ROUND-TRIP HAULAGE AS A MEANS OF INCREASING OPEN PIT MINING EFFICIENCY

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ABSTRACT. The round-trip concept is well-known in transport logistics. It implies movement of transport, that after unloading of a primary cargo is loaded again with another one on its way to the initial point in order to reduce the empty run in the total run time and thus to increase the time period of efficient operation.

In the early 1990s, this scheme was proposed for open pit mining operations. However, it has not been studied properly yet. We can explain it by limited mining conditions not allowing us to introduce it in industry and also by the conventional one-way orientation of open pit haulage movement. The only case of round-trip haulage introduction concerns internal dumping, it is relatively common and described in literature.

The research aims at developing the methods for wider introduction of round-trip haulage in open pits. The idea of the work is to increase the shovel-truck system efficiency due to such placement of temporary dump in the open pit space, under which the conditions for haul trucks round-trip movement arise.

To substantiate the applied technological schemes implying internal dumping, round-trip haulage accompanied by haul truck passing loading, the preliminary methodology has been developed. Based on its current stage, such internal dump placement is expected to increase the technology efficiency and create a positive impact on the open-pit cargo-flows system. Therefore, the future studies are expected to discover the potential abilities to increase internal dumping efficiency considering such parameters of temporary internal dump as its existence period, location and impact on the haulage system. Also, based on the round-trip haulage dependencies study findings, the active work is being carried out relating to creation of the second scheme type irrespective of internal dumping, that is likely to become a relatively universal technical solution for round-trip haulage introduction in open pit mining.

Keywords: round-trip, internal dumping, shovel-truck system, haulage, open pit mining

ДВУПОСОЧНИЯТ ТРАНСПОРТ КАТО СРЕДСТВО ЗА УВЕЛИЧИВАНЕ ЕФЕКТИВНОСТТА НА РАБОТА В ОТКРИТ РУДНИК

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РЕЗЮМЕ. Двупосочният транспорт е добре познат в транспортната логистика. След разтоварването на първоначалния товар, транспортната машина се зарежда с друг товар по обратния път към началната точка, за да се намали празния ход в общото работно време и по този начин се увеличи времето за ефективна работа. .

В началото на 90-те години на миналия век тази схема е предложена за открити рудници, но все още не е добре изучена. Това може да се обясни с ограниченията на работа в мините, които не ни позволяват да я въведем в промишлеността, както и с конвенционалния еднопосочен транспорт в откритите рудници. Единственото приложение на системата с двупосочен транпорст е при вътрешните насипища, което е сравнително често срещано и е описано в литературата.

Изследването е насочно към разработване на методи за по-широко въвеждане на двупосочния транспорт в открити рудници. Целта е да се повиши ефективността на товарно-транспортната система чрез разполагане на временни насипища в откриния рудник, при което се създават условия за двупосочно използване на рудничния транспорт. Разработена е предварителна технология, за да се обоснове прилагането на технологични схеми с вътрешни насипища и двупосочен транспорт с натоварване на самосвалите. На настоящия етап се очаква разполагането на вътрешно насипище да увеличи транспортната ефективност и да повлияе положително върху системата от товарни потоци в откриния рудник. Очаква се бъдещите проучвания да открият потенциални възможности за увеличаване на ефективността на вътрешните насипища като се вземат предвид такива параметри като: период на съществуване на временното вътрешно насипище, местоположение и въздействие върху транспортната система. Въз основа на резултатите от изследването на зависимостите в двупосочния транспорт, се извършва активна работа по създаването на втори вид схема, независима от вътрешното насипище, която има вероятност да се превърне в сравнително универсално техническо решение за въвеждането на двупосочен транспорт в открити рудници.

