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METHOD FOR LOCATION OF AN EXTERNAL DUMP IN SURFACE MINING USING THE A-STAR ALGORITHM

METODA LOKALIZACJI ZWAŁOWISKA ZEWNĘTRZNEGO W GÓRNICTWIE ODKRYWKOWYM Z WYKORZYSTANIEM ALGORYTMU A-STAR

The construction of a surface mine always involves the necessity of accessing deposits through the removal of the residual overburden above. In the beginning phase of exploitation, the masses of overburden are located outside the perimeters of the excavation site, on the external dump, until the moment of internal dumping.

In the case of lignite surface mines, these dumps can cover a ground surface of several dozen to a few thousand hectares. This results from a high concentration of lignite extraction, counted in millions of Mg per year, and the relatively large depth of its residual deposits.

Determining the best place for the location of an external dump requires a detailed analysis of existing options, followed by a choice of the most favorable one.

This article, using the case study of an open-cast lignite mine, presents the selection method for an external dump location based on graph theory and the A-star algorithm. This algorithm, based on the spatial distribution of individual intersections on the graph, seeks specified graph states, continually expanding them with additional elementary fields until the required surface area for the external dump – defined by the lowest value of the occupied site – is achieved. To do this, it is necessary to accurately identify the factors affecting the choice of dump location. On such a basis, it is then possible to specify the target function, which reflects the individual costs of dump construction on a given site. This is discussed further in chapter 3.

The area of potential dump location has been divided into elementary fields, each represented by a corresponding geometrical locus. Ascribed to this locus, in addition to its geodesic coordinates, are the appropriate attributes reflecting the degree of development of its elementary field. These tasks can be carried out automatically thanks to the integration of the method with the system of geospatial data management for the given area.

The collection of loci, together with geodesic coordinates, constitutes the points on the graph used during exploration. This is done using the A-star algorithm, which uses a heuristic function, allowing it to identify the optimal solution; therefore, the collection of elementary fields, which occupy the potential construction area of a dump, characterized by the lowest value representing the cost of occupation and dumping of overburden in the area.

The precision of the boundary, generated by the algorithm, is dependent on the established size of the elementary field, and should be refined each time by the designer of the surface mine.

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This article presents the application of the above method of dump location using the example of "Tomisławice," a lignite surface mine owned by PAK KWB Konin S.A. The method made it possible to identify the most favorable dump location on the northeast side of the initial pit, within 2 kilometers of its surrounding area (discussed further in chapter 3).

This method is universal in nature and, after certain modifications, can be implemented for other surface mines as well.

Keywords: surface mining, dump, excavation site, graph theory, A-star algorithm

Budowa kopalni odkrywkowej wiąże się zawsze z koniecznością udostępnienia złoża poprzez zdjęcie zalegającego nad nim nadkładu. W początkowej fazie eksploatacji masy nadkładowe lokalizowane są poza granicami wyrobiska odkrywkowego na zwałowisku zewnętrznym, aż do momentu przejścia do zwałowania wewnętrznego.

W przypadku kopalń odkrywkowych węgla brunatnego zwałowiska te osiągają powierzchnię od kilkudziesięciu do nawet kilku tysięcy hektarów. Spowodowane jest to dużą koncentracją wydobycia węgla brunatnego liczoną w milionach Mg na rok oraz stosunkowo dużą głębokością zalegania tych złóż.

W celu wyboru najkorzystniejszej jego lokalizacji powinno się przeprowadzić szczegółową analizę alternatywnych wariantów, a następnie wybrać wariant najkorzystniejszy.

