Advances in Military Technology
Vol. 19, No. 2, 2024, pp. 329-344
ISSN 1802-2308, eISSN 2533-4123
DOI 10.3849/aimt.01910

Composite Index for 2SFCA Based Accessibility Comparison and Field Hospitals Distribution Analysis along the Frontline

J. Jekl* and J. Jánský

University of Defence, Brno, Czech Republic

The manuscript was received on 29 June 2023 and was accepted after revision for publication as an original research paper on 10 December 2024.

Abstract:

Two-step floating catchment area (2SFCA) indices serve to measure accessibility in a geographical area. They were developed mainly to investigate the distribution of medical resources to civilians. Recently, the 2SFCA methodology was introduced to a military background where accessibility of field hospitals along a frontline is considered. This article aims to develop a new composite index with a clear interpretation that allows accessibility to be compared for two distinct situations in the following setting. In the first situation, accessibility is calculated and then the situation changes which impacts accessibility as well. The composite index that is developed in this article then interprets the change and assigns to it an interpretable numerical value. The final composite index is a weighted mean of eleven properties of accessibility indices. Furthermore, the developed index is appropriated for the use in military environment to investigate the distribution of field hospitals along a frontline.

Keywords:

2SFCA, composite index, field hospitals, frontline, spatial accessibility

1 Introduction

The last two decades led to a fast development of a methodology that calculates accessibility indices to measure hospitals' distribution in a geographic area. This was probably fuelled by an increase in computing power that is demanded by Geographic information systems (GIS) and the data availability where data empower GIS calculations. Gravity models and among them 2SFCA methodology seem to be the most prominent at the moment (see [1]).

* *Corresponding author: Department of Mathematics and Physics, Faculty of Military Technology, University of Defence, Kounicova 156/65, CZ-662 10, Brno, Czech Republic, jan.jekl2@unob.cz. ORCID 0000-0002-4177-7575.*

The two-step floating catchment area (2SFCA) method was developed in the 2000s to investigate geographical accessibility in an area to health care providers. The method works by aggregating supply-to-demand ratios for each healthcare provider and each population in two steps. Floating catchments localize the demand and supply into smaller local areas where locations influence each other and are not too far away. The method was developed primarily by [2-6], and it was later improved by subsequent authors in [7-15] and others. The method calculates accessibility for each population which allows identifying populations with low accessibility and comparison between populations to inquire into the fairness of resource distribution.

Since its implementation, the 2SFCA method has drawn widespread attention and it was later applied in other fields to measure the availability of firefighters [16], earthquake shelters [17-19], and other public resources. Recently an effective distribution of field hospitals in case of emergency was investigated [20-23] for civilian purposes. With a lack of utilization of 2SFCA methodology in the military environment, a proportional 2SFCA methodology was developed in [24]. In the process, the distribution of field hospitals along a frontline was investigated.

In this article, we develop a composite index (*CI*) that allows comparing several situations and their accessibility indices to decide which situation is better based on numerical value. The resulting composite index works similarly to other well-established indices, see Human Development Index [25], Gender Inequality Index [26], and many others. As a consequence, *CI* might be utilized in the future as a part of the multicriteria process for:

1. Identifying weaknesses in the allocation of field hospitals.
2. Improved allocation of medical resources.

Nevertheless, future work might be needed before this could be accomplished and this article offers an addition to the overall picture.

2 Methodology

To understand the 2SFCA method better, we subsequently summarize how it works. As the name suggests, the 2SFCA method is split into two steps. In the first step, we evaluate supply-to-demand ratios R_j for each healthcare provider as

$$R_j = \frac{S_j}{\sum_i P_i f(d_{i,j})} \tag{1}$$

where P_i-number of people that might need medical attention in population i, S_j-capacity (number of doctors, medical equipment) of the hospital j, $d_{i,j}$-distance (usually given in units of time or physical distance) between location i and j, and $f(d_{i,j})$ is a friction of distance function. Function f introduces the assumption into the model that with increasing distance the willingness of patients to travel decreases (see [6, 27], and others for further details).

In the second step, we evaluate accessibility indices A_i for each population i by adding supply-to-demand ratios R_j of providers in an area around population i

$$A_i = \sum_j R_j f(d_{i,j}) \tag{2}$$

We emphasize that only healthcare providers that are sufficiently near to population i, which means closer than a constant cut-off distance d_0, appear in formula (2) because of the function f. The usual interpretation of index A_i is that it measures how accessible is medical help for each population i. However, this value is difficult to interpret on its own, and it is usually applied to compare populations in an area between themselves.

Gaussian-based friction of distance

$$f_G(d_{i,j}) = \begin{cases} \dfrac{\exp\left[-\frac{1}{2}\left(\frac{d_{i,j}}{d_0}\right)^2\right] - \exp(-\frac{1}{2})}{1-\exp(-\frac{1}{2})} & d_{i,j} \le d_0 \\ 0 & d_{i,j} > d_0 \end{cases} \tag{3}$$

seems to be nowadays used the most in the literature [8, 17-19, 23, 28, 29]. However, in the article [24] a proportional friction of distance was developed to better include into the model the requirements of military during the frontline conflict. This function is derived in the following way. Let us start with a matrix D whose elements are distances $d_{i,j}$ (with the usual matrix notation that the element $d_{i,j}$ lies in the i-th row and j-th column). Moreover, we will need another matrix $\widetilde{D}$ in which are rows of D ordered from left to right in ascending order. By $\sigma_i(j)$ we will denote a system of bijections such that $d_{i,j} = \widetilde{d}_{i,\sigma_i(j)}$ for all i, j. Finally, let there be a function

