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REMOTE SENSING OF MINING AND HAULAGE EQUIPMENT ARRANGEMENT IN RUSSIA: A CASE-STUDY OF THE COAL AND IRON ORE INDUSTRY

Remote sensing data have allowed detecting and monitoring of arrangement of mining and haulage machines in open pit mines producing coal and iron ore in Russia. In coal mining, the highest concentration of mining and haulage equipment is revealed in open pit mines in Kuzbass; in the iron ore industry, open pit mines in the Belgorod and Kursk Regions operate 70% of the total equipment employed in the mining sector. The authors draw a conclusion on the essentiality of strengthening of in-house mining machine engineering in Russia and on creation of interregional centers for maintenance and repair of mining and haulage equipment.

Key words: *open pit mining, open pit coal mines, open pit iron ore mines, mining and haulage equipment, mining and haulage machines, mining machine building evolvement, remote sensing, remote monitoring.*

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Introduction

Evolvement of in-house machine engineering in the countries having huge solid mineral reserves in hold, such as Russia, was historically a top priority in the USSR [1]. In view of the current and anticipated advancement in coal and iron ore production, it seems advisable to analyze deployment of mining and haulage equipment in operation in open pit mines in these industries. Russian coal fields and iron ore bodies are operated by tens licensed owners, and it is impossible to collect information on mining and haulage machines from financial and economic indicators in book records across entire Russia. This problem can be handled with a sufficient accuracy by the agency of remote sensing [2–4]. Researchers apply the remote sensing satellite data to problem solving in many areas of science [5–21]. The theoretical and applied research school of the Siberian Federal University enjoys every success in various task solution to the benefit of the mining industry (open pit mining of solid minerals) using the satellite data, including information on the structure and number of the mining and haulage stock in operation in surface mines in Russia [22].

Research results

In the course of the analysis of the freely available high-resolution satellite images, the authors have compiled the contemporary picture of surface mining activities in all open pit coal mines in all coal mining regions in Russia. All in all, there are not less than 130 lignite and black coal fields in operation by the open pit method in Russia. Black coal output exceeds lignite production.

Coal mining activities embrace a wide geographic belt—more than 2000 km between 42 degrees north latitude in the south of the Primorsky Krai and 63 degrees north latitude in the north of the Magadan Region and 5960 km in length from the west (Ryazan Region, 39° east longitude) to the east (Magadan Region, 156° east longitude). Climate varies drastically inside this area, from almost subtropical climate in the south of the Primorsky Kari to dry continental and subarctic climate in the north of the Magadan Region.

Any mineral mining by the open pit method involves mining and haulage machinery and implies global transformation of natural terrain to an industrial landscape. The present paper authors matched the land photographic survey images of mining and haulage equipment operated in Shchadov

