,1}, d_{1,2}\}$, $M_{k_0,2} = \{d_{2,1}, d_{2,2}\}$, $M_{k_0,3} = \{d_{3,2}\}$ where the distance $d_{3,1}$ not considered in P2SFCA has for 2SFCA $f_G(d_{3,1}) = 0.304$ smaller impact that is additionally compensated by other terms, for example, by $f(d_{2,2}) = 1 > 0.888 = f_G(d_{2,2})$. Moreover, the disparity between functions $f(d_{i,j})$ and $f_G(d_{i,j})$ is further lessened by smaller distances in I and II.

Scenarios c) III and c) IV cover the situation where the distances are larger (as compared to the maximal distance) and it can be seen that the values of R_j, A_i are occasionally similar (A_2 in III and A_3 in IV) however mostly different (with difference going up to 8% in III and 35% in IV). However, even in this situation have means of A_i similar levels (difference 0% in III a 4% in IV). Sets $M_{k_0,i}$ are the same for scenarios I, II, III, and IV and their impact is limited. Hence, the dissimilarity (between scenarios I, II and III, IV) seems to be caused solely by the change in distances.

Scenario c) V and c) VI depict the situation where $M_{k_0,1} = \{d_{1,1}\}$, $M_{k_0,2} = \{d_{2,2}\}$, $M_{k_0,3} = \{d_{3,2}\}$ and the impact of sets $M_{k_0,i}$ is bigger whereas the distances are similar to scenarios I and II. Here it is possible to note again that R_j, A_i are occasionally similar (A_3 in V and R_1 in VI) but mostly different (with difference going up to 10% in V and 43% in VI). Overall impact on means of A_i is again smaller (difference 0% in V a 2% in VI).

5.2. Simulation

Accessibility indices A_i for each military unit were calculated and their elementary statistics are summarized in Table 4. Minimums, means, and medians are similar for both models. However, maximums differ by one. Furthermore, Figure 2 shows normalized histogram comparing both sets of indices.

Table 4.

Elementary statistics

	min	max	mean	median	std
2SFCA	0.483	2.522	1.388	1.315	0.486
P2SFCA	0.521	3.534	1.475	1.293	0.874

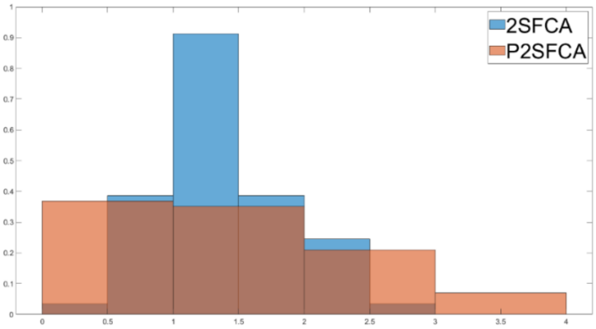

Fig. 2 Normalized histograms comparing accessibility indices A_i for both 2SFCA and P2SFCA.

It can be observed that A_i for 2SFCA model center around its peak with 45.6% of values between 1 and 1.5. On the other hand, indices A_i for P2SFCA model have similar levels for indices between 0 and 1 and between 1 and 2. Additionally, there is no peak standing out for P2SFCA model and the values are spread more uniformly.

WSR Test was performed to compare accessibility indices for both models with p-value=0.5918. As a consequence, null hypothesis that both sets of indices have the same median cannot be rejected.