$$\beta\left(\widetilde{d}_{i,j}\right) = \begin{cases} \widetilde{d}_{i,j} & \dfrac{\widetilde{d}_{i,1}}{\widetilde{d}_{i,j}} \ge 1 - \dfrac{1}{j} \\ 0 & \text{otherwise} \end{cases}$$

and then the friction of distance function is given as

$$f_P(x) = \begin{cases} 1 & x = \widetilde{d}_{i,1} \\ \dfrac{\exp\left[-\frac{1}{2}\left(\frac{x}{d_0}\right)^2\right] - \exp\left(-\frac{1}{2}\right)}{1-\exp\left(-\frac{1}{2}\right)} & \widetilde{d}_{i,1} < x \le d_0 \\ 0 & \text{otherwise} \end{cases}$$

together with the supply to demand ratios R_j and accessibility indices A_i as

$$R_j = \frac{S_j}{\sum_i P_i f_P\left[\beta\left(\widetilde{d}_{i,\sigma_i(j)}\right)\right]}, \quad A_i = \sum_j R_j f_P\left[\beta\left(\widetilde{d}_{i,\sigma_i(j)}\right)\right]$$

In fact, we work under the assumption that accessibility index A_i represents one parameter of how endangered each unit is with the lower value representing a bigger danger. Hence, we assume that the most endangered units need the most protection and A_i offers a tool for measuring units' danger levels.

In this article, we develop a composite index (CI) which serves as a comparison between two sets of accessibility indices A_i and A_i^{MOD} under the assumption that the number of populations n remains constant. In fact, we intend to measure the importance of each health care provider j by considering how much accessibility changes from A_i to A_i^{MOD} when one of the providers j is eliminated. Furthermore, we consider the setting of a frontline where populations are military units and health care providers are field hospitals. Composite index CI is thus developed under assumptions that are necessary for its potential application by military. From here onwards, A, A^{MOD} will denote vectors of accessibility indices $(A_1, A_2, \ldots, A_n)$ or $(A_1^{MOD}, A_2^{MOD}, \ldots, A_n^{MOD})$.

The proposed CI itself consists of several multiparametrical components C_1, C_2, C_3, and C_4 that are combined linearly as

$$CI = \sum_{i=1}^{4} w_{M,i} C_i$$

where $w_{M,i} \geq 0$, $\sum_{i=1}^{4} w_{M,i} = 1$ are weights. Each component C_i represents a different aspect of the change between A and A^{MOD}.

1. Component C_1: This component monitors an overall shift in the accessibility from A to A^{MOD}. It is given as

$$C_1 = \sum_{i=1}^{3} w_{1,i} \left[Q_i(A) - Q_i\left(A^{MOD}\right) \right] + w_{1,4} \left[HM(A) - HM\left(A^{MOD}\right) \right]$$

   where $w_{1,i} \geq 0$, $\sum_{i=1}^{4} w_{1,i} = 1$ are weights for the component C_1 and $Q_i(x)$ represents 1st $Q_1(x)$, 2nd $Q_2(x)$, and 3rd $Q_3(x)$ quartile of x, and $HM(x)$ is harmonic mean of x. The harmonic mean is included here because it works well with ratios (see definition of R_j in (1) and (2)). Overall, component C_1 is positive if the values of A^{MOD} decrease and negative if values of A^{MOD} increase.

2. Component C_2: This component serves to quantify the change in variability or inequality in accessibility from A to A^{MOD}. It is given as

$$\begin{aligned} C_2 = {} & w_{2,1} \left[s\left(A^{MOD}\right) - s(A) \right] + w_{2,2} \left[GI\left(A^{MOD}\right) - GI(A) \right] S_C \\ & + w_{2,3} \left[T\left(A^{MOD}\right) - T(A) \right] \end{aligned}$$

   where $w_{2,i} \geq 0$, $\sum_{i=1}^{3} w_{2,i} = 1$ are weights for the component C_2 and $s(x)$ is sample standard deviation of x,

$$GI(x) = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} |x_i - x_j|}{2n \sum_{i=1}^{n} x_i}$$

   is a Gini index of x (see [30-33] and many others), $T(x)$ is range of x given as

$$T(x) = \max(x) - \min(x)$$

   and S_C is the scaling coefficient that we calculate as

$$S_C = \frac{Q_2(A) + Q_2\left(A^{MOD}\right)}{2}$$

   Sample standard deviation $s(x)$ together with range $T(x)$ measure variability, where $s(x)$ works better for larger data sets and $T(x)$ better for smaller data sets. Gini index $GI(x)$ measures the inequality in the distribution of A_i. The scaling coefficient S_C is a midpoint between A and A^{MOD} medians. It is necessary because the Gini index is a scaleless value from 0 to 1 (meaning that if we work with $10 \cdot A_i$ then quartiles will change but the Gini index will remain the same).

   Component C_2 is positive if the variability and inequality in accessibility increases and negative if the variability and inequality in accessibility decreases (we consider this to be a mitigating factor).

3. Component C_3: This component serves to measure inner fluctuation from A to A^{MOD} and it is given as

$$C_3 = w_{3,1} PM\left(A, A^{MOD}\right) S_C + w_{3,2} \frac{\sum_{i=1}^{n} \left|A_i - A_i^{MOD}\right|}{n}$$

where $w_{3,i} \geq 0$, $\sum_{i=1}^{2} w_{3,i} = 1$ are weights for the component C_3, n is the number of elements in A. Function $PM(x,y)$ then measures how the order of x changes in y and it is given as

$$PM(x,y) = 1 - \frac{2}{n(n-1)} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} H\left[(x_i - x_j)(y_i - y_j)\right]$$

where H is well-known Heaviside step function [34]. The function $PM(x,y)$ takes values from the interval $[0,1]$, which is ensured by the factor $\frac{2}{n(n-1)}$. The value $PM(x,y) = 0$ means that the order of x remained the same in y. On the other hand, the value $PM(x,y) = 1$ means that all elements of the vector x have been shuffled in y. Function $PM(x,y)$ is again scaleless and the scaling coefficient S_C is used again.