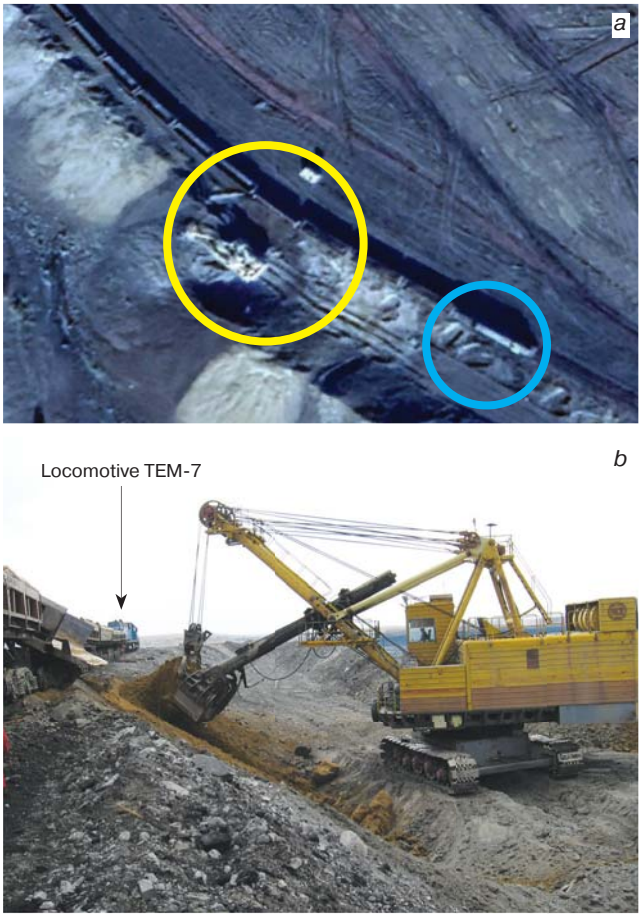

Fig. 1. Operation of shovel EKG-10 in internal dumping: (*a*) satellite image; (*b*) land photography

Fig. 2. Shovel EKG-8i in operation:
(*a*) satellite image; (*b*) land photography

Borodino Open Pit Mine and in a surface mine of Korshunikha Mining and Processing Plant with the satellite images of the same objects taken at a distance of 400 km from the Earth. Figure 1 shows operating shovel EKG-10 on an internal dump of Shchadov Borodino OPM. In the satellite image the internal dumping site is yellow circled and locomotive TEM-7 is blue circled (**Fig. 1a**).

Korshunikha MPP's surface mine performs preliminary blasting before excavation. After blasting, a muck pile is handled and loaded to railway cars or to dump trucks by crawler excavators. Figure 2 presents the images of shovel EKG-8i with bucket capacity of 8 m^3 in loading rocks to a dump truck in a face area (red circled in **Fig. 2a**).

Identification of mining and haulage machines in satellite images is the authors' know-how; the identification reliability is 100% given high-resolution images are available.

The mining and haulage machinery currently in stock in the coal mining sector of Russia's economy is listed in **Table 1**.

A half of drilling rigs SBSH-250 operate in open pit coal mines in Kuzbass. The other half is uniformly distributed between surface mines in lignite fields. All drilling rigs BTS-150 are involved in blasthole drilling in Shchadov Borodino OPM in the Krasnoyarsk Krai. Two drilling rigs SBR-160 operate in open pit mines in the Irkutsk Region.

The only import bucket-wheel excavator is operated in stripping in combination with a spreader in Nazarovo OPM. One spreader is kept in support in Berezovka OPM in the Krasnoyarsk Krai, and another spreader is engaged in external dumping in Bachaty OPM in Kuzbass. All rotary excavators

Table 1. Mining and haulage machines in operation in open pit coal mines in Russia

Mining and haulage machines	Number
Drilling rig SBSH-250	134
Drilling rig BTS-150	8
Drilling rig SBR-160	2
Bucket-wheel excavator SRs(K)-4000	1
Spreader OSHR-4000-5250/190	3
Draglines ESH-4/40—ESH -65/100	268
Crawler excavators EKG-5—EKG-40	387
Rotary excavator ER-1250, ERG-1600	25
Rotary excavator ERP-2500	2
Rotary excavator ERSHRD-5250	4
Hydraulic shovel with bucket capacity of 2–32 m^3	535
Railway dump cars 2VS-105	759
Locomotives TEM-7	81
Dump trucks with capacity from 20 to 450 t	3 792
Articulated dump trucks with capacity to 40 t	136

of domestic manufacture (in the former USSR) are employed in production of power-generating lignite in the Krasnoyarsk Krai, Primorsky Krai, in the Irkutsk and Chita Regions.

More than a half of hydraulic shovels of foreign manufacture operate in overburden removal in Kuzbass. The rest of the shovels are employed in complex-structure black coal deposits enclosed in hard sandstone.

A half of draglines are run in Kuzbass, and a fifth part is used in the Far East of Russia, in removal of quaternary overburden of low load-bearing capacity (**Fig. 3**).

Haulage machinery in surface coal mining comprises rail, motor and conveyor (Berezovo OPM) transport. Railway dump cars in combination with locomotive TEM-7 handle overburden from top stripping levels to internal and external dumps. Rail transport is equally distributed between the coal mining regions of Russia (Kuzbass, Krasnoyarsk Krai, Irkutsk Region, Chita Region and Primorsky Krai). Trains are composed of one locomotive TEM-7 and 8–11 dump cars 2VS-105 each having capacity of 105 t. Broken coal is removed from face areas by trains of locomotives TEM-7 and cars with capacity of 70 t to main-line railways of Russia.