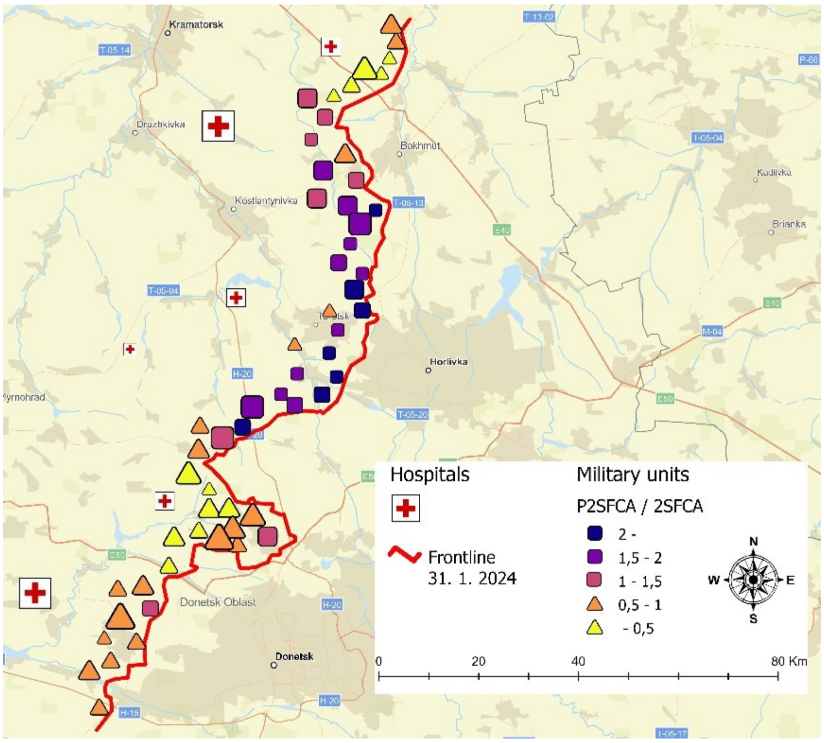

Fig. 3 Segment of Ukrainian frontline with simulated military units (triangles and squares) and field hospitals. Symbols' size represents hospital capacity and patient's demand (number of seriously wounded soldiers). Triangles mark military units for which is $P2SFCA < 2SFCA$ and squares mark units for which is $P2SFCA > 2SFCA$.

Figure 3 shows geographical distribution of both models. Triangles mark military units for which is $P2SFCA < 2SFCA$ (here and subsequently $P2SFCA$ denotes coefficient A_i for P2SFCA model and analogous notation is used for $2SFCA$) and squares mark units for which is $P2SFCA > 2SFCA$. It can be noted that the lower and upper portion of the frontline contains triangles and the middle portion contains squares. Furthermore, color indicates how many times is P2SFCA model smaller/bigger as compared with 2SFCA model. It is possible to visually identify two (yellow) regions on Figure 3, where $2 * P2SFCA < 2SFCA$ and scattered group of (blue) squares where $P2SFCA > 2 * 2SFCA$.

6. Conclusions and limitations

A new modified P2SFCA model and sets $M_{k_0,i}$ were developed for a better simulation of a humans' decision process. In fact, it seems to be a common knowledge that when humans have to decide between multiple options then they decide by comparing these choices among each other. This is indeed one of the features of P2SFCA model. On the other hand, classic

2SFCA models searches only in a strict radius. Classic 2SFCA model was already extended several times in multiple ways to better represent the real-world situation, see, for example, [7], [23], [24], [25], and [26]. However, dynamical modifications to the search radius were, as far as the authors know, considered solely in [9], [28].

Additionally, modified function $f(d_{i,j})$ was considered to better suit the needs of military and better represent the requirements of wounded soldiers. Similar analysis was performed and applied in other studies for classic 2SFCA model, see, for example, [3], [14], [27], [20]. However, Gaussian $f_G(d_{i,j})$ decay function is often times utilized as well, see, for example, [4], [10], [18], [28], [29]. Other resources focus on calculation of distances and how it is performed. However, in military settings, it is important to consider how the distance is calculated on a battlefield, see also [31], [32], [33], [34], [35].

Analysis of theoretical and simulated data showed, that P2SFCA model results in different indices A_i but means or medians remain similar. Hence, it seems that P2SFCA model distributes similar amount of accessibility throughout the region differently than 2SFCA method. This highlights military units that could be overlooked by 2SFCA and on the other hand it shows that certain units are in a better situation than is showed by 2SFCA model. In this situation, it is expected that P2SFCA model offers more precise information as opposed to 2SFCA model because it mirrors the actual situation on the battlefield better. Further improvements are necessary by customizing the model for the military doctrine of the studied army, see also [30].

Nevertheless, additional research is necessary before P2SFCA model could be deployed for military purposes. Proposed simulation works with the number of wounded soldiers that are station along frontline. In actual application, statistical models could be employed to infer this number for each military unit. However, additional consultations about military doctrine with military experts are necessary before this could be done. Furthermore, particular needs of any given army are dictated not only by their military doctrines but by the adversary as well. 2SFCA model was studied under the assumptions that there is a clear frontline between armies. However, military conflicts in the 20th century showed that this does not have to happen (see [35]). Hence, further generalization of 2SFCA model are necessary for different types of conflicts (if 2SFCA model can be applied at all).

Finally, practical applications of 2SFCA based models could lead to improved decision-making process such as in

- Field hospitals location selection: Location selection algorithm based on P2SFCA model could show where to place field hospitals to improve their efficiency (see also [8], [10]).
- Analysis of actual situation: Software tools analyzing real time data could highlight problematic situations in need of attention.
- Doctrine improvement: Analysis could highlight problematic parts of current military doctrine and lead to further improvements.

In this way, P2SFCA model could be utilized together with other optimization algorithms that consider other parameters of the problem under consideration in a multi-criteria model, see, for example, [18].

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