W artykule przedstawiono metodę wyboru lokalizacji zwałowiska zewnętrznego na przykładzie wieloodkrywkowej kopalni węgla brunatnego opartą na teorii grafów i algorytmie A-star. Algorytm ten na podstawie przestrzennego rozmieszczenia poszczególnych węzłów w grafie przeszukuje określone stany grafu, rozbudowując je o kolejne pola elementarne, aż do uzyskania wymaganej wielkości powierzchni przeznaczonej pod budowę zwałowiska zewnętrznego charakteryzującej się przy tym najmniejszą wartością zajętego terenu. Aby to osiągnąć konieczne jest dokładne zidentyfikowanie czynników mających wpływ na wybór lokalizacji zwałowiska zewnętrznego. Na ich podstawie można określić funkcję celu odzwierciedlającą wielkość poszczególnych kosztów budowy zwałowiska zewnętrznego na danym terenie, co zostało szczegółowo opisane w rozdziale 3.

Obszar potencjalnej lokalizacji zwałowiska zewnętrznego podzielono na pola elementarne, którego reprezentantem jest centrodia. Centroidzie tej, oprócz jej współrzędnych geodezyjnych, przypisano odpowiednie atrybuty odzwierciedlające stopień zagospodarowania jej pola elementarnego. Czynności te mogła zostać przeprowadzone automatycznie dzięki zintegrowaniu opracowanej metody z systemem zarządzania danymi geoprzestrzennymi o terenie.

Zbiór centroid wraz z jej współrzędnymi geodezyjnymi i przydzielonymi atrybutami stanowił wierzchołki grafu do przeszukiwania, którego użyto algorytmu A-star. Algorytm ten wykorzystuje funkcję heurystyczną, dzięki której jest w stanie za każdym razem wskazywać optymalne rozwiązanie, a więc taki zbiór pól elementarnych, których zajęcie pod budowę zwałowiska zewnętrznego będzie charakteryzowało się najmniejszą wartością reprezentującą koszty zajęcia i zwałowania mas nadkładowych na tym obszarze.

Dokładność przebiegu granicy wygenerowanej przez algorytm uzależniona jest od przyjętej wielkości pola elementarnego i za każdym razem powinna być ona uszczegółowiona przez projektanta kopalni odkrywkowej.

W artykule przedstawiono zastosowanie powyższej metody lokalizacji zwałowiska zewnętrznego na przykładzie kopalni odkrywkowej węgla brunatnego „Tomisławice" należącej do PAK KWB Konin S.A. Dzięki niej możliwe było wskazanie najkorzystniejszej lokalizacji zwałowiska po północno-wschodniej stronie wkopu udostępniającego i oddalonego od niego o ok. 2 km, co zostało opisane w rozdziale 3.

Opracowana metoda ma charakter uniwersalny i po pewnych modyfikacjach może być zaimplementowana także dla kopalń odkrywkowych innych kopalin.

Słowa kluczowe: górnictwo odkrywkowe, zwałowisko zewnętrzne, wkop udostępniający, teoria grafów, algorytm A-star

1. Introduction

The construction of a surface mine always involves the necessity of accessing deposits through the removal of the residual overburden above. In the beginning phase of exploitation, the masses of overburden are located outside the perimeters of the excavation site, on the external dump, until the moment of internal dumping.

In the case of lignite surface mines, these dumps can cover a ground surface of several dozen to a few thousand hectares. This results from a high concentration of lignite extraction, counted in millions of Mg per year, and the relatively large depth of its residual deposits (Kasztelewicz et al., 2008).

Determining the best place for the location of a dump requires a detailed analysis of existing options, followed by a choice of the most favorable one.

This procedure should yield a ranking of prospective dump locations organized according to the related costs of their potential establishment (Kumral & Dimitrakopoulos, 2008).

Various methods of optimization are applied for this purpose, most of them characterized by a deterministic approach and therefore used to compare predetermined location options (Sayadi et al., 2011).

Using the graph theory and the A-star algorithm allows for identification of the most favorable dump location. This algorithm, based on the spatial distribution of individual intersections on the graph, seeks specified graph states, continually expanding them with additional elementary fields until the required surface area for the external dump – defined by the lowest value of the occupied site – is achieved.

2. Method of spoil tip location using the A-star algorithm

As was already mentioned, the described method of choosing a dump location is based on graph theory and the A-star algorithm. It can be broken down into seven stages, which are presented on figure 1.