Component C_3 is always nonnegative and it serves the following purpose. If A^{MOD} is a rearrangement of A then the quartiles, sample standard deviation, harmonic mean, Gini index and range stay the same (and thus $C_1 = 0$, $C_2 = 0$); however the situation is different for each particular i. This change is then reflected only in the component C_3. On the other hand, if for example $A_i^{MOD} = A_i + k$, $k \in \mathbb{R}$ then $PM\left(A, A^{MOD}\right) = 0$. A drawback of map PM is that it only measures whether a change in the order occurred and not how big this change was. This purpose is served by the second part of component C_3.
4. Component C_4: This component describes the effect of outliers and their changes from A to A^{MOD}. It is given as

$$C_4 = w_{4,1} \frac{OUT\left(A^{MOD}\right) - OUT(A)}{n} S_C + w_{4,2} \left[\min(A) - \min(A^{MOD})\right]$$

where $w_{4,i} \geq 0$, $\sum_{i=1}^{2} w_{4,i} = 1$ are weights for the component C_4, function $OUT(x)$ measures the number of outliers in x (we have implemented this based on standard MATLAB detection method). Change of minimal accessibility is included as well but not maximal accessibility. This is because minimal accessibility has a higher impact on the overall situation.

We have chosen each element of each C_i after careful consideration of whether this element has any purpose in C_i. On the other hand, we do not claim that the components C_i are perfect. Other aspects could be included in CI and other elements could be worked into components C_i in follow-up research for further enhancement.

Overall, the negative value of CI illustrates what we consider a positive change in accessibility A_i and positive values of CI illustrate what we consider a negative change in accessibility A_i. Furthermore, this is based on our assumptions about military requirements. Utilization of CI in other areas might demand modifications to components C_i as well as to its interpretation. Similarly, the choice of weights impacts the explication of CI. Tab. 1 summarizes the weights that were used throughout this paper. The lowest weight was assigned to component C_3 as internal fluctuation is considered the least impactful for military purposes.

Tab. 1 Summarization of chosen weights for CI for each component. Component C_3 has the lowest weight as it is considered the least impactful for military purposes.

i	1	2	3	4
$w_{M,i}$	0.3	0.3	0.1	0.3
$w_{1,i}$	0.125	0.375	0.125	0.375
$w_{2,i}$	0.4	0.4	0.2	
$w_{3,i}$	0.5	0.5		
$w_{4,i}$	0.5	0.5		

Tab. 2 Values of components C_i and resulting index CI for different scenarios. The values of the relevant weights are shown in Tab 1.

	A	1	3	5	C_1	C_2	C_3	C_4	CI
I.a)	A^{MOD}	1	3	5	0	0	0	0	0
I.b)		5	3	1	0	0	2.833	0	0.283
II.a)		1.1	3.1	5.1	−0.117	−0.012	0.05	−0.05	−0.049
II.b)	A^{MOD}	1	4	5	−0.479	−0.002	0.166	0	−0.128
II.c)		0	3	5	0.827	0.551	0.167	0.5	0.580
III.a)	A^{MOD}	1.5	3	4	−0.119	−0.716	0.25	−0.25	−0.301
III.b)		0.5	3	5.5	0.286	0.489	0.167	0.25	0.324

3 Results

In this section, we investigate first of all individual components C_i that make up CI on theoretical data. In the second part, we will describe possible applications of CI on partially simulated data.

3.1 Theoretical data

This section aims to illustrate the meaning of the individual components of the coefficient CI on theoretical data. We will focus on the following three types of scenarios.

I. The vector A does not change, or only the values of A are rearranged.
II. A constant increases all or particular elements of A.
III. The range of A's elements will increase or decrease.

We now illustrate these scenarios in detail with concrete examples using the weights listed in Tab. 1.

The first scenario I.a) is trivial. Here, there is no change in values and $A = A^{MOD}$ holds-therefore $C_1 = C_2 = C_3 = C_4 = 0$ and thus the composite index $CI = 0$.

In scenario I. b) we describe the situation when the values of the vector A^{MOD} are created by permuting the values of the vector A. It can be seen that the vectors A and A^{MOD} have the same quantiles, harmonic means, variances, minimum values, Gini coefficients, and outliers. Then the equality $C_1 = C_2 = C_4 = 0$ must hold. The degree of permutation of A's elements is shown on the C_3 coefficient. Hence, we get $PM(A, A^{MOD}) = 1$ because the vector A with three elements has undergone three permutations, which is also the maximum number of possible permutations. In addition, these order changes are also reflected in the value of the expression $\sum_{i=1}^{n} \left|A_i - A_i^{MOD}\right| = 8$. In total, coefficients C_3 and CI are nonzero and the relevant values appear in Tab. 2.

