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Determination of factors of maximum influence on the occurrence of fires in conditions of limited *a priori* information in the war zone in the east of Ukraine

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abstract

The expediency of using the inverted Floyd–Warshall algorithm for a deeper study of factors of maximum influence on the occurrence and development of fires in the war zones of Donetsk and Lugansk oblasts is shown. It relates to the fact that fire is one of the important parameters of the monitoring system that affects the ecological situation in the region. However, in the absence of a priori information about fires and hostilities, the formation of a set of factors influencing the occurrence and development of fires in the region is a laborious process. The primary assessment of a priori information allows generalising and averaging the factors that influence the occurrence of fires in these regions. The inverted Floyd–Warshall algorithm is a simple algorithm to implement, although to eliminate errors in mathematical calculations and to form adjacency matrices, a program code was developed in the Python programming language. Using the built-in visualisation software tools, a weighted oriented graph of factors influencing fires was built; the weights of these factors, determined at the initial stage, are also indicated on the edges of the graph. An adjacency matrix has been compiled, which contains information about the presence or absence of links between graph vertices. The factors of maximum influence on the occurrence and development of fires in Donetsk and Lugansk oblasts are determined, considering the specifics of the area and the results of hostilities. The results of the algorithm confirmed that hostilities create a fire hazard situation in the region. Due to the lack of a complete set of data, it becomes almost impossible to obtain results of mathematical calculations that are more accurate, since open-source data cannot provide errorless data on hostilities. For the same reason, the study area is not divided into separate segments in order to obtain more accurate results of mathematical calculations for each segment. Despite this, the software implementation of the inverted Floyd–Warshall algorithm is a universal method for solving the problem of finding and selecting factors of maximum and minimum influence on the occurrence of fires in environmental monitoring issues.

Визначення факторів максимального впливу на виникнення пожеж в умовах обмеження апріорної інформації у зоні бойових дій на сході України

Ольга Бутенко, Анна Топчий

Резюме. З метою глибшого вивчення факторів максимального впливу на виникнення та розвиток пожеж на території Донецької та Луганської областей у зоні бойових дій показано доцільність використання інвертованого алгоритму Флойда-Уоршелла. Це пов'язано з тим, що пожежа є одним із важливих параметрів системи моніторингу, що впливає на екологічну ситуацію регіону. Однак, в умовах браку апріорної інформації про пожежі та бойові дії формування набору факторів, що впливають на виникнення та розвиток пожеж у регіоні, є трудомістким процесом. Первинна оцінка апріорної інформації дозволяє узагальнити та усереднити фактори, що впливають на виникнення пожеж в областях. Інвертований алгоритм Флойда-Уоршелла є простим алгоритмом для реалізації, однак для виключення помилок у математичних розрахунках та формуванні матриць суміжності було розроблено програмний код мовою програмування Python. За допомогою вбудованих програмних інструментів візуалізації побудовано зважений орієнтований граф факторів впливу на пожежі, ваги цих факторів, визначені на початковому етапі, також вказані на ребрах графа. Складено матрицю суміжності, що містить інформацію про наявність чи відсутність зв'язків між вершинами графа. Визначено фактори максимального впливу на виникнення та розвиток пожеж у Донецькій та Луганській областях з урахуванням специфіки місцевості та внаслідок бойових дій. Результати алгоритму підтвердили, що військові дії створюють пожежонебезпечну ситуацію в регіоні. Через відсутність повного набору даних отримати точніші результати математичних обчислень стає практично неможливим, оскільки дані відкритих джерел не можуть надати точні дані про бойові дії. Досліджувана територія з цієї причини не розбита на окремі сегменти для отримання більш точних результатів математичних обчислень для кожного сегмента. Незважаючи на це програмна реалізація інвертованого алгоритму Флойда-Уоршелла є універсальним методом вирішення задачі пошуку та вибору факторів максимального та мінімального впливу на виникнення пожеж у задачах екологічного моніторингу.

Ключові слова: екологія, пожежі в природі, вплив бойових дій, моніторинг, фактори, алгоритм.