There is a trend toward reequipment of motor transport. In the recent decades, surface mines both in Russia and abroad convert to heavy-duty truck-and-shovel systems, the benefits of which are reflected in the published literature. For instance, the world's largest dump truck with capacity of 450 t manufactured by BelAZ—BelAZ-75710 is operated in Kuzbass. The same tendencies are observed in many open pit coal mines, from the Novosibirsk Region to Russia's Far East.

The experience of operation of articulated off-road dump trucks in open pit mining is also positive. Such trucks effectively function in very heavy conditions of unsurfaced roads having low carrying capacity. Articulated dump trucks are run in open pit coal mines in South Kuzbass, Novosibirsk Region, in the Republic of Khakassia and on the Sakhalin Peninsula.

Russia holds 10 iron ore deposits in operation by the open pit mining method. The dominant output is provided by

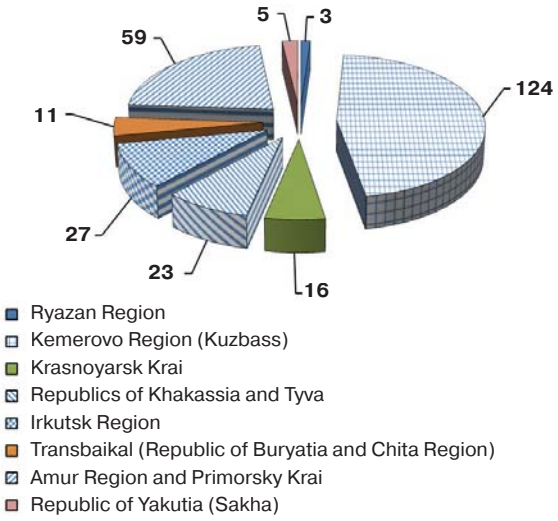

Fig. 3. Operating draglines per open pit coal mines in Russia

ferruginous quartzite mining in the Kursk Magnetic Anomaly. Open pit mining of iron ore covers a wide geographic zone of more than 1600 km between 53 degrees north latitude in the Chelyabinsk Region and 68 degrees north latitude in the north of the Murmansk Region and more than 3600 km from the west (Olenegorsk, 33^0 east longitude) to the east (Zheleznogorsk-Ilimsky, 104^0 east longitude). The climate in this area varies from moderate continental to coastal climate in the Republic of Karelia to dry continental climate in the Irkutsk Region.

The mining and haulage machinery in operation in iron ore mining by the open pit method is listed in **Table 2**.

Drilling rigs are distributed between open pit iron ore mines in compliance with overburden volume to be removed.

Draglines are operated in the Kursk and Belgorod Region. Mostly (24 machines) draglines are engaged in overburden handling in the surface mine of Mikhailovka MPP, and five draglines carry out stripping in the surface mines of Lebedi and Stoilo MPPs.

The only bucket-wheel excavator of foreign manufacture, with capacity of 5000 m^3/s is in service on an intermediate stripping bench 30 m high, in combination with a conveyor and a spreader in the surface mine of Stoilo MPP.

All open pit iron ore mines operate rail and motor transport, except for the surface mine of Stoilo MPP which uses conveyor in some overburden handling and the surface mine of Lebedi MPP which implements hydraulic jetting of upper overburden bench and then overburden is removed via pipes to the drain point on the hydraulic fill site.

Railway dump cars in combination with pulling systems PE-2M and OPE-1A remove overburden from upper strip levels or from internal rehandling storages to external dumps. Railway trains deliver ore from shovel faces or rehandling storages directly to concentration-and-agglomeration mills. All trains are composed of a pulling facility (PE-2M or OPE-1A) and 8–14 dump cars 2VS-105 with capacity of 105 t each. The use of the pulling equipment essentially increases the payload mass of a train. Rail transport is unused in overburden removal in the surface mines of Olenegorsk and Kovdor MPPs, as well as in the Maly Kuibas deposit.

