A Truck Allocation Optimization Model in Open Pit Mining to Minimize Investment and Transportation Costs

M F Isnafitri1, C N Rosyidi1, and A Aisyati1

1 Sebelas Maret University, Ir. Sutarmi 36 A Street, Surakarta, Indonesia

Abstract. In this research we developed an optimization model to determine truck allocation in open pit mining. The objective function is to minimize a total cost consists of investment and transportation costs. Investment cost is the purchase price of truck in early mining project according to the number of truck needed in each route. The transportation cost consists of fix cost for operators’ wages and variable cost in the form of fuel cost of trucks and shovels. The selection of truck types with different specifications is an important factor in the continuity of materials transportation by considering the costs incurred. The model is solved using Oracle Crystal Ball Software for 5000 iterations. The result of optimization shows that Truck 75570 is selected to transport for route 1 and Route 4, Truck 75174 is selected to transport for Route 2, Truck 772 is selected to transport for Route 3, Truck 777F is selected to transport for Route 5, and Truck 7547 is selected to transport for Route 6. The total cost resulted from the optimization is IDR 295,783,073,068.69.

Keywords: Truck Allocation, Investment Cost, Transportation Cost, Open Pit Mining

1. Introduction

In mining industry, the challenge to increase productivity of mining products with minimum costs are even greater. Mining is the most expensive and complex activities consisting of several processes that aim to maximize the economic value of ore [1]. Open pit mining is applied to ore deposits containing metals in extraction of raw minerals from the surface of the earth. Minerals that have been mined must go through various processes of separation to obtain raw materials that have a value (ore). Furthermore, raw materials that have a value are processed to produce finished products [2].

Materials that have economic value (ore) will be sent to the plant to go through several processes that produce finished products. In shipping the materials to each plant needs some equipments. In the mining process, the equipment is very important to ensure the continuity of mining production. The availability of transportation equipment, in this case is dump truck, greatly affects the sustainability of mining process. The excessive number of trucks will affect the increase of transportation and investment costs to satisfy the demands.

In addition, selecting the type of trucks and determining number of trucks are also important in the sustainability of transportation. Selecting truck with small capacity will make a greater number of trips than the larger capacity truck. Consequently, the transportation cost of truck with small capacity is greater with shorter transportation time. An appropriate allocation in terms of type and number of trucks causes become a challenge for companies in transporting the mining products [3]. In this paper, an optimization model is developed to solve the problem.
Research [4] have developed a mining truck allocation model to minimize the number of trucks that served by a shovel considering the shovel’s idle probability based on queue theory. Chan et al. [5] developed a supply chain distribution model considering the time period, multi-product, and uncertain demand to determine the truck using NSGA-II Algorithm. The other optimization model for determining the number of mining trucks using production capacity method and queue theory has been developed in [6] and [7]. Bajany et al. [8] developed an optimization model to determine transportation routes to minimize fuel consumption incurred by trucks and shovels in pit mining to minimize fuel cost. In this paper, we developed an optimization model to solve truck selection and is formulated as Mixed Integer Linear Programing (MILP).

Therefore, in this research will be developed an optimization model to determine truck allocation in open pit mining considering investment and transportation cost. This model aims to minimize total cost consists of investment and transportation costs.

2. System Description
In this research, mining product is a single metal-multi product. The production flow and routes of transportation is shown in Figure 1.

![Figure 1. Typical Mining Process Operation (adapted from [9])](image)

The assumption used in this model are as follows:
1. Shift duration time is 8 hours per day and every day.
2. Each route has the same distance
3. The number of shovels that serve trucks in each route is one unit.

According the production flow in Figure 1, materials that have been mined will be produced three types of products including concentrate, sizing, and pellet. From material mined, it will be sent to two locations of production process. A part of ore as much as $\alpha$ percent is sent to concentrator plant, then $(1-\alpha)$ percent will be sent to sizing unit plant. The maximum capacity of concentrator plant is 12 million tons, then the maximum capacity of sizing unit plant is 1 million tons. The output of sizing production process will be sold to demand location of sizing.

