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Nikola Stanić[*1], *Miljan Gomilanović*[*2], *Saša Stepanović*[*3], *Aleksandar Doderović*[*4]

SELECTION THE OPTIMAL TRUCK MODEL FOR TRANSPORT OF BY-PRODUCTS FROM THE TPP PLJEVLJA TO THE MALJEVAC LANDFILL[**]

Orcid: 1) https://orcid.org/0000-0002-6620-8563; 2) https://orcid.org/0000-0002-1209-7423; 3) https://orcid.org/0000-0003-3485-201X; 4) https://orcid.org/0000-0003-3665-6784

Abstract

This work presents an analysis of selection the optimal truck model for transport of ash, gypsum and slag from the Thermal Power Plant Pljevlja to the Maljevac landfill. The capacity of trucks for transport of by-products was calculated applying the Talpak program package for different types of trucks, taking into account different engagement times. The analysis was done for three types of trucks: Kamaz 53605-A5 (4x2), Mercedes-Benz Actros 4141 and Volvo FMX 520 10X4, for operation in one, two and three shifts. The results of analysis were used to select the optimal type of truck.

Keywords: *by-product, transport, optimization*

1 INTRODUCTION

Ash, slag and gypsum are the by-products occurring in the process of electricity production in the thermal power plants during the coal combustion and desulfurization of combustion gases. In practice, there are several different ways of transport and disposal of this material. Through this work, three variants of the truck transport of by-products from the silos at the Pljevlja Thermal Power Plant to the Maljevac – Cassette 3 ash landfill were compared. The analyzes were considered for the transport of by-products after the environmental reconstruction of the Thermal Power Plant Pljevlja.

This work presents an analysis of transport the by-products from the Thermal Power Plant Pljevlja to the Maljevac landfill, that is the Cassette 3. The scheme of the technological process included in this analysis is shown in Figure 1.

[*] *Mining and Metallurgy Bor, Zeleni bulevar 35, Bor, Serbia, e-mail: nikola.stanic@irmbor.co.rs*

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Figure 1 *Technological process of loading, transport and disposal of by-products*

Truck transport is increasingly used. Manufacturers produce more and more types of trucks suitable for working in different conditions and overcoming different exploitation capacities [1].

All kinds of materials can be transported by the means of truck transport, regardless of their physical and mechanical properties. Great possible mobility, flexibility, outstanding maneuverability during operation and great independence from energy sources are characteristics that come to full expression when using vehicles of auto transport and promise the best economy [2].

One of the most comprehensive reviews of influencing factors on the mechanization selection was given by the authors [3,4]. According to the mentioned authors, the selection of equipment is influenced by the following factors:

- Organizational factors,
- Required equipment flexibility
- Technical characteristics of the equipment,
- Planned production targets,
- Experience in working with a certain type of equipment,
- Lifetime of the equipment,
- Capital and operating costs,
- Reputation of the manufacturer and history of reliability the specific type of equipment,
- The possibility and term of procurement, as well as the manufacturer's guarantee,
- Type of drive (drive fuel),
- Required level of maintenance,
- The need to hire the additional auxiliary equipment,
- Degree of automation,
- Level of safety and comfort when handling the equipment,
- Plan of transport routes and structural parameters, section lengths, slopes, curves,
- The quality of the road surface,
- Speed, load capacity and cycle time of truck movement,
- Tire wear and rolling resistance,
- Construction of a waste dump/landfill,
- Waiting time for loading/unloading.

For most of the authors, see [5, 6, 7, 8, 9], the term optimal equipment actually means a technological system, which within the limitations of the working environment fulfills the production targets with ensuring the minimum costs.

Dimensioning of the truck transport system, i.e. its capacity, should ensure the removal of by-products of the Thermal Power Plant Pljevlja throughout the year, for the estimated operating time of the Pljevlja Thermal Power Plant after reconstruction of about 7,500 h/year. The characteristics of the silo after reconstruction are shown in Table 1.