In scenario II. a) the values of A_i^{MOD} are higher by 0.1 than the values of A_i. This increase in accessibility values is highlighted by the coefficient $C_1 = -0.117 < 0$. The sizes of the other coefficients are (in absolute value) considerably smaller. The coefficient C_2, which measures the change in variability, has a value of only $C_2 = -0.012$. The internal fluctuation is measured by the C_3 coefficient. When calculating it, we get $PM(A, A^{MOD}) = 0$, since the order of the elements of the vector A does not change. However, the coefficient C_3 is non-zero because the term $\sum_{i=1}^{n} \left|A_i - A_i^{MOD}\right|$ is non-zero. By calculating the coefficient of C_4, we find that its first part equals zero since there are no outliers in both sets. However, its second part is nonzero and C_4 as well.

Scenarios II.b) and II.c) show additional properties of the components C_i. The index C_1 is negative if the elements of the vector A are increasing and positive if elements of A decrease. However, in scenario II.c) the harmonic mean for A^{MOD} is in fact undefined because of the division by zero. In this case, value $HM(A^{MOD}) = 0$ is used as a mathematical extension of the harmonic mean. In scenario II.c), the index C_2 is more than 40 times larger in absolute value than in scenarios II.b) and II.a). This is because in II.c) the value range of the A file has increased significantly. On the other hand, $PM(A, A^{MOD}) = 0$ because the order of the values of vector A has not changed.

Scenarios III.a) and III.b) show the behaviour of components C_i when the range of A's elements changes. Tab. 2 shows that the component C_2 is positive when the range increases and negative when it decreases.

3.2 Applications of CI

We base our empirical analysis on simulated data that depict a segment of the Ukrainian frontline (see also [24]) at the end of January 2024, see [35]. Military units (57 in total) were generated along this frontline with several wounded soldiers assigned to each military unit. Locations for field hospitals were generated as well and distances from military units to these locations were calculated in ArcGIS PRO software.

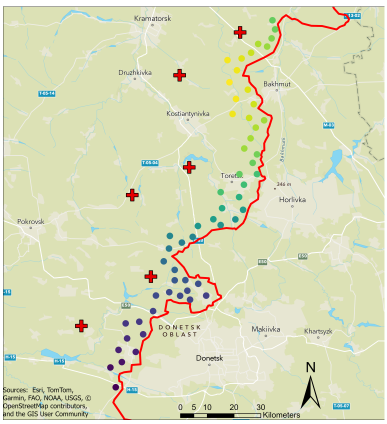

Fig. 1 Segment of eastern Ukrainian frontline together with simulated field hospitals (red crosses) and military units (coloured circles). The colour represents current accessibility indices A_i for scenario 1 (see Tab. 3) with dark colour representing the lowest and yellow the highest A_i.

Tab. 3 Distribution of field hospital capacities S_j for scenarios where one of the hospitals is lost. The first scenario considers decreasing capacities from north to south. The second scenario considers bigger and smaller hospitals.

Scenario	1	2	3	4	5	6
1	35	30	25	15	10	5
2	30	10	30	10	30	10

Total hospital capacity $\sum_{j=1}^{6} S_j$ was taken as 120 and it was distributed among field hospitals based on several scenarios. Table 3 summarizes the distribution of capacities for each scenario. The geographical distribution of field hospitals is shown in Fig. 1 and hospitals are ordered from north to south (meaning, that hospital H_1 is the one farthest to the north). The colour scheme for military units depicts accessibility indices A_i (for scenario 1, see Tab. 3) with the yellow colour indicating the highest A_i and the blue colour the lowest A_i.

First of all, let us investigate scenario 1 where field hospitals' capacities decrease from north to south. Fig. 2 summarizes the situation which occurs if one of the field hospitals is eliminated. Each group of connected points represents a scenario where a hospital H_j is eliminated and the left points represent A_i and right points A_i^{MOD} with the colour scheme representing values of A_i as well. Values above groups show components C_i in blue with overall CI in red.

We observe in Fig. 2 what we would naturally expect. Units on the north of the frontline have the highest values of A_i and after eliminating north hospitals H_1 or H_2 their situation worsens to the level of other units. However, only the most well-off units were affected and the situation did not become so much worse than it already was. This is

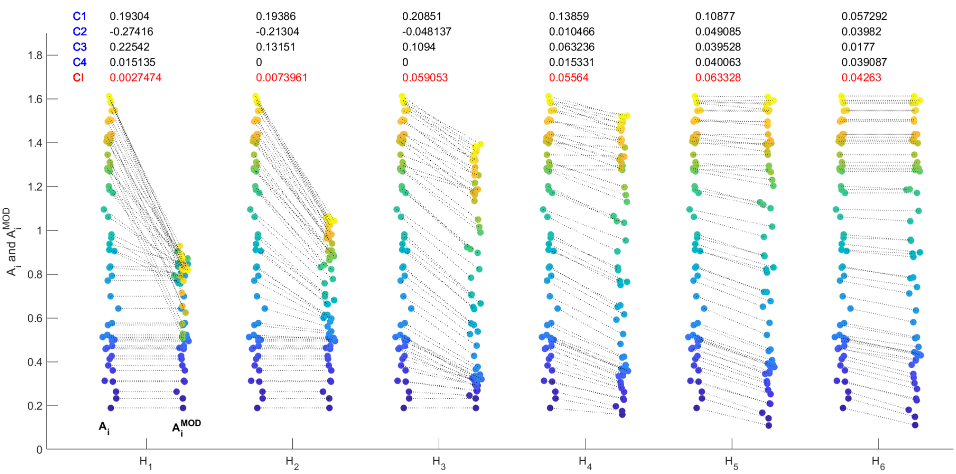

Fig. 2 Comparison of current accessibility indices A_i where one of the hospitals is lost in scenario 1. The picture is separated into six groups for the loss of each hospital. The left points in each group represent the original situation and the right points represent accessibility indices after a given hospital is lost.

represented by CI which is close to zero. Eliminating hospitals H_3 or H_4 that are in the middle of the frontline leads to a slight worsening of the situation for each unit as is shown with component C_1. Eliminating hospitals H_5 or H_6 results in a slight worsening of A_i but this time the change is larger for military units with the lowest A_i. Nevertheless, these units were already suffering from low accessibility and eliminated hospitals were the ones that had a small capacity to begin with.