In the first stage, it is necessary to choose an area in which a potential dump location could be identified. Then, factors that could affect dump construction for the chosen area are specified (stage II). This generates an estimation of costs related to the occupation of a given site.

The area chosen in stage I is then digitized into elementary fields, which are represented by their respective geometrical loci (stage III). Ascribed to these loci, in addition to their geodesic coordinates, are the appropriate attributes reflecting the degree of development of their corresponding elementary fields (stage IV). This task can be carried out automatically thanks to the integration of the method with the system of geospatial data management for the area.

The collection of loci, together with geodesic coordinates, constitutes the points on the graph explored using the A-star algorithm (stage V). The algorithm uses a heuristic function, which allows to identify the optimal solution; therefore, the collection of elementary fields, which occupy the potential construction area of a dump, characterized by the lowest value representing the cost of occupation and dumpingof overburden in the area.

The consideration of non-financial factors that could potentially influence a particular dump location is expressed in stage VI through the implementation of optimization limits, which can exclude certain elementary fields from the set of solutions. It is also possible to implement additional classification of selection preferences for elementary fields, or discrimination against

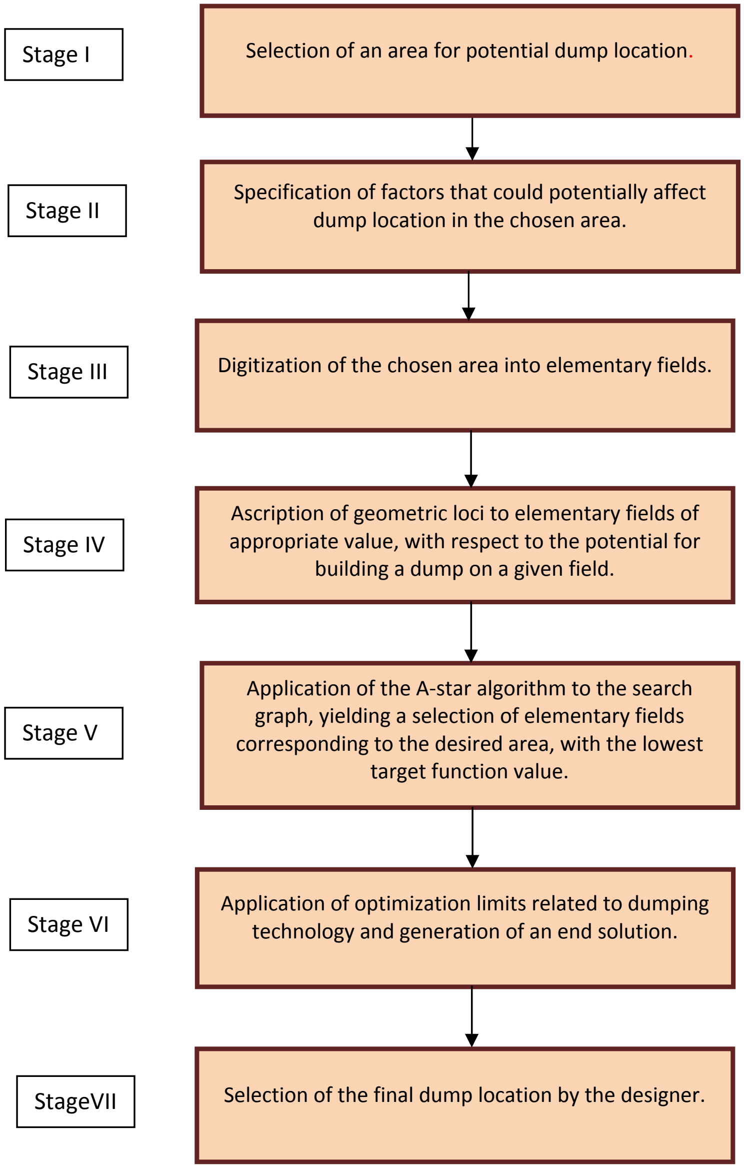

Fig. 1. Block diagram for the method of surface mine dump location using the A-star algorithm

those whose occupation is worth avoiding (e.g. through a system of "penalty points" for the data related to the potential development of a site).