Ключови думи: двупосочен транспорт, вътрешно насипище, товарно-транспортна система, транспорт, открит добив

Introduction

The current state of haulage systems at deep open pits in Ukraine

The shovel-truck system of a deep open-pit represents a complex that includes excavators, dump trucks and a ramified network of open-pit roads connecting faces and rock mass delivery points located both in the open-pit and on the surface. The network of open-pit roads has a complex topology; the traffic flow varies periodically in its individual sections, reflecting the features of the calendar distribution of the rock mass on the working horizons. The deeper the open pits are, the more complicated the transport communication system is, a significant part of which has a critical width, which leads to deterioration in traffic conditions and is an obstacle to the transition to heavier dump trucks.

The classic way to solve the problems arising when the depth of open-pits increases, is the reconstruction of combined open-pit transport system (Maryev et al., 2006). Two types of combined transport are used in Ukrainian iron ore open-pits, they are road-rail and haul truck-conveyor ones. However, technical solutions that were effective in the 70-80s of the last century at a depth of 250m of open-pits are already insufficiently effective at a depth of 450-500m (Bahturin Ju.A., 2009). In some areas, this led to the refusal of further use of in-pit crushing and conveying (IPCC) systems (open pit mine No.1 of the CGOK, open pit mine of Poltava GOK), In others it led to rejecting deeper commissioning of the IPCC systems based on the stationary crushers and to revision of the design solutions (Pervomayskiy and Annovsky open-pits of Northern GOK, InGOK open-pit).

Thus, deepening open-pits and imperfection of technical solutions for combined transport use have led to the increase in truck haulage distance in the iron ore open-pits in Ukraine and former Soviet republics (Bahturin Ju.A., 2009, Drizhenko A.Yu., Kozenko G.V et al., 2009;).

Round-trip haulage concept

Application of round-trip haulage (Figure 1) is one of the original solutions for improving the haul trucks efficiency. The possibility of applying it was first regarded when analyzing the haulage systems at the open pit mine №.1 of the CGOK in the early 90s of the XX century (Gorjainov A.N., 2006). The round-trip haulage appeared due to the placement of overburden rocks in the mined-out part of the open-pit.

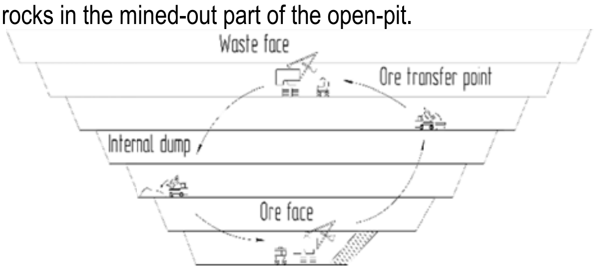

Fig.1. Round-trip haulage in an open pit mine

Round-trip haulage principle is well-known and widely used in transport logistics (Astafiev Yu.P., 1991). It implies movement of transport, which after unloading a primary cargo is loaded again with another one on its way to the initial point in order to reduce the empty run in the total run time and thus to increase the time period of the efficient operation. In some sources, the additional load of transport on its way to the initial point is also called Backhaul [Montague M., 2016; Castendyk D.N.. Eary L.E., 2009).

The same years, the round-trip haulage was organized and described in the Pervomayskiy open pit of the Northern GOK (Malyuta A.D., Belan A.D. et al., 1992).

The works (Gorjainov A.N., 2006; Malyuta A.D., Belan A.D. et al., 1992) do not provide generalization of the regularities describing the possibility of using haul trucks on the round-trip haulage routes in the open pit mine and there were no ideas for the deliberate creation of round-trip haulage conditions.

Subsequent cases of its purposeful application and general theoretical justification were not found in the information sources. The main reason for this is emergency round-trip haulage conditions, which are not very typical for open pit mining. Primarily this is due to the prevailing, in most situations, one-sided orientation of cargo flows in the open pit (Voronov Ju. E. and Bujankin A. V., 2003). The described cases of round-trip haulage are associated with the existence of areas (transport communications) with cargo flows counter direction in the open pit. This is mainly characteristic of a mining situation, when there is existence of an active internal dump inside the open pit (Gorjainov A.N., 2006).