Second, scenario 2 shows a situation with three large hospitals H_1, H_3, H_5 and three small hospitals H_2, H_4, H_6. We observe that the loss of hospitals H_2 and H_4 does not affect the situation too much and the effect of losing hospital H_6 is larger as this affects units with the lowest accessibility. The loss of H_3 is not dramatic as it affects only the most well-off units.

Nevertheless, losing hospital H_1 results in a dramatic change for certain units where their accessibility was more than halved. However, only a portion of units were affected and the situation did not change much for most of the units. Furthermore, component C_2 is close to a zero by which we see that the variability and inequality did not change as well. Altogether, CI for H_1 is double that for H_3 indicating that hospital H_1 deserves more protection. Analogously, losing hospital H_5 affects units with the lowest accessibility and variability then rises as well. This situation then results in the largest CI and it indicates that hospital H_5 might be the most important one.

Other distributions of hospitals' capacities were considered for measuring the impact of hospital elimination together with scenarios 1 and 2 (see Tab. 3). However, studied scenarios produced comparable results and therefore we did not include them here.

Instead, we will investigate another potential application of CI. Let us assume that we want to redistribute medical resources and need to compare the current situation with the proposed options to choose the best option. Currently, all the resources are distributed equally and there are 6 potential redistributions, see Tab. 4 that summarizes current and proposed options, redistributions 1 and 2 are the same as scenarios 1 and 2 in Tab. 3. The

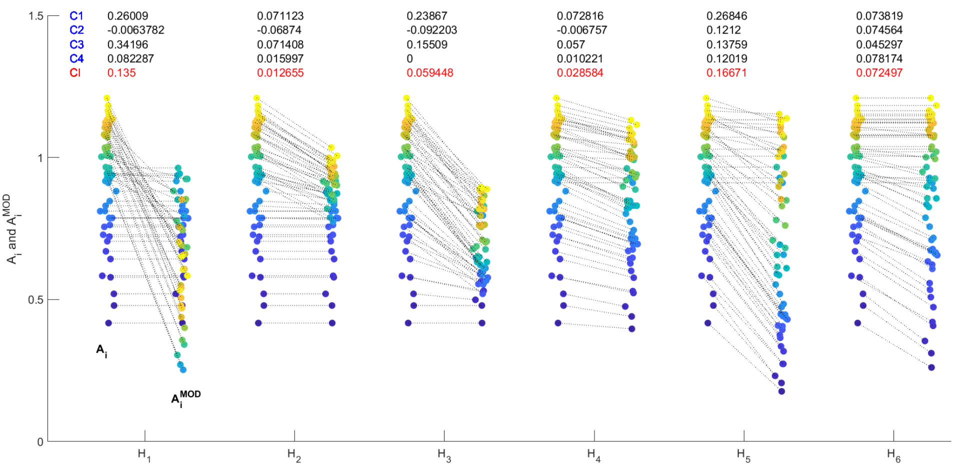

Fig. 3 Comparison of current accessibility indices A_i where one of the hospitals is lost in scenario 2.

Tab. 4 Current distribution of capacities together with a list of suggested redistributions that will be compared to the current situation.

H_j	1	2	3	4	5	6
current	20	20	20	20	20	20
3	5	10	15	25	30	35
4	10	30	10	30	10	30
5	10	15	45	15	25	10
6	15	20	25	15	10	35

current and proposed distributions are compared based on *CI* and the results are shown in Fig. 4.

We observe that the redistribution 1 a 3 worsens the accessibility by a big margin. Redistributions 2 and 5 might lead to a slightly worse situation where the units with the lowest accessibility are affected. Redistributions 4 and 6 might be considered comparable to the current situation (or if we ignore component C_3, which measures internal redistribution, even advantageous). Therefore, redistributions 4 and 6 offer the best results and we should choose one of them based on these results.

4 Discussion and limitations

Precedent examples illustrated possible applications of the composite index for comparison of accessibility indices on theoretical and simulated data.

Two simulated scenarios where a hospital was lost showed that the *CI* favours situations in which:

1. The units with the highest accessibility are affected, see Fig. 2 for hospitals H_1 and H_2 that have lower *CI* as compared with hospitals H_3-H_6.
2. Where the difference in accessibility between units is reduced, see Fig. 3 for hospitals H_2 and H_4 as opposed to other hospitals on Fig. 3 with larger *CI*.

On the other hand, *CI* produced medium values when units were moderately affected and the largest values of *CI* were obtained when there was a dramatic change in accessibility or when the units with the lowest accessibility were highly impacted. Similarly, when options for redistribution of capacities were considered then *CI* refuted the situations where the variability and inequality increased and the minimal accessibility decreased as well, see Fig. 4 for distributions 1 and 3. We consider this to be a positive trait of *CI* for military requirements where each life of a soldier is precious and might be endangered.

Investigation of theoretical small case situations, see Tab. 2, showed the effects of individual components that are contained in *CI*. For example, raising each value by 0.1 in situation II.a) resulted in $CI = -0.049$. This can be interpreted as a marginal positive change that occurred because of an increase in overall accessibility. On the other hand, when one value was decreased to zero in II.c) this resulted in $CI = 0.580$ which indicates a significantly worse situation on the frontline. Theoretical data therefore agree with our intention how to develop the components.