Due to the fact that the selection of elementary fields identified by the algorithm may present an irregular shape, it also utilizes additional optimization limits, the application of which is dependent on both: the designer of the surface mine and the location conditions occurring in a given area.

The precision of the boundary, generated by the algorithm, is dependent on the established size of the elementary field and should be refined each time by the designer of the surface mine (stage VII).

2.1. Target function specifying the costs of heaping on a spoil tip

External dumping is the most commonly used method of storing overburden from a mine pit in surface mining. It involves the necessity of occupying additional surface area for mining activities and the incurrence of costs related to ownership and the rebuilding of technical infrastructure, which will interfere with future mining activities in the same area (Stribanovic et al., 2013).

The heaping process also requires the construction of transport roads and conveyor belts (in the case of continuous systems), as well as the incurrence of specified costs of the dumping process itself. After the use of a dump area, reclamation of the land is required (Zajączkowski, 2006).

If c_i represents the function specifying the total costs of dump construction for an elementary field, it can be written as:

$$C_i = \sum_{t=0}^{n} \frac{c_{area}}{(1+d)^t} + \sum_{t=0}^{n} \frac{c_{technology}}{(1+d)^t} + \sum_{t=0}^{n} \frac{c_{reclamation}}{(1+d)^t} - \sum_{t=0}^{n} \frac{p_{area}}{(1+d)^t} \quad [\text{zł}]$$

where:

c_{area} — costs related to occupation of the area near a dump, which include mainly:
- expenses related to purchase of the area, which is expanded by a strip of land around the excavation site for ditches and inroads, as well as technological routes for conveyor belts.
- taxes and fees related to the ownership and use of the land over an agreed period of time, mainly: agricultural tax; property tax; other payments and annual fees for the exclusion of the land from other forest or agricultural production and compensation for premature tree felling,
- costs related to the rearrangement or liquidation of existing infrastructure (roads, waterworks and canals, energy and telecommunication networks, water storage facilities, etc.),

$c_{technology}$ — costs related to the technological process of dumping overburden on an external dump, such as:
- expenditures related to the construction of conveyor belts going from one end of the excavation site transport ramp to the conveyor machinery on different dump levels,
- costs related to the transport of overburden from the excavation site to the dump,
- costs related to the dumping of overburden using spreaders

$c_{reclamation}$ — costs related to reclamation of the dump area, including mainly:
- costs of technological reclamation (leveling of the top and slope areas on the sides of the dump, preliminary agricultural practices, management of water resources on the dump tip, etc.),
- costs of biological reclamation (introduction of plant life to facilitate soil-forming processes and vegetation),

p_{area} — income associated with the recovery of certain costs related to the occupation of the dump area (e.g. sale of unnecessary land which had to be bought along with the dump area, recycling of scrap metal, wood, etc.),

t — individual years of dump construction,

d — discounts determined by the interest rates of safe financial investments with a maturity of n-years.

In the case of dump location choice, not all of the abovementioned elements need to be taken into account. It is important to note that different dump location options, with the application of the same dumping technology, do not change the technological process itself in terms of: the required amount of dumped overburden mass, quantities dumped in individual years or even the number and types of dumping machines (Adam et al.1987). It can also be assumed that the costs of dump reclamation will not depend directly on its location.

2.2. A-star Algorithm

The A-star algorithm is an example of a graph search algorithm, finding the shortest path between two given points on a graph, or more precisely: between the starting point and the chosen target point (Botea et al. 2002).

The algorithm creates a path from the starting point, each time selecting point x from the other unexplored points in a given step, so as to minimize the function $f(x)$, defined as:

$$f(x) = g(x) + h(x)$$

where:

$g(x)$ — the path between the starting point and x, which is the sum of the weight of the edges that already belong to the path plus the weight of the edge connecting the current junction with x,

$h(x)$ — the path from x to the target point predicted by heuristics.