In addition, the output of concentrator plant is concentrate which a part of concentrate as much as $\beta$ percent will be sent to pelleting plant, then $(1-\beta)$ percent will be sold to demand location of pellet. The maximum capacity of pelleting plant is 4.2 million tons, then the output of pelleting plant will be sold to demand location of pellet.
Therefore, materials that have been mined or the finished products that have gone through the production process, will be transported to the respective destinations according to the production flow. The mining products are transported using a certain type of truck and hence the company expenses transportation cost. The amount of transportation cost is influenced by the type of trucks from each manufacturer according to the specifications. The most important specification is the load size or capacity of each truck. In selecting the type of truck that will be used by the company and the respective number of trucks to transport mining products and finished products, the company expenses the purchasing cost of the selected trucks for the mining project. Hence, the optimal solution to minimize costs is obtained by considering the number of trucks and the type of trucks selected to be used during the mining project.

3. Model Development

3.1 Notations

Based on Figure 1, that the following notations are used for the locations:

- $s_1$: mining area
- $s_2$: sizing unit plant
- $s_3$: concentrator plant
- $s_4$: pelleting plant
- $r_1$: sizing unit demand location
- $r_2$: concentrate demand location
- $r_3$: pellet demand location

The routes of transportation use the following notations:

- Route 1: transported ore to sizing unit plant
- Route 2: transported ore to concentrator plant
- Route 3: transported concentrate to pelleting plant
- Route 4: transported sizing unit product to sizing unit demand location
- Route 5: transported concentrate to concentrate demand location
- Route 6: transported pellet to pellet demand location

The model notations used in this paper are as follows:

**Index**

- $Q$: type of product indexed by $q \in Q$
- $S$: area of mining process indexed by $s \in S$
- $R$: demand location indexed by $r \in R$
- $J$: type of truck indexed by $j \in J$
- $I$: shovel indexed by $i \in I$
- $T$: time period indexed by $t \in T$
- $E$: the relation function between $k$ and $l$, $E = \{(s_1, s_2), (s_1, s_3), (s_2, r_1), (s_3, s_4), (s_3, r_2), (s_4, r_3)\}$

**Parameter**

- $t_{k,l}^j$: time to truck $j$ transported from $k$ to $l$, $\forall k \in \{s_1, s_2, s_3, s_4\}$ and $l \in \{s_1, s_2, r_1, r_2, r_3\}$ (hour)
- $t_{i,k}^j$: time to truck $j$ transported from $l$ to $k$, $\forall k \in \{s_1, s_2, s_3, s_4\}$ and $l \in \{s_2, s_3, s_4, r_1, r_2, r_3\}$ (hour)
- $t_{k,i}^j$: the loading time by the shovel $i$ to truck $j$ at $k$ area, $\forall k \in \{s_1, s_2, s_3, s_4\}$ (hour)
- $t_{l,i}^j$: the unloading time by truck $j$ at $l$ area, $\forall l \in \{s_2, s_3, r_1, r_2, r_3\}$ (hour)
- $CT_j$: cycle time of truck $j$ (hour)
- $CT_i$: cycle time of shovel $i$ (hour)
\( n \) frequency of filling by shovel \( i \) to truck \( j \)
\( c_j \) load capacity of truck \( j \) (ton)
\( c_i \) load capacity of shovel \( i \) (ton)
\( c_{i,h} \) hourly loading capacity of shovel \( i \) (ton/hour)
\( v_{l,k}^i \) the driving speed of an empty truck (km/hour)
\( v_{k,l}^j \) the driving speed of a loaded truck (km/hour)
\( y_j^t \) number of trips that have to do by truck \( j \) in time period \( t \)
\( f_j \) fuel consumption of truck \( j \) (liter/hour)
\( P_j \) engine power of truck \( j \) (kW)
\( P_i \) engine power of truck \( i \) (kW)
\( LF \) load factor
\( f_{k,l}^j \) fuel consumption of truck \( j \) in a single cycle (liter)
\( f_{k,l}^j \) fuel consumption of a loaded truck \( j \) from \( k \) to \( l \), \( \forall k \in \{s_1, s_2, s_3, s_4\} \) and \( l \in \{s_2, s_3, s_4, r_1, r_2, r_3\} \) (liter/hour)
\( f_{l,k}^j \) fuel consumption of an empty truck \( j \) from \( l \) to \( k \), \( \forall l \in \{s_2, s_3, s_4, r_1, r_2, r_3\} \) and \( k \in \{s_1, s_2, s_3, s_4\} \) (liter/hour)
\( f_{idle}^j \) fuel consumption of truck \( j \) during engine idling at \( k \) and \( l \) areas, \( \forall k \in \{s_1, s_2, s_3, s_4\} \) and \( l \in \{s_2, s_3, s_4, r_1, r_2, r_3\} \) (liter/hour)
\( f_i^j \) fuel consumption of shovel \( i \) at \( s \) area (liter/hour)
\( F_j \) the total fuel consumption of truck \( j \) in time period \( t \) (liter)
\( F_i \) the total fuel consumption of shovel \( i \) in time period \( t \) (liter)
\( sh \) shift duration in time period \( t \) (hour)
\( m_{q,t}^s \) number of product \( q \) that produced in \( s \) area in time period \( t \) (ton)
\( W_j \) input capacity of truck \( j \) (ton)
\( b_j \) purchase price of truck \( j \) (Rp)
\( e_{k,l} \) distance between \( k \) with \( l \), \( \forall k \in \{s_1, s_2, s_3, s_4\} \) and \( l \in \{s_2, s_3, s_4, r_1, r_2, r_3\} \) (km)
\( fc \) fix cost of transportation process (Rp)
\( vc \) variable cost of transportation process (Rp)
\( u \) operator wages (Rp/month)
\( t_u \) frequency of operator wages in time period \( t \) (Rp)
\( pf \) price of fuel (Rp/liter)
\( n_{k,l}^j \) number of truck selected to transport between \( k \) and \( l \) in time period \( t \), \( \forall k \in \{s_1, s_2, s_3, s_4\} \) and \( l \in \{s_2, s_3, s_4, r_1, r_2, r_3\} \), and \( n \in \{1, 2, ..., n_{k,l}^j\} \)