Table 1 *Characteristics of the silo after reconstruction the Pljevlja Thermal Power Plant*

	Slag	Ash	Gypsum
Silo capacity, m^3	400	3200	600
Discharge rate, m^3/h	50	200	83
Bulk density, t/m^3	0.95	0.8	1.2

For the purposes of an analysis, the annual amount of by-products that need to be transported to the Maljevac landfill was adopted:

- Ash 420,000.00 t
- Slag 70,000.00 t
- Gypsum 154,000.00 t

2 ANALYSIS OF A RATIONAL TRUCK MODEL FOR TRANSPORT OF BY-PRODUCTS

Transport calculation was done using a simulation model-software Talpac 10.2. The software Talpac simulates the technological phases of loading and transport on the basis of the operational and technological parameters of these phases and results in the operational capacities of loading and transport machinery. The software package Talpac represents a simulation model of the loading and transport process at the open pits. The software enables optimization of the transport fleet, calculation the technical and economic parameters of equipment operation such as cycle length, capacity, etc. [10, 11, 12]

The analysis of transport system was performed for the following initial conditions:

- Operating hours of the Thermal Power Plant, 7500 h/year
- Shift duration, 8 hours
- Annual ash capacity, 420,000 t, 525,000 m^3 (γ=0.8 t/m^3)
- Annual slag capacity, 70,000 t, 73,684 m^3 (γ=0.95 t/m^3)
- Annual gypsum capacity, 154,000 t, 128,333 m^3 (γ=1.2 t/m^3)
- Maximum slope of the route, < 8%
- Minimum bend radius, 15 m
- Trucks of different load capacities

Variant 1 - Truck Kamaz 53605-A5 (4x2)

Table 2 shows the view and technical characteristics of the Kamaz 53605-A5 (4x2) truck.

Table 2 *View and technical characteristics of the Kamaz 53605-A5 (4x2) truck*

Engine power, kW (KS)	221 (300)
Load capacity, kg	11300
Box capacity, m^3	5.6

The results of capacity calculation for the Kamaz 53605-A5 truck are shown in Table 3.

Table 3 *Results of capacity calculation for the Kamaz truck (Report from Talpac)*

Production Summary - Full Simulation		
Truck		***[PRJ] Kamaz Kamaz 53605-A5 (4x2)***
Availability	%	70.00
Payload in Template	ton	6.72
Operating hours per Year	Oph/year	5,302.50
Average Payload	ton	6.89
Production per Operating Hour	ton	30.28
Production per Loader Operating Shift	ton	159
Production per Year	ton	160,556
Queue Time at Loader	min/ Cycle	0.05
Spot Time at loader	min/ Cycle	0.40
Average Loading Time	min/ Cycle	0.13
Travel Time	min/ Cycle	11.94
Spot Time at Dump	min/ Cycle	0.30
Average Dump Time	min/ Cycle	0.20
Average Cycle Time	min/ Cycle	13.03
Fleet Size		5
Average No. of Bucket Passes		2.00
Haulage System		
Production per Year	ton/Year	802,778
Excavation Target	t	644,000.00
Loader hrs to move Target	OphYear	6,077
Total Truck hrs to move Target	Oph/Year	21,269

Variant 2 - Truck Mercedes Actros 4141

Table 4 shows the view and technical characteristics of the Mercedes Actros 4141 truck.

Table 4 *View and technical characteristics of the Mercedes Actros 4141 truck*

Engine power, kW (KS)	**300 kW-410 KS**
Load capacity, kg	25000
Box volume, m^3	15

The results of capacity calculation for the Mercedes Actros 4141truck are shown in Table 5.