For each step, the algorithm joins to the path the point with the lowest coefficient f. It ends when it reaches the target point (stop condition of the algorithm).

The A-star algorithm is complete, which means that in each case it will find the optimal path and then end the operation; that is, if such a path exists. An important condition for the proper operation of the algorithm is that the heuristic $h(x)$ never exceeds the value of weight on the path between the two points.

In general, the applied optimization algorithm for spoil tip location can be summarized as follows:

1. Assume an empty area as the beginning state, $s_0 := 0$.
2. Assign $g(s) := 0$. Calculate $h(s)$. Assign $f(s) := g(s) + h(s)$.
3. Insert s into the *Open* set.
4. As long as the *Open* set is not empty, repeat:
    4.1. Download and delete one s state from the *Open* set (the current best in terms of value $f(s)$).
    4.2. If the s state has a surface area greater than or equal to A, stop the algorithm and restore s as the solution.
        4.2.1. Apply optimization limits

4.3. Generate all the resulting *s* states, and for each of them perform:
    4.3.1. If the *s* state appears in the *Closed* set, do not explore it further.
    4.3.2. Calculate $g(s')$, $h(s')$ and assign $f(s') : = g(s') + h(s')$.
    4.3.3. If the *s* state does not appear in the *Open* set, add it to the *Open* set.
4.4. Add *s* to the *Closed* set.

In order for the given algorithm to be effective in the calculation sense, it is necessary to choose the appropriate data structures for the implementation of *Open* and *Closed* sets.

For the *Open* set, the operation of adding a new state to the set, while still maintaining order, is critical. With regard to this, a *priority queue*, which performs the insertion of value by dividing by two, is the appropriate data structure. The complexity of insertion is the same as O(logN), where *N* stands for the current size of the queue. The complexity of downloading the best state from the priority queue is constant and amounts to 0(1), since the best element is always first in the queue.

However, checking whether a given state already exists in the set is a critical operation for the *Closed* group. With regard to this, the appropriate data structure is a *hash map*, which is a fast data structure, albeit at the capacity of RAM memory. Checking if a certain state appears on the hash map has a linear complexity of O(N). Therefore, along with the increase in the number of stored structures, the hash map will every so often require the assignment of new and larger mathematical tables, also at the growing capacityof RAM. In the absence of free space, the algorithm will stop and not generate the optimal result.

The moment the algorithm shows that a given *s* state has achieved the required surface area *A* (step 4.2), it guarantees that the *s* state presents the optimal solution, i.e. $s = s^*$.

This can be explained as follows: as long as the *s* state has achieved required surface area *A*, it means that $h(s) = 0$, and thus $f(s) = g(s)$. It should also be noted that *s* has a lower value $f(s)$ than all states occupying the *Open* set at this moment. Hence all the states in the *Open* set, which have achieved *A*, are guaranteed to have a cost value greater than $g(s)$, because they are located in a position further in the *Open* set than *s* (which was downloaded first). This remark applies equally to all states that have not yet reached *A*, because they can – at best – do this at a greater expense than $g(s)$. This explanation is complimented by the fact that the algorithm, in the solution-seeking process, does not omit any potentially significant states. For the initial state $s = 0$, the resulting states are the ones corresponding to the individual allotments $s' = d_i$, $i = 1,\ldots,n$; and further, within the main loop, the algorithm attempts to expand them in all possible ways.

Block diagram of the A-star algorithm for dump location was presented on figure 2.

3. Case Study

The following case study presents the use of the A-star algorithm for dump location in the context of “Tomisławice,” a lignite pit mine near the city of Konin.

The period of exploitation in “Tomisławice” amounts to about 18 years. In this time, 41.9 million Mg of lignite and 331 million m^3 of overburden will be extracted. Taking into account operational losses, the net resources will total 39.5 million Mg. The average thickness of the overburden within the accepted operational limits is 46.8 m, and the average thickness of lignite – 6.2 m (Jagodziński & Michalski, 2010).