### 3.2 Model Development

As we previously mentioned, the objective function of this research is to minimize the total cost consists of investment and transportation costs. Investment cost is the purchase price of truck selected in each route, it is shown by equation (16). The transportation cost is the price of moving equipment from one location to other location. In this case is consisting fix cost and variable cost, it is shown by equation (15).

**Decision Variable**

\[
X_{j,k,l}^t = \begin{cases} 
1, & \text{if type of truck } j \text{ is selected to transport between} \\
& k \text{ and } l \text{ in time period } t \\
0, & \text{otherwise}
\end{cases}
\] (1)
Mathematical Formulation

\[ t_{i,k} = \frac{e_{k,i}}{v_{i,k}} \]  
(2)

\[ t_{k,i} = \frac{e_{k,i}}{v_{i,k}} \]  
(3)

\[ t_{j} = t_{i,k} + t_{k,i} + t_{j} + t_{i} \]  
(5)

\[ n_{k,i} = \frac{CT_{j}}{CT_{i} \times n} \]  
(6)

\[ n = \frac{c_{j}}{c_{i}} \]  
(7)

\[ y_{j} = 1 + \text{int} \left( \frac{m_{j} \times t}{n_{k,i}} \right) \]  
(8)

\[ f_{i} = 0.3 \times P \times LF \]  
(9)

\[ f_{i} = 0.3 \times P \times LF \]  
(10)

\[ F_{f} = f_{i} t_{i,k} + f_{j} t_{k,i} + f_{ idle} (t_{i} + t_{i}) \]  
(11)

\[ F_{j} = \sum_{j=1}^{j} (y_{j} f_{i} t_{i,k} + y_{j} f_{j} t_{k,i} + y_{j} f_{idle} (t_{i} + t_{i})) \]  
(12)

\[ F_{i} = \sum_{i=1}^{i} CT_{i} \times sh \]  
(13)

\[ v_{c} = (F_{j} + F_{i}) \times pf \]  
(15)

Objective Function

Transportation Cost (TC)

\[ = \sum_{t=1}^{T} \sum_{s=1}^{S} \sum_{r=1}^{R} \sum_{j=1}^{J} X_{j,k,l} (f_{c} + (v_{c} e_{k,l})) , \forall q, j, s, r, t, k, l \]  
(16)

Investment Cost (IC)

\[ = \sum_{t=1}^{T} \sum_{j=1}^{J} X_{j,k,l} n_{k,l} b_{j} , \forall j, t, k, l \]  
(17)

\[ \text{Minimize Objective} = \text{TC} + \text{IC} \]