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Introduction

Fires are a key factor in damage to the natural landscape and ecosystems [Johnstone *et al*. 2016; Molina *et al.* 2019; Zechuan *et al*. 2022]. Studies have shown that fires not only damage natural resources and ecosystems, but also have a harmful effect on human life [San-Miguel-Ayanz *et al.* 2013; Modugno *et al.* 2016; Argañaraz *et al.* 2017; Zechuan *et al*. 2022]. The annual increase in the number of fires emphasizes the need to study the spatial distribution and factors influencing their occurrence [Hering *et al.* 2009; Moreira *et al.* 2020; Twidwell *et al.* 2019; Zechuan *et al*. 2022]. The factors influencing the occurrence of fires are studied in [Avila-Flores *et al.* 2010; Oliveira *et al*. 2012; Guo *et al.* 2015; Zechuan *et al*. 2022] and show that fires are the result of the interaction of many factors, the weights of these factors are not the same in different ecosystems [Collins *et al.* 2015; Zechuan *et al*. 2022].

These factors covered four categories: climatic, topographic, vegetative, and anthropogenic [Ganteaume *et al.* 2013; Wu *et al.* 2021; Zechuan *et al*. 2022].

Climatic influence on the wind-water balance and fire heat exchange of forest combustible materials [Rollins *et al.* 2002; Xiao-Ying *et al*. 2013; Zechuan *et al*. 2022]. They also affect the moisture content of combustible materials during forest fires [Sharples *et al*. 2009; Zechuan *et al*. 2022]. The occurrence of fires is also closely related to climatic factors [Westerling *et al.* 2006; Zechuan *et al*. 2022]. In the context of the continuous development of the social economy and modern transport, the number of factors causing fires increases significantly [Archibald *et al.* 2009; Penman *et al*. 2012; Mundo *et al.* 2013]. One of the key factors is the human factor [Han *et al.* 2015; Guo *et al.* 2016; Guo

et al. 2016; Zechuan *et al.* 2022]. The human factor affects not only the occurrence of fires, but also their intensity, frequency, and distribution. The complexity and multiplicity of fire systems is due to the combined influence of various factors in different ecosystems [Sturtevant *et al.* 2007; Miranda *et al.* 2011; Wu *et al.* 2014; Zechuan *et al.* 2022].

The article considers and analyses the causes of fires in relation to the ecological system of the Donbass region. Due to the technogenic congestion, the ecological situation of the Donbass has always needed continuous monitoring, but in the conditions of hostilities, it can turn out to be catastrophic. Thus, monitoring and determining the factors of maximum and minimum impact on the occurrence of fires is an urgent task of environmental monitoring. Fire is one of the important parameters of the monitoring system that affects the ecological situation in the region.

The hostilities have led to the fact that part of the *a priori* information about fires has been lost and cannot be restored, the resumption of environmental monitoring is difficult due to active hostilities, and is impossible at all in the occupied territories. In the context of a shortage of the initial data set for analysis, the use of Earth remote sensing (ERS) data and methods of mathematical analysis and mathematical modelling is relevant. In this paper, the factors of fire occurrence in the territory of Donetsk and Lugansk oblasts are determined, based on which a graph with given weights and an adjacency matrix are built. The purpose of this work is the software implementation of the inverted Floyd–Warshall algorithm in the Python programming language to identify the factors of maximum and minimum impact on the occurrence of fires in the eastern part of Ukraine due to active hostilities.

General theoretical data

Typically, the Floyd–Warshall algorithm is used in logistics problems to find the shortest distance between individual delivery points. However, it can be adapted to find the factors of maximum influence by using its inverted form. In general, the Floyd-Warshall algorithm is a type of dynamic programming—a technique that eliminates inaccuracies by considering the solution to be obtained as interconnected solutions. This means that the solutions are formed from the solution obtained in the previous step, and there is more than one possible solution.

