Assessment of placer mining performance based on specific diesel fuel consumption

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Abstract. The need for prompt reduction of mining cost for development of placer deposits was substantiated. The cost structure for mining and processing of minerals was analyzed. A high share of the diesel fuel consumption cost (about 40%) in the total cost was identified. A share of fuel consumption cost for various mining machines (bulldozers, excavators, loaders, dump trucks) is rather stable. Results of photo-chasing fuel consumption observations for a placer deposit in Magadan oblast were compared with reference data. Based on the comparison data, it was recommended to account for an adjustment factor depending on the type of mining machines. Due to high complexity of machine-hour calculation, it was recommended to assess performance of mining operations with regard to diesel fuel consumption. The article compares two options for sand transportation to a washing plant. Their performance was assessed based on a diesel fuel consumption criterion.

1. Introduction

Currently, about 70 tons of gold or about 25% of its total production are extracted from placer deposits. The amount of alluvial gold produced will remain at this level due to reprocessing of technogenic deposits. Due to deterioration of the quality of the raw material base, companies try to reduce the mining cost (it is more than 70% of the total company cost) and to increase the volume of gold extraction.

Mining cost reduction methods have to be based on simple economic assessment of existing and alternative technological processes of the enterprise.

Two factors determine the nature of placer deposits.

First, most fields are located in remote areas of Siberia, the Far East and the Extreme North where there is no central power supply. All mining operations are performed by self-propelled diesel-powered machines. Electric-powered machines are powered by diesel power plants. Long distances and poor-quality roads increase the transportation cost.

Second, due to the low gold content in the sand and constant growth of overburden rock thickness, enterprises have to process huge volumes of rock mass. For example, an average enterprise with annual gold extraction of about 500 kg processes about 4 million m³ per year. Diesel fuel consumption is about 6000 m³ per year. About 30 m³ of diesel fuel is consumed daily during a working season. If the diesel fuel cost for transportation is 50-55 RUB per liter, the annual cost exceeds 300 million RUB being the largest expense item.
With regard to these peculiarities of placer deposits, selection of the machine and its capacity for performing specific mining operations minimizing specific diesel fuel consumption is the main cost reduction reserve.

2. Methods

To assess machine performance, the following formula (1) is often used

\[ C = \frac{S_h}{Q_h}, \]

where \( C \) – cost of 1 m³ of the rock mass processed, RUB/m³; \( S_h \) – hourly operational cost, RUB/h; 
\( Q_h \) – production rate per hour, m³/h.

The “hourly operational cost” is mentioned in foreign reference books [1]. It is the cost for 1 machine-hour. Calculation of 1 machine-hour cost includes expenses on [2]:
- depreciation (including a property tax);
- diesel fuel;
- oil;
- crawler carrier or wheel tires;
- high-wearing elements, filters, maintenance;
- gross salary of operators.

As a rule, depreciation cost is a large share of the total cost. The depreciation is a tax term involving legal allocation of a certain share of the machine cost to the product cost. The depreciation is an economic tool which accounts for the cost of physical depreciation of machines for 1 working hour which is equal to the ratio of the depreciated value of the machine to the residual service life.

The cost of hourly physical deterioration is hard to determine, since it depends on the initial cost of the machine, its service life, loading level (low, medium, high), operator's qualification, outdoor temperature, engine replacement, the number of machine hours for the analyzed year and previous years.

The authors tried to determine the actual (physical) motor life for Komatsu machines operating at one of the alluvial deposits of Magadan oblast. The results are presented in Table 1.

**Table 1.** Calculation of the service life of Komatsu machines operating in the Extreme North conditions.

| Parameters                        | Model          |
|-----------------------------------|----------------|
|                                   | D375 Bulldozer | WA470-3 Loader | PC220 Excavator | HM350A Dump Truck |
| Number of working hours per month| 510            | 560            | 560             | 560              |
| Number of working months per year| 8.0            | 6.5            | 6.5             | 6.5              |
| Number of working hours per year  | 4080           | 3640           | 3640            | 3640             |
| Lifetime till discarding *        | 8              | 7              | 7               | 8                |
| Motor capacity till discarding, h | 32640          | 25480          | 25480           | 25480            |

*Note: the number of working years was identified by the data provided by several enterprises.