Mining situations with the existence of temporary internal dumps of a relatively small volume, are fairly common for mining practice in the recent decades in Ukraine (Drizhenko A.Yu., Kozenko G.V et al., 2009). However, the possibility of applying the round-trip haulage is not taken into account during the decision-making on internal dumps creation.

Main Exposition

Problem Statement

The main aim of the research is development of methods for wider introduction of round-trip haulage at open pit mines.

The two main hypotheses of the study are:

1. The reason of the current active internal dumping application is caused by transport work variations that are not always considered properly at the mine planning stage.
2. The opportunity to use internal dumps both for fulfilment the needs causing their construction and effective round-trip haulage organization is possible.

Applied methodology and methods

Temporary internal dumping usage

An example of temporary internal dumps (Drizhenko A.Yu., Kozenko G.V et al., 2009; Litvin Ja.O., 2011) use is solving of current, sometimes extremal issues, when the fleet of haul trucks in service is not sufficient to fulfill the planned volumes of mining operations in this case. The shortage of haul trucks is compensated by the necessary and sufficient reduction in the overburden transportation distance. Such temporary dumps are usually placed at open-pit sites where mining operations are not planned for the nearest future. A part of the overburden rocks can also be used for creation or expanding the temporary ramps and for increasing the protection embankment parameters.

The regulation on the designing internal dumps (Shapar A., Kopach P., 2004) is focused on solving the problems, aggravated with the increase of iron ore open pits' depth. Internal dumping is allowed in open-pit (Drizhenko A.Yu., Kozenko G.V et al., 2009; Shapar A., Kopach P., 2004) only if it is envisaged by the project for deposit exploitation. The project is intended to define the lifetime and the order of temporary dumps relocation. The regulation (Shapar A., Kopach P., 2004) is a detailed consideration of the principal technological schemes with the placement of overburden in the section of the open-pit worked out to the final depth. However, in the regulation (Shapar A., Kopach P., 2004) there is no methodological basis for choosing the location of temporary dumps, their volume and useful life.

The annual, quarterly and monthly mining plans are the information basis for assessing the feasibility of using temporary dumps in different mining situations. Analyzing mining plans allows determining the location of recoverable rock volumes, the location of rock mass delivery points and the position of the haul roads system. The position of centers of gravity of mining blocks and haul trucks unloading points allows us to estimate the average distance of the rock mass haulage for each cargo traffic for the considered planning period.

Nevertheless, taking into account the known length of mining blocks (200-500m and more) and involving mining blocks located on several horizons into simultaneous operation, the combination of mining blocks during different scheduling periods can be different, including one that leads to the emergence of temporary shortage in trucks and the need to create a temporary dump.

Transport work fluctuations analysis

We are studying the influence of relative positions of open-pit faces on transport work using the methods of simulation modeling.

Planning the work of the shovel-truck system is carried out according to the average value of the transportation distance. In the course of mining operations, the actual distance of transportation fluctuates within a certain range relative to the mean value. Due to our hypothesis, in periods when the transportation distance is less than the average or equal to the average value, the available number of dump trucks is sufficient to fulfill the production goal. In periods when the actual distance exceeds the average one, it is necessary to reduce the performance of the excavator or to find another, more closely located rock mass delivery point (temporary internal dump).

We will study the effect of excavator faces movement on the haulage distance and transportation work on condition of unlimited number of haul trucks.

The initial data for carrying out the simulation were collected basing on analysis of annual programs fulfillment by open-pits that used temporary dumps of overburden rocks not specified by the project.

Collecting and processing actual data on the duration of excavator stopes mining allowed us to determine the statistical regularities of the processes. It was established that the process of excavators' work on rock mass loading is described by the normal distribution law. Similar results were obtained in Czaplicki J.M. (2014) work, devoted to the study of statistical regularities in mining.