Constraints

\[ \sum_{j=1}^{J} X_{j,k,l} = 1 , \forall k \in \{s_1, s_2, s_3, s_4\}, l \in \{s_1, s_2, s_3, r_1, r_2, r_3\}, t \]  
(19)

\[ \sum_{q=1}^{Q} \sum_{j=1}^{J} X_{j,k,l} m_{q,t} \leq \sum_{j=1}^{J} X_{j,k,l} W_{j} , \forall k \in \{s_1, s_2, s_3, s_4\}, l \in \{s_1, s_2, s_3, r_1, r_2, r_3\}, t \]  
(20)

\[ \sum_{t=1}^{T} \sum_{j=1}^{J} X_{j,k,l} (t_{k,l} + t_{k,l} + t_{l}) \leq sh \]  
(21)

The objective function of the model is to minimize the total costs consists of transportation and investment costs. The transportation cost consists of fix cost for operators’ wages and variable cost in the form of fuel cost of trucks and shovels. Shovels’ fuel consumption is calculated during the
working periods, and trucks’ fuel consumption is calculated during their loading, unloading, and transportation periods. The fuel consumption is determined using the load factor of each equipment. The load factor values used in this paper are 35%, 20%, and 10% for loaded truck, empty truck, and idled truck. While for shovel’s load factor in this research is assumed to be 100%. In addition, investment cost is the purchase price of truck in early mining project according to the number of truck needed in each routes.

The first constraint (19) ensures the transportation between two locations uses one type of truck for each routes. Constraint (20) ensures that the total product transported by truck is less than the load capacity of the truck. Constraint (21) ensures that cycle time needed for each truck in the trip between two locations is less than the time duration in the mining activities.

4. Methods to Determine Truck Allocation

In this section, we use match factor method to determine the type and number of trucks. First, Research [10] a factor known as work harmony between the conveyance and the digging tool should be determined. The match factor depends on the number of shovel and truck, cycle time of shovel, frequency of filling, and cycle time of truck [11]. The match factor is calculated using Equation (22).

\[
MF = \frac{n_k \times CT_i \times n}{N_i \times CT_j}
\]

(22)

If the result of match factor is:

a. MF < 1, then the shovel will often idling.
b. MF = 1, then the shovel and trucks are no one idling.
c. MF > 1, then the truck will often idling.

Equation (21) then can be simplified into:

\[
n_{k,l}^t = \frac{CT_j}{CT_i \times n}
\]

(23)

Equation (23) can be used to calculate the actual number of truck needed to be served by one unit shovel in each routes. The cycle time of truck (CTj) consists of time when truck j transported the product from location k to location l, then back from location l to location k, unloading in location l, and when the truck loading in location k. The cycle time of shovel (CTi) is the time when the truck loaded by the shovel in one cycle. Then to fulfil the input capacity of truck j, it can be calculated from the cycle time of shovel multiplied by frequency of filling (n).

After the number of truck have been calculated, then is calculating the number of trips that must be done by each type of trucks in each routes. It aims to obtain transportation cost to be incurred by the company. The number of trips that must be done by each truck is expressed as follow:

\[
y_j^t = 1 + \text{int} \left( \frac{m_j^t}{n_k} \right)
\]

(24)

5. Numerical Example

The numerical example is given to show the model implementation. Optquest of Crystal Ball Software is used to solve the model. The model parameters in the form of specification data of each truck, specification of shovel, and the number of materials to be transported each year are shown in Table 1, Table 2, and Table 3 respectively. The specification of trucks and shovel is adapted from official catalog on each manufacturer type of truck and shovel’s website. Then the number of material to be transported is adapted from research [9].
Table 1. Specification of Trucks

| Type of Truck | Capacity (ton) | Engine Power (kW) | Empty Speed (km/h) | Loaded Speed (km/h) |
|---------------|----------------|-------------------|--------------------|--------------------|
| 772           | 46             | 399               | 79.7               | 43.7               |
| EH 750        | 38             | 353               | 68.2               | 34.6               |
| 7547          | 45             | 368.4             | 50                 | 39                 |
| HD 405-6      | 41             | 358.9             | 70                 | 43.4               |
| 777F          | 91             | 689.9             | 64.5               | 35.5               |
| HD 785-7      | 91             | 867.1             | 65                 | 32.6               |
| 75570         | 90             | 772.2             | 60                 | 29.7               |
| EH 1000       | 98             | 824.4             | 63                 | 31.8               |
| 785C          | 136            | 990.7             | 54.8               | 30                 |
| HD 1500-7     | 141            | 1034.1            | 58                 | 33.4               |
| 75137         | 136            | 1177.5            | 50                 | 30                 |
| HD 1200-1     | 140            | 853.1             | 57.5               | 36.7               |
| HD 1600 M-1   | 160            | 1057.6            | 55                 | 32.3               |
| 75 174        | 160            | 1013.5            | 64                 | 38                 |
| 630E          | 172            | 1253.2            | 54.5               | 30.2               |
| EH 3000       | 156            | 1285.6            | 54.7               | 29                 |
| 793D          | 218            | 1718.8            | 54.3               | 29.2               |
| 7530          | 200            | 1691.6            | 43                 | 28.7               |
| 3500          | 193            | 1378.3            | 55.7               | 29.5               |
| T252          | 181            | 1323.8            | 51.5               | 27.8               |