The developed composite index is based on theoretical assumptions and tested on simulated data. It lacks yet further rigorous investigation for the military's requirements

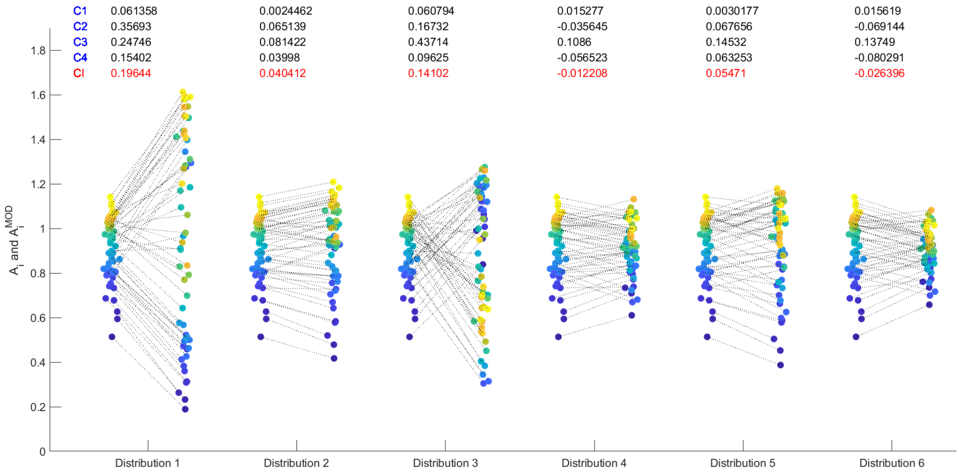

Fig. 4 A scenario where an initial distribution of hospital capacities is redistributed. Each group represent one of six possible redistributions with the current accessibility indices to the left and after the redistribution on the right.

that is necessary before index *CI* could be utilized in real applications. Additional development with the help of military personnel might be necessary to appropriate the index for the specific needs of any given military based on its doctrine, see also [36].

Nevertheless, the work done on the composite index could be utilized further for civilian needs in guiding the effective allocation of resources, see on a similar note the investigation of resource redistribution on Fig. 4. Where the military might consider potential threats to any given hospital, civilian officials might consider several locations to build a new hospital. In that case, a multiparametric index combining multiple factors and not only *CI* could be utilized in these situations. See also the p-median method in [37] and other indices in [32] for other factors that could be included. Furthermore, as far as we know, the composite index has not been yet used for accessibility measurements and this article then opens new avenues for further research.

We think that the strength of accessibility indices lies in the fact that it has an approachable interpretation and that they can be used in combination with real-time data and processed algorithmically as an aid in decision processes, see Fig. 4 and the redistribution of resources. It is our subjective opinion that distributions 3 and 5 are visually almost identical and it seems to be difficult distinguishing them. However, composite index *CI* shows that the distribution 5 is the better one. We also think that index *CI* should be utilized cautiously in tandem with human insights to yield the best results. Similarly, accessibility indices A_i offer only one point of view on field hospitals and it might be useful to implement them into a bigger decision-making process to generate the best result.

Similarly, composite indices might prove to be useful in other areas as well. For example, for investigating a potential loss of a distribution centre on resupplying. However, as we are not familiar with this field additional investigation might be necessary before applying composite indices.

We would like to emphasize, that certain parts of the change between A and A^{MOD} could be described via other means. For example, central tendency is described by the median and quartiles in the component C_1. However, central tendency can be described also by the mean. Nevertheless, the role of mean would overlap with median and as a consequence, certain parameters of the change between A and A^{MOD} would be overshadowed by this.

5 Conclusion

We have developed theoretically a composite index CI for comparing two sets of accessibility indices and we have shown its potential usefulness in aggregating multiple properties into one interpretable index. This in fact is the clear strength of composite indices as they offer a way for comparison between several countries, armies, situations, and so on. However, there is also an obvious drawback to composite indices that they demand a series of simplifications that might leave out potentially vital information.

Accessibility indices have been developed quite extensively in the last two decades and they find their applications across multiple segments of civilian life. However, two-step floating catchment area methods offer promising research direction as illustrated by many recent papers on this topic, see [38-43]. Now with recent developments, see [24], they might be applied for military purposes as well.

Acknowledgement

This research work was supported by the Project for the Development of the Organization DZRO "Military autonomous and robotic systems" under Ministry of Defence and Armed Forces of Czech Republic.

References

[1] STACHERL, B. and O. SAUZET. Gravity Models for Potential Spatial Healthcare Access Measurement: a Systematic Methodological Review. *International Journal of Health Geographics*, 2023, **22**(34). DOI 10.1186/s12942-023-00358-z.

[2] PENG, Z. The Jobs-Housing Balance and Urban Commuting. *Urban Studies*, 1997, **34**(8), pp. 1215-1235. DOI 10.1080/0042098975600.

[3] RADKE, J. and L. MU. Spatial Decompositions, Modeling and Mapping Service Regions to Predict Access to Social Programs. *Geographic Information Sciences*, 2000, **6**(2), pp. 105-112. DOI 10.1080/10824000009480538.

[4] GUAGLIARDO, M. Spatial Accessibility of Primary Care: Concepts, Methods and Challenges. *International Journal of Health Geographics*, 2004, **3**(3). DOI 10.1186/1476-072X-3-3.