Setting of the problem. The open-pit has the amount of n excavator stopes. The excavator works on the i-th block with the average rate of face advancing V_i (m/shift) and the standard deviation σ_i. For each face, the width of the excavator stope A_i (m) and the length of the excavator block Lb_i are determined. As the excavators move along the blocks, the distance made by haul trucks to transport the overburden increases with each shift. After the excavator switchover to a new stope, the haulage distance increases by the width of the excavator stope. The open-pit benches (Figure 2) connect the automobile road of L_j length with the delivery point of the rock mass. The simulated open-pit has 8 excavators, 6.7-7.4 m/shift rate of faces advance and the starting overburden transportation distances of 1.1-3.2 km. The stripping site for 120 shifts was simulated in the study.

The results of modeling. In the example considered, the average level of transport work was 15.05 thousand t-km/shift (Figure 3). The range of deviation of the maximum and minimum values of transport work for one shift from the mean value made up ±0.8 thousand t-km/shift. During the simulation period, in 55% of cases the transport work exceeded the average value, in 45% of cases it was less than the average value. The maximum values of transport work per shift are consistent with the situation of mining excavator stopes that are the farthest from the system of automobile ramps. The change of the several excavators' position to the new stopes corresponds to the minimum values.

Consequently, the cases of uneven transport work arise periodically in the open pit mining process. Even in the difficult conditions of haul trucks shortage, peculiar to Ukrainian mining, there are still few methods of transport work regulations. But due to the need of corresponding limitations in mine's productivity, they are rarely used, opposite to the temporary internal dumping.

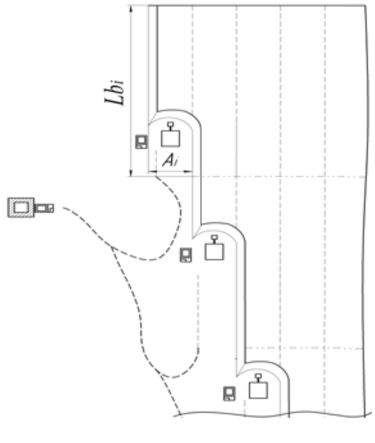

Fig. 2. Provisional diagram of excavator stopes disposition

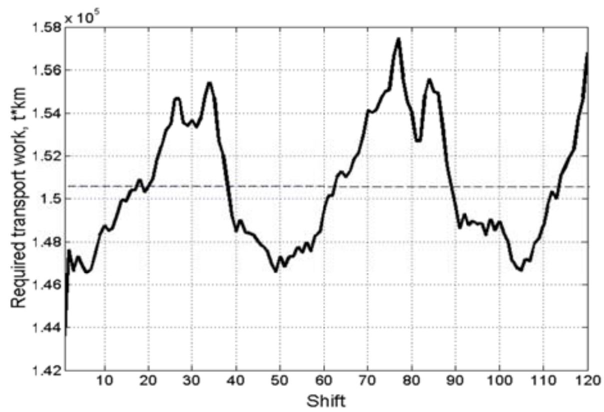

Fig. 3. Transport work fluctuations (modeling results)

Round-trip haulage system analysis

The simplest layouts of shovel-truck system cargo flows

For further study, let us consider a few elementary (the simplest) cases of shovel-truck systems in order to study the basic regularities of the haul trucks round-trip haulage emergence.

In the general case, several variants of the mutual arrangement of faces and unloading points of different types in plan are possible. In the first option loading and unloading points are placed at the tops of the quadrangle (areal disposition); in the second case, the loading and unloading points of the rock mass are arranged along a line (linear disposition).

In the counter direction of different types of cargo traffic (Figure 5), the emergence of concomitant conditions is the most likely to happen. So, first of all let us look at its features):

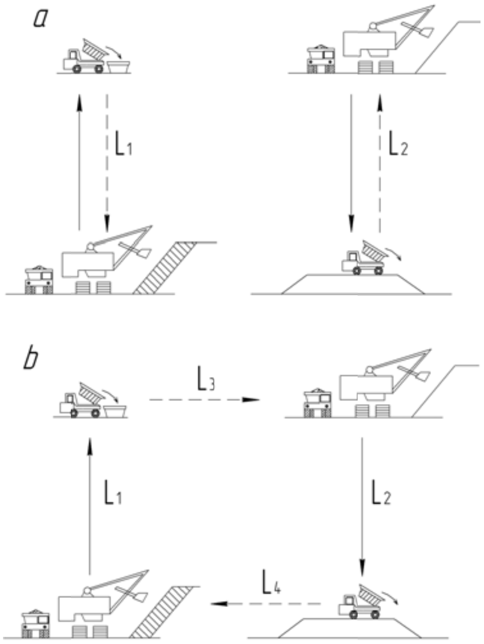

Fig. 5. Areal disposition of shovel-truck system cargo flows with counter direction: a) ordinary haulage b) round-trip haulage