Table 5 *Results of calculation the transport capacity for the Mercedes Actros truck (Report from Talpac)*

Production Summary - Full Simulation		
Truck		*[PRJ] Mercedes Actros 25 t*
Availability	%	70.00
Payload in Template	ton	12.00
Operating hours per Year	Oph/year	5,302.50
Average Payload	ton	12.29
Production per Operating Hour	ton	50.89
Production per Loader Operating Shift	ton	267
Production per Year	ton	269,831
Queue Time at Loader	min/ Cycle	0.04
Spot Time at loader	min/ Cycle	0.33
Average Loading Time	min/ Cycle	0.40
Travel Time	min/ Cycle	12.36
Spot Time at Dump	min/ Cycle	0.33
Average Dump Time	min/ Cycle	0.33
Average Cycle Time	min/ Cycle	13.80
Fleet Size		3
Average No. of Bucket Passes		4.00
Haulage System		
Production per Year	ton/Year	809,494
Excavation Target	t	644,000.00
Loader hrs to move Target	Oph/Year	189.51
Total Truck hrs to move Target	Oph/Year	8,253

Variant 3 - Truck Volvo FMX 520

Table 6 shows the view and technical characteristics of the Volvo FMX 520 truck.

Table 6 View and technical characteristics of the Volvo FMX 520 truck

**(image downloaded from the site BAS World, Volvo FMX 520 10X4 Tipper Truck New Tipper Truck - BAS World)*

Engine power, kW (KS)	**370 (520)**
Load capacity, kg	49500
Box capacity, m^3	30

The results of capacity calculation for the Volvo FMX 520 10X4 are shown in Table 7.

Table 7 *Results of calculation the transport capacity for the Volvo FMX 520 truck (Report from Talpac)*

Production Summary - Full Simulation		
Truck		*[PRJ] VOLVO FMX 520 50 t*
Availability	%	70.00
Payload in Template	ton	36.00
Operating hours per Year	Oph/year	5,302.50
Average Payload	ton	36.25
Production per Operating Hour	ton	125.48
Production per Loader Operating Shift	ton	659
Production per Year	ton	665,349
Queue Time at Loader	min/ Cycle	0.05
Spot Time at loader	min/ Cycle	0.33
Average Loading Time	min/ Cycle	1.07
Travel Time	min/ Cycle	14.40
Spot Time at Dump	min/ Cycle	0.33
Average Dump Time	min/ Cycle	0.33
Average Cycle Time	min/ Cycle	16.51
Fleet Size		2
Average No. of Bucket Passes		9.01
Haulage System		
Production per Year	ton/Year	1,330,698
Excavation Target	t	644,000.00
Loader hrs to move Target	Oph/Year	3,666
Total Truck hrs to move Target	Oph/Year	5,132

The analysis of transport the by-products of combustion in the Thermal Power Plant Pljevlja included three variants in which different types of trucks were considered where the main parameter being their carrying capacity. The basic parameters of the variant analysis are shown in the following table (Table 8).

Table 8 *Basic parameters of the analyzed equipment*

	Truck type	Load capacity, t	Box volume, m^3	Required number of trucks	Possible capacity, t/year	Required working time for realization the planned capacity, h/year	System utilization, (%)
1.	Volvo FMX 520	50	30	2	1,330,698	2,566	0.48
2.	Mercedes Actros 4141	25	15	3	809,494	2,751	0.79
3.	Kamaz 53605-A5	11.3	5.6	5	802,778	4,253	0.80

Comparing the shown variants, the advantage is given to the variant 2, that is, the variant for the Mercedes Actros 4141 truck with a capacity of 25 t. The advantage of this variant is reflected in the fact that the Investor has already the trucks of this type, but also has an organized maintenance system, experience in the exploitation and maintenance of this type of truck. From the aspect of analyzed parameters, the Investor has the best characteristics in terms of system utilization and required number of truck engagements, which is and directly related to the number of engaged drivers.

3 ANALYSIS OF TRANSPORT FROM THE ASPECT OF TIME ENGAGEMENT

The analysis of transport the by-products of combustion in the Thermal Power Plant Pljevlja also included the three sub-variants in which different time engagement of trucks for transport, i.e., for work in one, two and three shifts, were considered. The analysis was performed for the selected type of Mercedes Actros 4141 truck. The results of analysis are shown in the following table (Table 9).