[5] LUO, W. and F. WANG. Measures of Spatial Accessibility to Healthcare in a GIS Environment: Synthesis and a Case Study in Chicago Region. *Environment and Planning B: Urban Analytics and City Science*, 2003, **30**(6), pp. 865-884. DOI 10.1068/b29120.

[6] LUO, W. and Y. QI. An Enhanced Two-Step Floating Catchment Area (E2SFCA) Method for Measuring Spatial Accessibility to Primary Care Physicians. *Health and Place*, 2009, **15**(4), pp. 1100-1107. DOI 10.1016/j.healthplace.2009.06.002.

[7] MCGRAIL, M. and J. HUMPHREYS. Measuring Spatial Accessibility to Primary Care in Rural Areas: Improving the Effectiveness of the Two-Step Floating Catchment Area Method. *Applied Geography*, 2009, **29**, pp. 533-541. DOI 10.1016/j.apgeog.2008.12.003.

[8] DAI, D. Black Residential Segregation, Disparities in Spatial Access to Health Care Facilities, and Late-Stage Breast Cancer Diagnosis in Metropolitan Detroit. *Health and Place*, 2010, **16**(5), pp. 1038-1052. DOI 10.1016/j.healthplace.2010.06.012.

[9] DAI, D. and F. WANG. Geographic Disparities in Accessibility to Food Stores in Southwest Mississippi. *Environment and Planning B: Planning and Design*, 2011, **38**(4), pp. 659-677. DOI 10.1068/b36149.

[10] LUO, W. and T. WHIPPO. Variable Catchment Sizes for the Two-Step Floating Catchment Area (2SFCA) Method. *Health and Place*, 2012, **18**(4), pp. 789-795. DOI 10.1016/j.healthplace.2012.04.002.

[11] LANGFORD, M., G. HIGGS and R. FRY. Multi-modal Two-Step Floating Catchment Area Analysis of Primary Health Care Accessibility. *Health and Place*, 2016, **38**, pp. 70-81. DOI 10.1016/j.healthplace.2015.11.007.

[12] WAN, N., B. ZOU and T. STERNBERG. A 3-step Floating Catchment Area Method for Analyzing Spatial Access to Health Services. *International Journal of Geographical Information Science*, 2012, **26**(6), pp. 1073-1089. DOI 10.1080/13658816.2011.624987.

[13] WIDENER, M. and J. SHANNON. When are Food Deserts? Integrating Time into Research on Food Accessibility. *Health and Place*, 2014, **30**, pp. 1-3. DOI 10.1016/j.healthplace.2014.07.011.

[14] WIDENER, M., S. FARBER, T. NEUTENS and M. HORNER. Spatiotemporal Accessibility to Supermarkets Using Public Transit: An Interaction Potential Approach in Cincinnati, Ohio. *Journal of Transport Geography*, 2015, **42**, pp. 72-83. DOI 10.1016/j.jtrangeo.2014.11.004.

[15] BAUER, J. and D. GRONEBERG. Measuring Spatial Accessibility of Health Care Providers-Introduction of a Variable Distance Decay Function Within the Floating Catchment Area (FCA) Method. *PLOS ONE*, 2016, **11**(7). DOI 10.1371/journal.pone.0159148.

[16] KC, K., J. CORCORAN and P. CHHETRI. Measuring the Spatial Accessibility to Fire Stations Using Enhanced Floating Catchment Method. *Socio-Economic Planning Sciences*, 2020, **69**. DOI 10.1016/j.seps.2018.11.010.

[17] LIU, W., H. XU, J. WU, W. LI and H. HU. Measuring Spatial Accessibility to Refuge Green Space after Earthquakes: A Case Study of Nanjing, China. *PLOS ONE*, 2022, **17**(6). DOI 10.1371/journal.pone.0270035.

[18] SU, H., W. CHEN and M. CHENG. Using the Variable Two-Step Floating Catchment Area Method to Measure the Potential Spatial Accessibility of Urban Emergency Shelters. *GeoJournal*, 2022, **87**(4), pp. 2625-2639. DOI 10.1007/s10708-021-10389-3.

[19] SU, H., W. CHEN and C. ZHANG. Evaluating the Effectiveness of Emergency Shelters by Applying an Age-Integrated Method. *GeoJournal*, 2023, **88**(4), pp. 951-969. DOI 10.1007/s10708-022-10669-6.

[20] AYDIN, N. A Stochastic Mathematical Model to Locate Field Hospitals under Disruption Uncertainty for Large-Scale Disaster Preparedness. *An International Journal of Optimization and Control: Theories and Applications*, 2016, **6**(2), pp. 85-102. DOI 10.11121/ijocta.01.2016.00296.

[21] SALMAN, F. and S. GÜL. Deployment of Field Hospitals in Mass Casualty Incidents. *Computers and Industrial Engineering*, 2014, **74**, pp. 37-51. DOI 10.1016/j.cie.2014.04.020.

[22] HASSAN, S., K. ALNOWIBET, P. AGRAWAL and A. MOHAMED. Optimum Location of Field Hospitals for COVID-19: A Nonlinear Binary Metaheuristic Algorithm. *Computers, Materials and Continua*, 2021, **68**(1), pp. 1183-1202. DOI 10.32604/cmc.2021.015514.

[23] ALISAN, O., M. ULAK, E. OZGUVEN and M. HORNER. Location Selection of Field Hospitals Amid COVID-19 Considering Effectiveness and Fairness: A Case Study of Florida. *International Journal of Disaster Risk Reduction*, 2023, **93**. DOI 10.1016/j.ijdrr.2023.103794.