In this case, the distance between the point of unloading of the first cargo flow and the face of the second cargo flow will probably be less than the distance between the face and the point of unloading of the first cargo flow. It is possible to make the following assumption necessary for the emergence of a round-trip haulage scheme for haul trucks movement:

$$L_1 + L_2 + L_3 + L_4 < 2 * (L_1 + L_2) \qquad (2)$$

where: L_1 – the distance between the ore face and the ore unloading point, km;

L_2 – the distance between the stripping face and the unloading point of the overburden, km;

L_3 – the distance between the point of ore unloading and stripping face, km;

L_4 – the distance between the overburden unloading point and the mining face, km.

The loaded mileage proportion (3) is most explicit in describing the efficiency of haul trucks work organization (Voronov Ju. E. and Bujankin A. V., 2003). It is equal to the ratio of the distance traveled with the load to the total length of the run. Let us apply this proportion for evaluating the efficiency of the round-trip haulage.

$$\beta = \frac{L_{loaded}}{L_{total}} = \frac{L_{loaded}}{L_{loaded} + L_{empty}} \qquad (3)$$

where, β – loaded mileage proportion;

L_{loaded} – distance of transport movement in the loaded state, m;

L_{total} – total run's distance, m;

L_{empty} - distance of empty transport movement, m.

The key condition of the round-trip haulage (1) can be simplified to the form $L_3+L_4<L_1+L_2$. This condition will be fulfilled when the transportation distance between points of cargo flows of different types (L_3, L_4) is less than the distance between points of cargo flows of the same type (L_1, L_2). In this case, the loaded mileage proportion for the round-trip haulage will be greater than that for each cargo flow of the same type. To study the dependence of the loaded mileage proportion on the location of excavating faces and rock mass delivery points, let us consider the following simple model of an excavating and haul truck complex. We set the distances L_1, L_2 and L_3, L_4 pairwise equal and gradually reduce the ones between the points of cargo flows of different types.

The result (Figure 6) shows a quadratic dependency of the variables with the expected maximim loaded mileage proportion at the closer located cargo flows points of the different type.

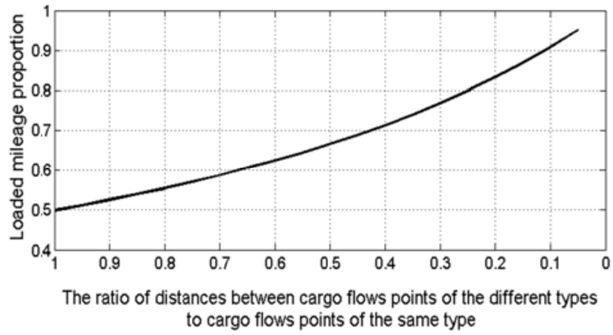

Fig.6. The dependence of the loaded mileage proportion to the ratio of distances between cargo flows points of the different types to cargo flows points of the same type.

However, this kind of cargo flows points location does not belong to open-pits normal conditions of operation [9]. Cargo flows of a passing direction (Fig.7a) are typical for open-pits. It is obvious that their mutual arrangement eliminates the possibility of the round-trip haulage. However, these same conditions lead to decisions to create internal dumps (Fig. 7b) in order to compensate the temporary lack of transport work necessary for attaining the planned objective.