Table 2. Specification of Shovel

| Type of Shovel | Capacity (ton) | Engine Power (kW) | Bucket Fill Factor (%) | Efficiency (%) |
|----------------|----------------|-------------------|------------------------|---------------|
| 6015B          | 14.6           | 556               | 95                     | 62            |

Table 3. Quantity of Material Product (ton)

| Year | Ore Sent to Sizing Unit (ton) | Ore Sent to Concentrator (ton) | Concentrate Sent to Pelletizing (ton) | Selling Sizing Unit Product (ton) | Selling Concentrate (ton) | Selling Pellet (ton) |
|------|-------------------------------|--------------------------------|--------------------------------------|----------------------------------|--------------------------|---------------------|
| 1    | 950,009                       | 12,000,000                     | 4,200,000                           | 424,804                          | 1,379,675                | 2,517,089           |
| 2    | 929,231                       | 12,000,000                     | 4,200,000                           | 435,492                          | 1,401,215                | 2,532,579           |
Based on Table 3, there are six routes of transportation. In each route, using Equation (23), the number of truck is shown in Table 4. The material transported is a single metal-multiproduct in open pit mining which considered for 5 years operation. The result of optimization run for 5000 iterations is shown in Table 5. From the table, Truck 75570 is selected to transport for Route 1 and Route 4, Truck 75174 is selected to transport for Route 2, Truck 772 is selected to transport for Route 3, Truck 777F is selected to transport for Route 5, and Truck 7547 is selected to transport for Route 6. The total cost resulted from the optimization is IDR 295,783,073,068.69.

Table 4. Number of Truck

| Type of Shovel | Cycle Time of Shovel (hour) | Type of Truck | Cycle Time of Truck (hour) | Number of Truck |
|----------------|----------------------------|---------------|-------------------------|----------------|
| 6015B          | 0.00533                    | 772           | 0.129                   | 8              |
|                |                            | EH 750        | 0.126                   | 10             |
|                |                            | 7547          | 0.129                   | 8              |
|                |                            | HD 405-6      | 0.128                   | 9              |
|                |                            | 777F          | 0.188                   | 6              |
|                |                            | HD 785-7      | 0.188                   | 6              |
|                |                            | 75570         | 0.185                   | 6              |
|                |                            | EH 1000       | 0.196                   | 6              |
|                |                            | 785C          | 0.237                   | 5              |
|                |                            | HD 1500-7     | 0.239                   | 5              |
|                |                            | 75137         | 0.237                   | 5              |
|                |                            | HD 1200-1     | 0.238                   | 5              |
|                |                            | HD 1600 M-1   | 0.291                   | 5              |
|                |                            | 75 174        | 0.291                   | 5              |
|                |                            | 630E          | 0.294                   | 5              |
|                |                            | EH 3000       | 0.286                   | 6              |
|                |                            | 793D          | 0.338                   | 5              |
|                |                            | 7530          | 0.334                   | 5              |
|                |                            | 3500          | 0.326                   | 5              |
|                |                            | T252          | 0.324                   | 5              |