Table 9 *Basic parameters of the analyzed transport system for different number of shifts*

Subvariant	Shift No.	Required number of trucks	Possible capacity, t/year	Required working time for realization the planned capacity, h/year	System utilization, (%)
1.	3	3	809,494	2,751	0.79
2.	2	4	915,353	2,386	0.70
3.	1	7	797,247	1,369	0.80

The following tables (Tables 10, 11 and 12) show the results of the transport capacity calculation for the Mercedes Actros truck for different shifts (Reports from the Talpac software package).

Table 10 *Results of calculation the transport capacity of the Mercedes Actros truck for 1 shift*

Production Summary - Full Simulation		
Haulage System: Haulage System-1 *Material: [PRJ] P+S+G*		*Haul Cycle: [PRJ] Route 1* *Roster: [PRJ] PV 1 SHIFT*
Truck		*[PRJ] Mercedes Actros 25 t*
Availability	%	70.00
Payload in Template	ton	18.00
Operating hours per Year	OpHr/year	1,695.75
Average Payload	ton	18.40
Production per Operating Hour	ton	67.16
Production per Loader Operating Shift	ton	447
Production per Year	ton	113,892
Queue Time at Loader	min/ Cycle	0.18
Spot Time at loader	min/ Cycle	0.33
Average Loading Time	min/ Cycle	0.53
Travel Time	min/ Cycle	12.85
Spot Time at Dump	min/ Cycle	0.33
Average Dump Time	min/ Cycle	0.33
Average Cycle Time	min/ Cycle	14.56
Fleet Size		7
Average No. of Bucket Passes		4.97
Haulage System		
Production per Year	ton/Year	797,247
Excavation Target	t	644,000.00
Loader hrs to move Target	Oph/Year	1,957
Total Truck hrs to move Target	Oph/Year	9,589

Table 11 *Results of calculation the transport capacity of the Mercedes Actros truck for 2 shifts*

Production Summary - Full Simulation		
Haulage System: Haulage System-1		*Haul Cycle: [PRJ] Route 1*
Material: [PRJ] P+S+G		*Roster: [PRJ] PV 2 SHIFTS*
Truck		*[PRJ] Mercedes Actros 25 t*
Availability	%	70.00
Payload in Template	ton	18.00
Operating hours per Year	Oph/year	3,391.50
Average Payload	ton	18.40
Production per Operating Hour	ton	67.48
Production per Loader Operating Shift	ton	449
Production per Year	ton	228,846
Queue Time at Loader	min/ Cycle	0.08
Spot Time at loader	min/ Cycle	0.33
Average Loading Time	min/ Cycle	0.53
Travel Time	min/ Cycle	12.85
Spot Time at Dump	min/ Cycle	0.33
Average Dump Time	min/ Cycle	0.33
Average Cycle Time	min/ Cycle	14.45
Fleet Size		4
Average No. of Bucket Passes		4.97
Haulage System		
Production per Year	ton/Year	915,383
Excavation Target	t	644,000.00
Loader hrs to move Target	Oph/Year	3,409
Total Truck hrs to move Target	Oph/Year	9,544

Table 12 *Results of calculation the transport capacity of the Mercedes Actros truck for 3 shifts*

Production Summary - Full Simulation		
Truck		*[PRJ] Mercedes Actros 25 t*
Availability	%	70.00
Payload in Template	ton	12.00
Operating hours per Year	Oph/year	5,302.50
Average Payload	ton	12.29
Production per Operating Hour	ton	50.89
Production per Loader Operating Shift	ton	267
Production per Year	ton	269,831
Queue Time at Loader	min/ Cycle	0.04
Spot Time at loader	min/ Cycle	0.33
Average Loading Time	min/ Cycle	0.40
Travel Time	min/ Cycle	12.36
Spot Time at Dump	min/ Cycle	0.33
Average Dump Time	min/ Cycle	0.33
Average Cycle Time	min/ Cycle	13.80
Fleet Size		3
Average No. of Bucket Passes		4.00
Haulage System		
Production per Year	ton/Year	809,494
Excavation Target	t	644,000.00
Loader hrs to move Target	Oph/Year	189.51
Total Truck hrs to move Target	Oph/Year	8,253

Comparing the shown subvariants, the advantage is given to the subvariant 2, that is, the subvariant for two shifts. The advantage of this sub-variant is reflected in the fact that the smallest number of trucks is engaged enabling the constant removal of combustion by-products dynamically aligned with production capacities. This plays a particularly important role when separate transport and deposition of gypsum and slag and ash is carried out on the other side, that is, when a simultaneous transport of different types of materials to different deposit sites is required.