The initial data set for the implementation of the Floyd–Warshall algorithm is a matrix graph, and the result is the shortest path of all graph vertices [Chairi *et al.* 2016; Triana 2018]. The Floyd–Warshall algorithm compares all possible paths on a graph for each edge of all vertices. Suppose there is a graph G with vertices V, each numbered from *1* to n. Suppose there is also a shortest path function (u, v, k) that recovers the shortest path from u to v using only vertex 1 in k as an intermediate point. The goal of using this function is to find the shortest path from each vertex u to vertex v through intermediate node *1* to $k + 1$. The shortest path from u to v is calculated by the formula that is the basis of the algorithm:

$$d_{u,v}{}^{m} = min(\mathrm{d}_{\mathrm{u,m}}{}^{\mathrm{m-1}} + \mathrm{d}_{\mathrm{m,v}}{}^{\mathrm{m-1}}; \mathrm{d}_{\mathrm{u,v}}{}^{\mathrm{m-1}}), \qquad (1)$$

where u and v are the values of each element of the matrix, which are equal to the length of the shortest arc connecting vertex u with vertex v.

m is the order of the matrix.

If the indicated vertices in the graph are not connected by an edge, then

$$d^{0}(u, v) = \infty.$$

The process of determining the minimum distance using the Floyd–Warshall algorithm can be broken down into the following steps:

1. At the first iteration, each cell of the matrix is compared with the largest element of the pair—the distance between the two start points and the sum of the distance from the start point to the end point (target point = first iteration) and the distance from the start point (start point = first iteration) until the end point. In other words, $W[u, v] > W[u, k] + W[k, v]$.

2. The distance between the two start points is replaced by the sum of the distance from the start point to the end point (target point = first iteration) with the distance from the start point (start point = first iteration) to the end point ($W[u, k] + W[k, v]$).

3. If the first iteration fails, then the distance used is the distance between the two starting points ($W[u, v]$).

4. The iteration process is performed until the last iteration (the number of iterations = the total number of graph vertices) [Ayunita *et al.* 2017; Triana 2018].

Practical implementation of the inverted Floyd–Warshall algorithm for finding factors of maximum influence on the occurrence of fires

At the initial stage, to implement this algorithm and build a weighted directed graph, an analysis of the factors affecting the occurrence of fires in the territory of Donetsk and Lugansk oblasts caused by the active hostilities was carried out. Given the lack of *a priori* information, these factors were generalised and averaged (Fig. 1, Table 1). Each factor influencing the occurrence and development of a fire has its own weight [0, 1], where 0 is no effect, and 1 is direct effect (the weights are presented on the edges of a weighted directed graph).

Table 1. **Factors affecting the occurrence and development of a fire**

Таблиця 1. **Фактори, що впливають на виникнення та розвиток пожежі**

Vertex number	Factor	Vertex number	Factor
0	Active fighting	5	Power lines (PL)
1	Wind speed	6	Gas facilities
2	Forest	7	Combined heat and power plant
3	Residential development	8	Human factors
4	Railway infrastructure	9	Fire

The adjacency matrix D0 contains the values 0 and 1, which indicate whether there is a connection between the vertices of the graph. Considering the weights of the weighted directed graph, the matrix D1 is constructed based on the matrix D0.

$$D_1 = \begin{vmatrix} \infty & \infty & 0.3 & 0.8 & 0.6 & 0.7 & 0.9 & 0.9 & 0.4 & 1 \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 1 \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 1 \\ \infty & 0.2 & \infty & \infty & \infty & 0.3 & \infty & 0.3 & 0.3 & 1 \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 1 \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 1 \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 1 \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & 1 \\ 0.2 & \infty & \infty & 0.3 & 0.2 & 0.2 & 0.2 & 0.4 & \infty & 1 \\ \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty & \infty \end{vmatrix}$$

where for software implementation ∞ is replaced by the text value *Inf*.

Using formula (1), the factors of minimal influence on the occurrence and development of fires were found, which are 0.2. The factors of minimal influence on the occurrence and development of fires include the presence of a residential area around the source of fire, the human factor, the presence of railway infrastructure, the presence of power lines and gas facilities.