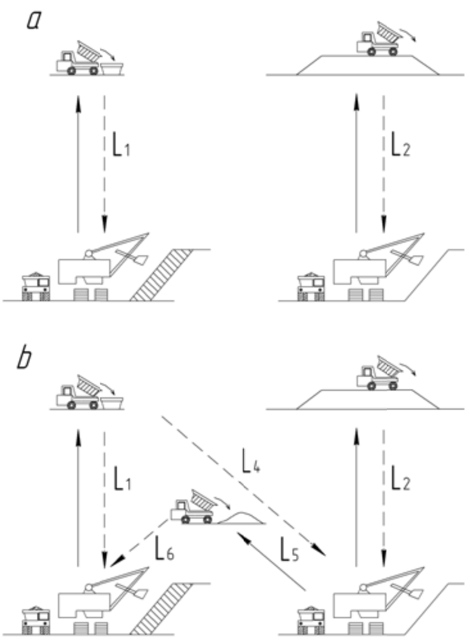

Fig.7. Areal disposition of shovel-truck system cargo flows with passing direction: a) ordinary haulage, b) round-trip and ordinary haulage

To study the influence of the location of internal dump under creation on the haul trucks movement, we will complement the above model with two transportation sections that are: from the stripping face to the internal dump L_5 and from the internal dump to the mining face L_6. By changing the ratio of the distances L_5 and L_6 at the constant distances between the faces and the permanent unloading points L_1, L_2, L_4, we determine the boundary of round-trip haulage route appearance.

It was established that with a decrease in the distance between the internal dump and the ore face, the probability of creating conditions for round-trip haulage and rise in the loaded mileage proportion increases.

At the next stage of the study, an assessment of haul trucks movement with a gradual change in the distances L_1, L_2 and L_4 was made. The presence of the dependence of the possible internal dump locations, which lead to round-trip haulage, from the ratio of the distances between the faces and the permanent unloading points L_1, L_2, L_4 was defined (Figure 8).

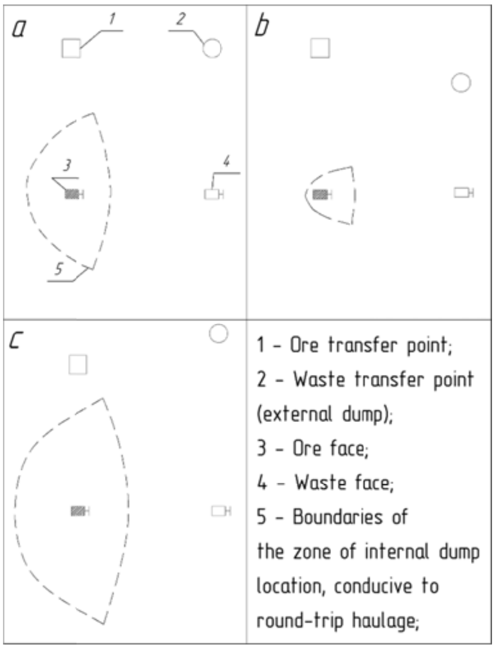

Fig. 8. Zones of internal dump location conducive to round-trip haulage

Areas of rational internal dump location

As mentioned above, the ratio of the distances "ore face – ore unloading point L_1" and "stripping face – overburden unloading point L_2", significantly affects the conditions for round-trip haulage appearance, which can be formed due to the corresponding arrangement of the internal dump. Therefore, if the length of ore haul is greater than the length of the overburden haul, the area of the rational arrangement of the internal dump decreases (Figure 8b). In contrast, if the length of ore haul is less than the length of the overburden haul, the number of places suitable for the location of the temporary internal dump suitable for creation of round-trip haulage increases (Figure 8c).