Similarly to open pit coal mining, iron ore surface mines tend to modification and change to heavy-duty truck-and-shovel systems. All iron ore surface mines, except for Maly Kuibas, operate dump trucks with capacity to 200 t while the average capacity of dump trucks in open pit mining is 120 t.

Table 2. Mining and haulage machines in operation in open pit iron ore mines in Russia.

Mining and haulage equipment	Number
Drilling rig SBSH-250	91
Bucket-wheel excavator	1
Spreader OSHR-5000/80	1
Draglines ESH-10/70; ESH-11/70; ESH-13/50; ESH-15/40	29
Crawler excavator EKG-5–EKG-18	205
Hydraulic shovel with bucket capacity to 18 m^3	10
Railway dump cars 2VS-105	2187
Pulling equipment PE-2M and OPE-1A	180
Dump trucks with capacity of 20–220 t	438

By the authors' estimates, open pit mines from the Murmansk to the Irkutsk Region in Russia produce to 200 Mt of iron ore of different quality and composition yearly. Such output to be maintained requires stripping of 450–460 Mt of overburden rocks. The average stripping ratio in open pit iron ore mines in Russia is 2.28 t/t. Mining and haulage machines in service include 91 drilling rigs, 29 draglines, 215 crawler excavator, 1 bucket-wheel excavator, 180 pulling systems with 2187 railway dump cars and 438 dump trucks.

The geography of mining and haulage equipment in the coal industry inside Russia spreads from from Gorlovka high-quality anthracite in the Novosibirsk Region (alongside with small coal production in the Ryazan Region) to the east Magadan Region and the south Sakhalin Region. In the Ural's Korkino coal field, the last coal ton was produced from an open pit mine 498 m deep in 2017. Iron ore in European Russia and in the Urals, except for Korshunikha and Rudnye Gory fields, is produced by open pit mining. The maximum concentration of mining and haulage machinery is a feature of Stoilo, Lebedi and Mikhailovka MPPs which operate up to 70% of all mining and haulage equipment involved in open pit mining in the iron ore industry.

Thus, by the authors' evaluation, annual output of coal of all grades as well as production of iron ore by the open pit method in the territory of Russia, from the Murmansk Region to the Sakhalin Peninsula totals 495.1 Mt. This output to be maintained requires stripping output at the level of 1560–1568.2 Mm^3. The average stripping ratio in all open pits in coal and iron ore fields in Russia is 3.159 m^3/t. The remote sensing data show that the fleet of mining and haulage machines employed in open pit mining of coal and iron ore is presented by 235 drilling rigs, 297 draglines, 1157 crawler excavators, 32 bucket-wheel excavators, 81 locomotives, 180 pulling systems PE-2M and OPE-1A, 2946 railway dump cars, 4366 dump trucks, including 136 off-road dump cars, and 3 spreaders.

In view of the essential renovation of mining and haulage machinery, it is of the current concern to launch and evolve mining and haulage machine building in Russia, with construction of new heavy engineering plants and with expansion of production capacities at operating plants.

Conclusion

The remote sensing survey of mining and haulage machinery operated in open pit mining in Russia has provided the required figures. The data obtained for the regions with the highest concentration of mining and haulage machines allow planning arrangement of large interregional centers for mining and haulage equipment maintenance and repair toward maximization of the generally known economic effect of cost saving from scaling up of production. As a result, the repair expenses and service charges of equipment will be cut down together with the total cost of open pit mining. The information obtained from the satellite images of mining and haulage machines features high reliability and is applicable to a long-term strategy for advancement of mining machine building and repair in Russia. Creation of the mentioned centers is an actual step toward reduction of import dependency of the mining industry in Russia on the foreign suppliers of mining and haulage machines.

In the mining industry characterized by the maximal capital productivity ratio owing to around-the-clock work of mining and haulage machines, duration of the depreciation period of mechanical facilities shortens. Accordingly and naturally, the mining industry should incessantly renew the equipment stock.

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