Table 5. Result of Decision Variable

| Type of Truck | Route 1 | Route 2 | Route 3 | Route 4 | Route 5 | Route 6 |
|---------------|---------|---------|---------|---------|---------|---------|
| 772           | 0       | 0       | 1       | 0       | 0       | 0       |
| EH 750        | 0       | 0       | 0       | 0       | 0       | 0       |
| 7547          | 0       | 0       | 0       | 0       | 0       | 1       |
| HD 405-6      | 0       | 0       | 0       | 0       | 0       | 0       |
| 777F          | 0       | 0       | 0       | 0       | 0       | 1       |
| HD 785-7      | 0       | 0       | 0       | 0       | 0       | 0       |
| 75570         | 1       | 0       | 0       | 1       | 0       | 0       |
| EH 1000       | 0       | 0       | 0       | 0       | 0       | 0       |
| 785C          | 0       | 0       | 0       | 0       | 0       | 0       |
6. Conclusion
In this paper we developed an optimization model to minimize a total cost in determine truck allocation in open pit mining to minimize investment and transportation cost. The amount of transportation cost is influenced by the type of trucks from each manufacturer according to the specifications. The respective number of trucks to transport mining products and finished products, the company expenses the purchasing cost of the selected trucks for the mining project. Using the model, the optimal number of truck is determined to minimize investment and transportation cost. The result of optimization showed that Truck 75570 is selected to transport for Route 1 and Route 4, Truck 75174 is selected to transport for Route 2, Truck 772 is selected to transport for Route 3, Truck 777F is selected to transport for Route 5, and Truck 7547 is selected to transport for Route 6. The total cost resulted from the optimization is IDR 295,783,073,068.69. For further research, the model can be integrated in a cut off grade model to result a two stage optimization model in determining the cut off grade and transportation decisions. Another further research will be done by considering idling factor for the shovel, truck, or both.

References
[1] Goodfellow, R.C., & Dimitrakopoulos, R. (2016). Global Optimization of Open Pit Mining Complexes with Uncertainty. *Appl. Soft Comput.* 292-304.
[2] Paithankar, A., Chatterjee, S., Goodfellow, R., & Asad, M.W.A. (2020). Simultaneous Stochastic Optimization of Production Sequence and Dynamic Cut-Off Grade In Open Pit Mining Operation. *Journal Elsevier, Resources Policy* 66 (2020) 101634.
[3] Morad, A.M., Mohammad, P.M., Aghababaei, H., & Sattarvarnd, J. (2019). A Methodology for Truck Allocation Problems Considering Dynamic Circumstances in Open Pit Mines, Study of the Sungun Copper Mine. *The Mining Geology Petroleum Engineering Bulletin*, 57-65.
[4] Ta, C.H., Ingolfsson, A., & Doucette, J. (2013). A Linear Model for Surface Mining Haul Truck Allocation Incorporating Shovel Idle Probabilities. *European Journal of Operational Research*, 770-778.
[5] Chan, F.T.S., Jha, A., & Tiwari, M.K. (2015). Bi-Objective Optimization of Three Echelon Supply Chain Involving Truck Selection and Loading Using NSGA-II with Heuristics Algorithm. *App. Soft Computing*.
[6] Gusman, M., Asri, Y., & Prengki, I. (2019). Optimization of Digging and Loading Equipment and Hauling for Overburden Production with Quality Capacity Methods and Queing Methods in East Pit, August 2017 Period PT. Artamulia Tata Pratama, Site Tanjung Belit, Bungo, Jambi. *International Conference on Education, Science and Technology*.
[7] Prasmoro, A.V. (2014). Optimasi Produksi Dump Truck Volvo FM 440 Dengan Metode Kapasitas Produksi dan Teori Antrian di Lokasi Pertambangan Batubara (Studi pada Salah Satu Kontraktor Pertambangan Area Samarinda, Kalimantan Timur). *Jurnal OE, Volume VI*, 93-108.
[8] Bajany D.M., Xia X., & Zhang L. (2017). A MILP Model For Truck-Shovel Scheduling To Minimize Fuel Consumption. The 8th International Conference on Applied Energy, 2739-2745.

[9] Mohammadi, S., Kakaie, R., & Ataei, M. (2017). Determination of The Optimum Cut-Off Grades and Production Scheduling in Multi-Product Open Pit Mines Using Imperialist Competitive Algorithm (ICA). Resource Policy 51, 39-48.

[10] Hartman, H.L. (1992). SME Mining Engineering Handbook Second Edition, Volume 1. Colorado, Society for Mining, Metallurgi, and Exploration inc.

[11] Basuki, S. & Nurhakim. (2004). Modul Ajar dan Praktikum Pemindahan Tanah Mekanis, Program Studi Teknik Pertambangan, Universitas Lambung Mangkurat, Banjarbaru.