One of the main tasks of the study is to find an opportunity to carry out the planned volume of rock mass excavation under conditions of insufficient number of haul trucks. We believe that this mining situation has developed as the specific situation of excavating faces and rock mass delivery points' location, that on the whole, have the available number of trucks ensuring the implementation of the annual production program. We divide this task into several stages. At the first stage, using the mentioned above haulage analysis model, we will determine the necessary transport work for rock mass haulage to the planned delivery points and the number of haul trucks required. Knowing data on the existing transport fleet, we determine the shortage of trucks, and the weighted average haul length (4), at which the planned volume of rock mass excavation with the placement of a part of the overburden in the temporary dump can be accomplished.

$$L_{mweighted} = \frac{\sum_{i=1}^{NF}\sum_{j=1}^{NU} P_{ij} L_{ij}}{\sum_{i=1}^{NF}\sum_{j=1}^{NU} P_{ij}} \qquad (4)$$

where: NF – the number of loading points (faces);

NU – the number of unloading points;

P_{ij} – traffic flow intensity on route ij, trucks per min;

L_{ij} – distance between points of loading i and unloading j, m;

Using the method for finding the area of internal dump locations contributing to the introduction of round-trip haulage, it is necessary to determine those of its positions, which ensure the fulfillment of the planned volume of mining operations with the existing mining equipment.

Using known coordinates and distances between the faces and constant unloading points of the rock mass, we analyze the possible locations of the internal dump, in which the distance of the weighted average transportation of the overburden takes the required value. Location options are characterized by the distance to the stripping face and the maximum receiving capacity of the internal dump (in order to control its volume). Displaying all of them on the plan allows us to see the area of the temporary internal dump, designed to compensate the transportation work.

We make a simultaneous comparison of both zones location (Figure 9). The points belonging to parts of both zones are the priorities for the subsequent determining of the optimal location of the internal dump.

Although, the obtained results are only a partial confirmation of the stated hypothesis, it can be used as a part of the future evaluation of the internal dumping location conducive to round-trip haulage. Therefore, the findings create a promising foundation for the consequent studies on the issue.

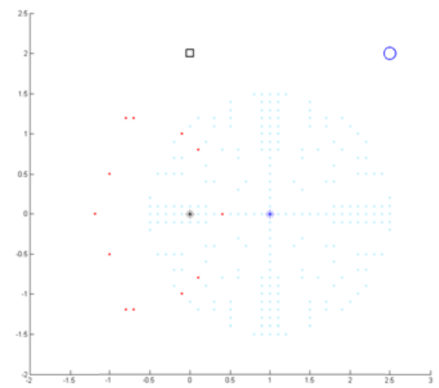

Fig. 9 An example of internal dumping locations: the red points are suitable for round-trip haulage zone edges; the blue points are suitable for the transport shortage compensation; the black star is an ore face; the blue star is a waste face; the black square is an ore transfer point; the blue circle is a waste dump

Conclusions

The study investigates the peculiarities of round-trip haulage in open-pit mining operations. Based on the examples described in the literature, the main concomitant condition which is defined is the existence of counter-directed cargo traffic in the open-pit. It, in turn, is most likely to occur in internal dumping usage.

Mining technical conditions leading to the need of the temporary internal dumps creation were analyzed. The main one is the difference of the current transport work from its average value over the planning period, in which there is a need in reducing the length of haul to ensure a planned excavation of the rock mass.

When searching for a location for the internal dump, it is rational to take into account not only the compensation of temporarily increased transport work, but also the possibility of creating a round-trip haulage. For this purpose, a method taking into account both factors for determining the position of the internal dump are developed. For the known location of the faces and permanent unloading points, the boundaries of the two zones were determined, in which the creation of internal dump leads: in the first one to the possibility of creating a round-trip haulage, in the second one to compensation of the transport work shortage. The points common for these zones are the priority ones for the subsequent calculation of internal dump effective location. The main limitation of the method is its early stage. It needs improvement with regard to its current ability to give the high-accuracy results only for a flat surface between the analysed points that represents only a small area of mining situations.

The more serious issue revealed during the study is that there are not so many open pit mines around the world applying the temporary internal dumping. Moreover, even in case of technology exploitation, mining conditions necessary for the creation of a round-trip haulage will occur rarely in many open-pits. Therefore, an alternative scheme of movement organisation irrespective of internal dumping is being developed to become a relatively universal solution of round-trip haulage application in open-pit mining.

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