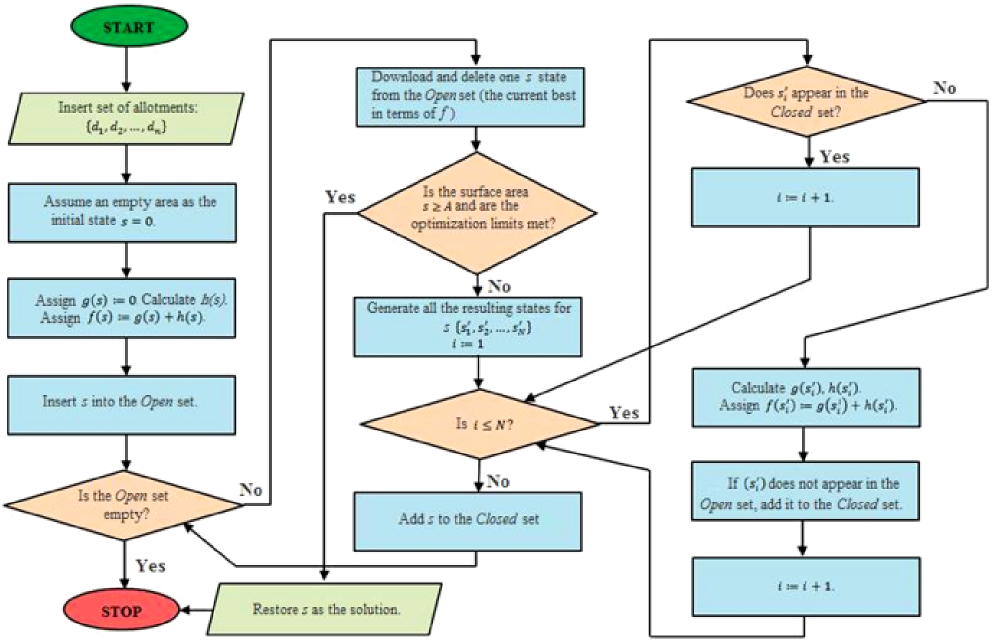

Fig. 2. Block Diagram of the A-star algorithm for dump location

In an effort to specify the most favorable dump location for mining, it was necessary to identify the factors affecting the process of selection. This is why a detailed analysis of environment and infrastructure was also carried out. The analysis included complex cataloguing of a 2,540-hectare area in the region of the excavation site. Taking into consideration a safety zone of 400 m from the pit itself, 2,223 of 100 × 100 m fields were delineated within the chosen area. Each field was represented by its geometrical locus, to which 15 attributes were ascribed to indicate its development.

The size adopted for the field analyses should be the product of two basic elements. The first is the variation in the development of the different areas. The more varied the area is, the bigger the measurements of the elementary fields can be. The second element is the adopted dumping technology. In case of the "Tomisławice" mine, the A_2RsB 8800 spreadermachinery, capable of transporting a block of dumped material up to 100 m in width, was used for dumping.

Properly prepared geospatial data was automatically entered into a data store SDF (*Spatial Data Files*), using the program AutoCAD Civil 3D.

Next, each attribute was assigned a specific value of the target function, reflecting the magnitude of incurred costs that would accompany the prospective occupation of a given field in the construction of a dump.

The A-star algorithm identified the most favorable dump location on the northeast side of the excavation pit, within 2 kilometers of its surrounding area. Any other dump location would mean an increase in dumping costs.

The conducted analysis indicated that the cost of transporting overburden to the external dump does not have to be the deciding factor in choosing its location. As presented in the "Tomisławice" case study, more important in choosing its location were the costs related to rebuilding infrastructure, occupation and possession of protected forest and agricultural land(quality class III-V).

Dump location, as a result of the A-star algorithm, and the chosen boundary for real dumping operations shown on the orthophotomap were presented on figure 3.