4 CONCLUSION

Based on the comparison of the presented variants and sub-variants, it is concluded that according to the criteria of the number of engaged trucks, system capacity and time engagement of the trucks, the variant 2 is optimal, which implies the operation of the Mercedes Actros 4141 truck in sub-variant 2, with work in 2 shifts. When choosing the variant, it was taken into account that the Investor already has trucks of this type, an organized maintenance system and experience in the exploitation and maintenance of this type of truck. Another advantage of this variant is from the aspect of analyzed parameters, where the variant 2 has the best characteristics in terms of system utilization and required number of truck engagements. In this variant, there is a good dynamic compatibility between the production of by-products in the thermal power plant and capacity of removal to the ash, slag and gypsum landfills. An important aspect of considering the overall issue of optimizing the transport of ash, slag and gypsum as a potential man-made mineral raw material for production the building materials is that the thermal power plant work products are deposited in different locations, that the capacities for transport different types of materials differ significantly, and that the adopted system with its flexibility fully meets these requirements.

REFERENCES

[1] r. Borović, Truck Transport at the Open Pits, Faculty of Mining and Geology, University of Belgrade, 1995, ISBN 86-80887-32-3 (in Serbian)

[2] D. Ignjatović, Mining Machines, Script Part II, Faculty of Mining and Geology, University of Belgrade, 2011 (in Serbian)

[3] B. Samanta, B. Sarkar, S. Mukherjee, Selection of Opencast Mining Equipment by a Multi-Criteria Decision-Making Process. Mining Technology, 111(2)(2002) 136-142.

[4] Australian Government, Department of Resources, Energy and Tourism, Case study: Analyses of Diesel Use for Mine Haul and Transport Operations, Canberra, September 2010.

[5] Y. Lizotte, Economic and Technical Relations Between Open-Pit Design and Equipment Selection. Mine Planning and Equipment Selection. Singhal (Ed). Balkema, Rotterdam, 1988, p.3-12.

[6] N. Sharma, An Alternative Approach to Procurement of Equipment: Coal India’s Experience. International Conference on the Management of Mining Machinery, 8-9 July 1999, Calcuta, India.

[7] A. Bozorgebrahimi, R. Hall, M. Morin, Equipment Size Effects on Open Pit Mining Performance. Interna-tional Journal of Surface Mining, Reclamation and Environment, 19(1)(2005) 41-56.

[8] H. Aykul, E. Yalcin, I. Ediz, D. Dixon-Hardy, H. Akcakoca, Equipment Selection for High Selective Excavation Surface Coal Mining, Journal of the South African Institute of Mining & Metallurgy, 107(3)(2007)195-210.

[9] M. Banković, Optimization of the Loading and Transport Systems in the Function of the Open Pit Planning, Doctoral Dissertation, Faculty of Mining and Geology, University of Belgrade, 2018 (in Serbian)

[10] N. Stanić, S. Stepanović, D. Bugarin, M. Gomilanović, Selection the Rational Model of Transport Truck by the Selective Coal Mining at the Open Pit Gacko, Mining and Metallurgy Engineering Bor, 1-2 (2017) 23-34.

[11] N. Stanić, M. Gomilanović, S. Stepanović, S. Softić, Selection of a Rational Truck Model for Waste Transport at the Open Pit Gacko Using the AHP Method, Mining and Metallurgy Engineering Bor, 3-4 (2021) 41-52.

[12] S. Stepanović, N. Stanić, N. Marković, A. Doderović, Selection the Variant Technical Solution of the Transport and Service Road to the Eastern External Landfill and Collective Water Collector, Mining and Metallurgy Engineering Bor, 1-2(2019) 19-30.