[24] JEKL, J. and J. JÁNSKÝ. Geographical Distribution Analysis of Field Hospitals Along the Frontline: 2SFCA Method-based Approach. In: *Proceedings of the Challenges to National Defence in Contemporary Geopolitical Situation*. Brno, Czech Republic, 2024, pp. 403-410. DOI 10.3849/cndcgs.2024.403.

[25] Human Development Index [online]. [Viewed 2024-07-02]. Available from: https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

[26] Gender Inequality Index [online]. [Viewed 2024-07-02]. Available from: https://hdr.undp.org/data-center/thematic-composite-indices/gender-inequality-index#/indicies/GII

[27] JÖRG, R. and L. HALDIMANN. MHV3SFCA: A New Measure to Capture the Spatial Accessibility of Health Care Systems. *Health and Place*, 2023, **79**. DOI 10.1016/j.healthplace.2023.102974.

[28] ZHOU, Z., X. ZHANG, M. LI and X. WANG. An SCM-G2SFCA Model for Studying Spatial Accessibility of Urban Parks. *International Journal of Environmental Research and Public Health*, 2023, **20**(1). DOI 10.3390/ijerph20010714.

[29] YANG, J., O. ALISAN, M. MA, E.E. OZGUVEN, W. HUANG and L. VIJAYAN. Spatial Accessibility Analysis of Emergency Shelters with a Consideration of Sea Level Rise in Northwest Florida. *Sustainability*, 2023, **15**(13). DOI 10.3390/su151310263.

[30] KAKWANI, N. *Income Inequality and Poverty Methods of Estimation and Policy Applications*. New York, USA: Oxford University Press, 1980. ISBN 0-19-520227-9.

[31] CERIANI, L. and P. VERME. The Origins of the Gini Index: Extracts from Variabilità e Mutabilità (1912) by Corrado Gini. *Journal of Economic Inequality*, 2012, **10**, pp. 421-443. DOI 10.1007/s10888-011-9188-x.

[32] JEKL, J. and J. JÁNSKÝ. Security Challenges and Economic-Geographical Metrics for Analyzing Safety to Achieve Sustainable Protection. *Sustainability*, 2022, **14**(22). DOI 10.3390/su142215161.

[33] DRUCKMAN, A. and T. JACKSON. Measuring Resource Inequalities: The Concepts and Methodology for an Area-based Gini Coefficient. *Ecological Economics*, 2008, **65**(2), pp. 242-252. DOI 10.1016/j.ecolecon.2007.12.013.

[34] Heaviside Step Function [online]. [Viewed 2024-07-25]. Available from: https://mathworld.wolfram.com/HeavisideStepFunction.html

[35] Latest news on Live Maps [online]. [Viewed 2024-01-31]. Available from: https://liveuamap.com

[36] SUCHÁNEK, Z. and A. OULEHLOVÁ. Field Hospital Logistics Support System Risk Assessment. In: TUŠER, I. and Š. HOŠKOVÁ-MAYEROVÁ, eds. *Trends and Future Directions in Security and Emergency Management*. Springer, 2022, pp. 241-252. ISBN 978-3-030-88907-4. DOI 10.1007/978-3-030-88907-4_13.

[37] KOCATEPE, A., E. OZGUVEN, M. HORNER and H. OZEL. Pet- and Special Needs-Friendly Shelter Planning in South Florida: A Spatial Capacitated P-median-Based Approach. *International Journal of Disaster Risk Reduction*, 2018, **31**, pp. 1207-1222. DOI 10.1016/j.ijdrr.2017.12.006.

[38] WHITEHEAD, J., A. PEARSON, R. LAWRENSON and P. ATATOA-CARR. Defining General Practitioner and Population Catchments for Spatial Equity Studies Using Patient Enrolment Data in Waikato. *Applied Geography*, 2020, **115**. DOI 10.1016/j.apgeog.2019.102137.

[39] WHITEHEAD, J., K. BLATTNER, R. MILLER, S. CRENGLE, S. RAM, X. WALKER et al. Defining Catchment Boundaries and Their Populations for Aotearoa New Zealand's Rural Hospitals. *Journal of Primary Health Care*, 2023, **15**(1), pp. 14-23. DOI 10.1071/HC22133.

[40] OHASHI, K., K. FUJIWARA, T. OSANAI, T. TANIKAWA, K. BANDO, S. YAMASAKI et al. Potential Crowdedness of Mechanical Thrombectomy and Cerebral Infarction Mortality in Japan: Application of Inverted Two-Step Floating Catchment Area Method. *Journal of Stroke and Cerebrovascular Diseases*, 2022, **31**(9). DOI 10.1016/j.jstrokecerebrovasdis.2022.106625.

[41] LEE, W., J. JURKOWSKI and N. GENTILE. Food Pantries and Food Deserts: Health Implications of Access to Emergency Food in Low-Income Neighborhoods. *Urban Social Work*, 2023, **7**(1), pp. 29-42. DOI 10.1891/USW-2022-0008.

[42] SUBAL, J., P. PAAL and J. KRISP. Quantifying Spatial Accessibility of General Practitioners by Applying a Modified Huff Three-Step Floating Catchment Area (MH3SFCA) Method. *International Journal of Health Geographics*, 2021, **20**(1). DOI 10.1186/s12942-021-00263-3.

[43] JAVANMARD, R., J. LEE, K. KIM, J. PARK and E. DIAB. Evaluating the Impacts of Supply-demand Dynamics and Distance Decay Effects on Public Transit Project Assessment: A Study of Healthcare Accessibility and Inequalities. *Journal of Transport Geography*, 2024, **116**. DOI 10.1016/j.jtrangeo.2024.103833.