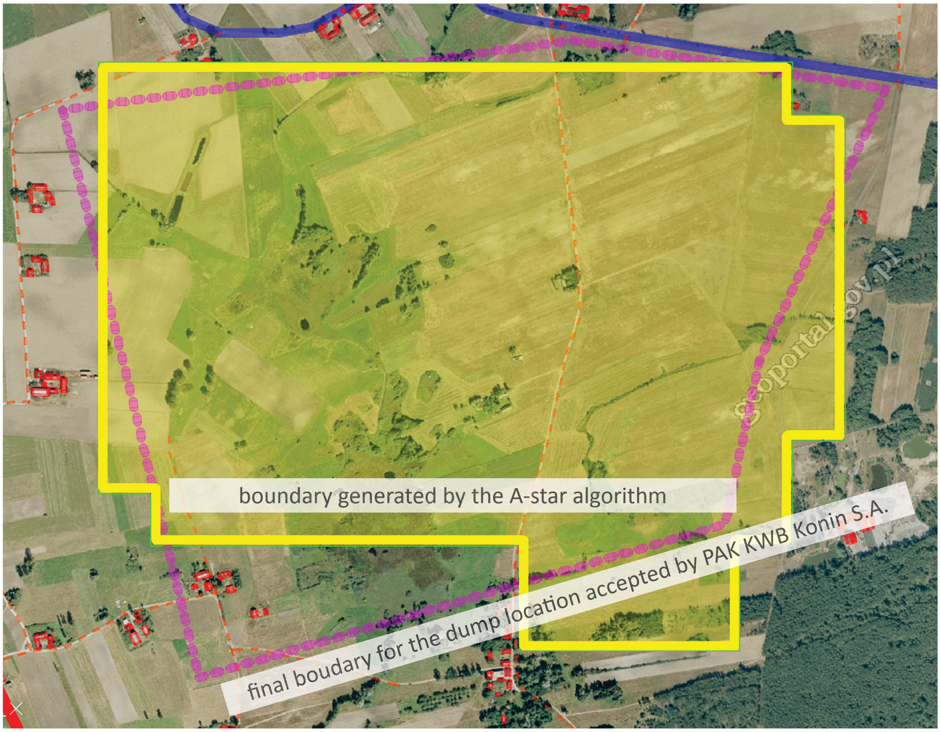

Fig. 3. Dump location, as a result of the A-star algorithm, and the adopted boundary for dumping operations shown on the orthophotomap

The difference between these two boundaries concerns the southeastern part of the area designated for the dump location where, according to the optimization algorithm, it is more favorable to occupy around 8 hectares in the eastern part, rather than its western part, on which farms are located.

The final choice of boundary for dumping operations was nevertheless dictated by other conditions, e.g. the conditions of sale concerning a given piece of farmland, or even buying the whole farm – including land which was unnecessary for purposes of excavation.

Of course, such factors are difficult to predict during the design phase and cannot be taken into consideration by the optimization algorithm. The universalism of this method results from the fact that, in such a case, nothing prevents further clarification of information related to the purchase of a given piece of land. Any changes are accounted for by modifying the target function c_i for each elementary field, and thus making it possible to repeat the whole algorithm.

4. Summary

The method of dump location using the A-star algorithm, presented in the article, enables identification of a location that will be defined by the lowest value of the occupied area in the context of dumping overburden, taking into account technological, infrastructural, and environmental conditions. It is characterized by wide usability and can be easily adapted to the specific conditions that occur in a given analyzed area.

Its versatility is ensured by the option of adding any optimization limits, which the designer of the surface mine can insert, depending on the particular conditions of a chosen terrain.

Its operation is presented using the case study of "Tomisławice" – the youngest lignite mining pit in Poland – which is part of a conglomerate surface mine near the city of Konin. The method allowed the identification of the best place for dumping overburden within a 2 km radius of the target area.

It can be noted from the conducted analysis that the costs of transporting overburden mass to an external dump need not be the deciding factor in choosing its location. As shown in the example of the "Tomisławice" pit, the costs related to rebuilding infrastructure, occupying and possessing protected forest or agricultural land, play a more significant role.

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