Based on the data in Table 1, approximate hourly depreciation is calculated (Table 2). Diesel fuel consumption for the machines listed in Table 1 and Table 2 was determined during the photo synchronization. The machines were fueled through fuel flowmeters, and operation hours were recorded using meters installed. Table 3 shows actual (measured) and reference-based fuel consumption values for the average engine load [3, 4].
Table 2. Approximate hourly life.

| Parameters                        | Model       | D375 Bulldozer | WA470-3 Loader | PC220 Excavator | HM350A Dump Truck |
|-----------------------------------|-------------|----------------|----------------|-----------------|------------------|
| Cost of a new vehicle, million RUB |             | 70             | 16             | 10              | 25               |
| Motor capacity till discarding, moto hours |             | 32640          | 25480          | 25480           | 25480            |
| Hourly lifetime, RUB/h            |             | 2145           | 628            | 392             | 1138             |

- Note: the cost of vehicles is relevant for December 12, 2017 at the rate of 58 RUB per 1 USD.

The duration of fuel consumption observation varied from from several weeks to several months, i.e., the data in Table 3 are reliable.

Table 3. Diesel fuel consumption per 1 working hour.

| Model   | reference-based DFC for average loading [1] | actual DFC | Adjustment factor |
|---------|---------------------------------------------|------------|------------------|
| D375    | 62.55                                       | 77.15      | 1.23             |
| WA470-3 | 25.45                                       | 28.13      | 1.10             |
| PC220   | 13.60                                       | 18.50      | 1.36             |
| HM350A  | 27.45                                       | 16.15      | 0.59             |

The cost of oils depends on the type of a machine. Without a large error, it can be 4% of the diesel fuel consumption cost. This value was calculated on the basis of the Komatsu reference information [3].

In the machine-hour cost, the crawler carrier repair cost is significant. Depending on operating conditions, a set of tracks (e.g., D375) is used for 1.0-1.5 years, and costs about 4 million RUB. For example, if the bulldozer operates 4000 hours per year, the carrier repair cost is 700-1000 RUB per one hour.

For wheeled vehicles, the tire cost is about 6-7% of the machine-hour cost.

Hourly cost of wearing parts, filters, and maintenance depends on the engine loading level (as well as on running gear and tire loading level). Therefore, to calculate the cost, it is necessary to use an adjustment factor which accounts for the degree of increase (or decrease) in the actual diesel fuel consumption value in comparison with the reference-based one. Table 3 shows the value of the factor for the placer deposit in Magadan oblast.

3. Results and discussion

Calculation of the machine-hour cost with regard to the described peculiarities is presented in Figure 4. Note: 1) the price of 1 liter of the diesel fuel is 52 RUB; 2) reference-based values of the cost items are taken for an average load level; 3) the actual values of the cost of items 2-6 are calculated by multiplying the reference-based index by an adjustment factor from Table 3; 4) the cost values for item 6 are based on the Caterpillar reference recommendations [1]; 5) HM350A dump truck was not fully loaded due to idle hours when awaiting loading.

The value of the machine-hour cost and machine performance can be used to calculate the cost of 1 m³ of rock mass processed.
The machine-hour cost calculation method is quite complicated and requires a large amount of input data. A simpler machine-hour cost calculation method was developed. However, this method is approximate.

### Table 4. Mining machine-hour cost calculation, RUB/h.

| Expense items | Machine-hour cost, RUB/h |
|---------------|-------------------------|
|               | D375 Bulldozer | WA470-3 Loader | PC220 Excavator | HM350A Dump Truck |
|               | reference-based | actual | reference-based | actual | reference-based | actual |
| 1. Diesel fuel | 3253 | 4012 | 1323 | 1463 | 707 | 962 | 1427 | 840 |
| 2. Depreciation | 2145 | 2638 | 628 | 691 | 392 | 576 | 1138 | 671 |
| 3. Oils (4% of DF) | 130 | 160 | 53 | 59 | 26 | 38 | 57 | 34 |
| 4. Crawler carrier | 700 | 861 | - | - | 50 | 73 | - | - |
| 5. Tires | - | - | 158 | 174 | - | - | 208 | 123 |
| 6. Filters, high-wearing elements, repair (~ 10% of items 1-5) | 623 | 767 | 216 | 239 | 112 | 165 | 283 | 167 |
| 7. Gross salary of an operator | 800 | 800 | 700 | 700 | 600 | 600 | 600 | 600 |
| **Total** | **7651** | **9238** | **3078** | **3326** | **1887** | **2414** | **3713** | **2435** |

In terms of mechanics, it is clear that the greater the load on the car, the greater diesel fuel consumption, engine, running gear, and tire wear, oils consumption, repair costs and other expenses (except for salaries) are. Diesel fuel consumption influences other costs. The diesel fuel consumption adjustment factor presented in Table 3 reflects cost changes.