As stated above, an inverted Floyd–Warshall algorithm is used to find the maximum influence factors. Thus, the final formula would be as follows:

$$(d_{u,v}{}^{m})_{max} = 1 - d_{u,m}{}^{m} \qquad (2)$$

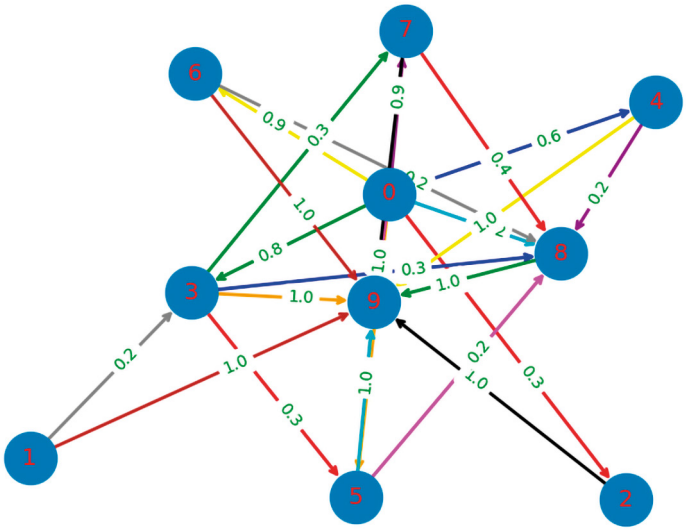

Fig. 1. Oriented graph with weights for the factors influencing the occurrence and development of fires in the territory of Donetsk and Luhansk oblasts caused by hostilities.

Рис. 1. Орієнтований граф із вагами для факторів впливу на виникнення та розвиток пожеж на території Донецької та Луганської областей внаслідок бойових дій.

Thus, according to formula (2), the factors of maximum influence on the occurrence and development of fires are 0.9, which include active hostilities, and the presence of active hostilities near gas facilities and combined heat and power plants brings a dangerous fire hazardous situation for the region, which affects the ecological condition as a whole.

The most important disadvantage, which may lead to inaccurate calculation results, is that the territory of Donetsk and Luhansk oblasts should be divided into smaller study areas, for which the algorithm should be implemented separately. In this case, for each smallest area there is a possibility to determine more precisely all factors of influence on the occurrence and development of fires in the region, considering the presence of fire-hazardous infrastructure. By having more accurate information on the battlefields in these truncated areas, more correct results can be obtained, confirming the difficulty of research in a data-poor environment.

Conclusions

In the course of this work, a practical implementation of the inverted Floyd–Warshall algorithm was carried out to identify the factors of maximum influence on the occurrence and development of fires in Donetsk and Luhansk oblast caused by the hostilities.

The results of the algorithm implementation in Python confirmed that the military activities create a fire hazardous situation in the region and are the factors of maximum influence on the occurrence and development of fires.

The implementation of the algorithm has time and memory complexity, but the main advantage is the ease of reconstructing the links between the vertices of the weighted oriented graph and the simplicity of implementation.

Despite the simplicity of the mathematical implementation of this algorithm, the Python programming language environment was chosen to eliminate calculation errors due to human error. The more influencing factors are involved in the calculations, the higher the probability of error occurrence at each iteration step becomes. However, the implemented Floyd–Warshall algorithm using the Python programming language is applicable for any number of factors, which makes the solution to the problem universal.

The disadvantage of the solution of the specified problem is the large area of research, generalisation of influence factors on the occurrence and development of fires in the entire territory.

With limited *a priori* information, it becomes almost impossible to obtain more accurate results from mathematical calculations, as open-source data cannot provide accurate battlefield data.

The study of factors influencing the occurrence of fires by various methods can be used as a tool for predicting their occurrence. This is useful for building decision rules in an emergency.

The main application of the algorithm is in various networks including transport, but has wide application for fire studies as well. For this reason, the inverted Floyd–Warshall algorithm was chosen for this issue.

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