According to Table 4, the machine-hour cost exceeds the hourly diesel fuel consumption cost 2.3-2.6 times (on average – 2.45 times). With an error of about 10%, the machine-hour cost can be determined by increasing the fuel consumption cost per hour 2.45 times. Hence, the cost of 1 m³ of rock mass, RUB per m³, can be calculated by formula (2)

\[ C_t = \frac{(2.45 \times q_h \times P_{df})}{Q_h} \]

where \( C_t \) is the cost of 1 m³ of rock mass based on direct operation costs, RUB/m³;
\( q_h \) – hourly diesel fuel consumption per 1 operation, l/h;
\( P_{df} \) – price of 1 liter of diesel fuel, RUB/l;
\( Q_h \) – hourly machine performance, m³/h.

Summing up the costs of diesel fuel for all mining machines, it is possible to calculate the total direct costs of the enterprise for mining operations for any period (hourly, daily, seasonal).

At place deposits, the share of the workshop and plant cost is about 25% of the total cost. Therefore, the total cost for any period (S, RUB) can be calculated by formula (3)

\[ C_t = 2.45 \times q_h \times P_{df} \times 4/3 = 3.27 \times q_h \times P_{df} \]

where \( q_h \) – diesel fuel consumption for the period under study, l;
\( P_{df} \) – price of 1 liter of diesel fuel, RUB/l.

Expression (1) shows that a decrease in hourly fuel consumption or an increase in machine performance is required to reduce the cost of 1 m³ of the rock mass processed.

### 4. Conclusion

Diesel fuel consumption can be reduced by changing the size of the machine or substituting one type of the machine with another one (e.g., one can substitute a bulldozer with a wheel loader).
Machine performance can be enhanced by improving mining operations parameters (reduction of the transportation distance, elimination of frozen rocks breakage operations, layer-by-layer removal of the thawing layer, placing of overburden in a developed zone, career road planning, etc.).

Let us give an actual example of diesel fuel consumption and cost reduction by replacing equipment [5].

The conditions of the example are as follows.
1. Sand washing plant performance is 100 m$^3$/h.
2. Three WA470-3 wheel loaders with hourly fuel consumption of 28.13 l/h are involved in sand transportation. Sand transportation distance is 400 m. The sand transportation distance is 400 m.
3. Hourly fuel consumption for sand transportation is 28.13 x 3 = 84.39 l.
   If the fuel price is 52 RUB/l, the direct operation cost is 84.39 x 52 x 2.45 = 10751 RUB/h

To improve the efficiency of mining operations, sand transportation machines were replaced. The required performance (100 m$^3$/h) is ensured by two MAZ-6501 dump trucks (20 tons) which are loaded with a WA470-3 wheel loader. The replacement results are as follows:
1. Hourly fuel consumption for a WA470-3 wheel loader is 18.45 l/h.
2. Hourly fuel consumption for a dump track is 7.5 l/h.
3. Hourly fuel consumption for a WA470-3 wheel loader and two dump tracks is 18.45 + 2 x 7.5 = 33.45 l/h.
   The direct operational cost is 33.45 x 52 x 2.45 = 4261 RUB/h.

Machine replacement reduced the sand transportation cost 2.52 times. 220 thousand m$^3$ sand transportation cost reduction for a season is $(10571 - 4261) \times 220000 / 100m^3 / h = 14,278$ mil RUB.

Thus, hourly diesel fuel consumption as a criterion for equipment operation efficiency can be used to assess existing mining schemes and select the most economical options for their implementation.

References
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[3] Technical and Application Reference 2003 (Tokyo: Komatsu) p 880
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