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SELECTION OF A RATIONAL SOLUTION FOR TRANSPORT OF THE BY-PRODUCTS FROM THE COMBUSTION PROCESS IN TPP PLJEVLJA TO THE MALJEVAC LANDFILL[**]

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Abstract

This paper presents an analysis of selection the optimal model for transportation of by-products from the Thermal Power Plant Pljevlja to the Maljevac landfill. The analysis was done for two types of transport, truck transport and transport with belt conveyors. The paper presents the results of analysis the technological process of transport the by-products from the Thermal Power Plant Pljevlja to the Maljevac landfill, and evaluation the most important criteria for selection the optimal solution. During the selection of criteria and evaluation, three criteria were singled out as follows: ecology, economy and reliability of the system. The analysis showed that the most favorable variant from the aspect of capital costs and aspect of reliability is the variant of truck transport. The variant of continuous transport is more favorable from the aspect of normative costs. The environmental criteria had to be met by both variants.

Keywords: *transport, transport optimization, cost rationalization*

1 INTRODUCTION

The location of the Thermal Power Plant Pljevlja is situated in the industrial zone of the town of Pljevlja, on the fourth kilometer of the road Pljevlja - Djurdjevića Tara - Žabljak, at the altitude of 760 m.

The Maljevac landfill belongs to the group of wet landfills because finely ground waste (slag and ash) is hydraulically transported and disposed of in the form of hydro mixture. The mixture, transported by pipelines, consists of water and ash (in a ratio of 1:6 to 1:10). Through the pipeline, the mixture is brought to the landfill where the ash is deposited. Through the overflow structure, located on the right side of the landfill, the water from the landfill surface is drained by gravity to the dredging station, thus forming a closed system of recirculation the transport water.

Construction of a partition took place in two phases. In the first phase, the basic dam was built, with a crown elevation of 790.5 meters above sea level, and in the second phase, the embankments 1, 2, 3 and 4 steps were successively constructed with a final maximum elevation of 810 meters above sea level.

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Currently, the works are being carried out on remediation the Cassettes 1 and 2, while ash disposal is being carried out in the area of Cassette 3. According to the valid documentation, the Cassette is being built in several phases, and the construction phases of a landfill up to the levels 817 and 821 have been completed. Currently, the works on construction the embankment at level 824 are being completed.

Based on the examples from the region for the thermal power plants of similar or the same capacity that burn coal, the transport of by-products from the thermal power plant to the ash landfill can be divided into two parts:

- Internal transport.
- External transport.

Internal transport means the transport of ash, slag and gypsum from the place of production to the place of storage inside the thermal power plant. For ash, it is usually compressed air, which is transported to the silo where it is reloaded. Slag and gypsum are most often transported by conveyors with a rubber belt.

External transport means the transport of by-products from the place of storage inside the thermal power plant to the place of permanent disposal (ash landfill). Different modes of transport are used in practice. Table 1 shows the types of transport with examples from the region. The locations of the ash landfills are situated in the immediate vicinity of the thermal power plant.

Table 1 *Types of transport with examples from the region*

Location	**Gacko**	**Ugljevik**	**Kostolac**	**Kolubara**	**Obrenovac**
Ash	Hydro mixture	Truck	Hydro mixture	Hydro mixture	Hydro mixture
Slag	Truck	Truck	Belt conveyor /Truck	Truck	Truck
Gypsum	-	Truck	Belt conveyor		

2 ANALYSIS OF VARIANT SOLUTIONS

As a part of the Analysis, two variants of the transport of ash, slag and gypsum from the Pljevlja Thermal Power Plant to the Maljevac ash landfill, i.e., to the Cassette 3, were considered.

As a part of the first variant, the transport by trucks with a carrying capacity of 25 t is planned.

In the second variant, the transport is provided by conveyors with a rubber belt.

In both cases, the transport from three separate silos located in the vicinity of the Pljevlja Thermal Power Plant to the Cassette 3, the Maljevac ash landfill, was considered for a work system in four brigades (3 working, 1 on vacation). The capacity of silos for ash storages, slag and gypsum is shown in Table 2.

Table 2 *Characteristics of the silo after reconstruction the Thermal Power Plant Pljevlja*

	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

Dimensioning of the transport system, i.e., its capacity, should ensure the transport of by-products of the Thermal Power Plant Pljevlja throughout the year, for the estimated operating time of the Thermal Power Plant Pljevlja after reconstruction is about 7500 h/year. For the purposes of the analysis, the annual amount of by-products that need to be taken to the landfill was adopted. The expected annual quantities of materials are:

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

Variant 1 - Truck transport of by-products of the Thermal Power Plant Pljevlja

In the Variant 1, the truck transport of by-products of the Thermal Power Plant Pljevlja to the Maljevac ash landfill, i.e., to the Cassette 3, was analyzed. For the purposes of the analysis, the dump trucks with a carrying capacity of 25 t and box volume of 15 m^3 were adopted. Comprehensive recommendations on selection the machine types for defining the discontinuous loading and transport systems, are given in the Manual for the Surface Mining [1]. Calculation of transport costs is a direct function of distance between the current position of the loading vehicle and unloading point.

The technological processes included in this analysis are:

- Loading
- Transport outside the ash landfill contour
- Transport within the ash landfill contour
- Disposal of by-products
- Leveling and planning of disposed material

The material is loaded into trucks after placing the truck under the silo opening. The material is loaded into the means of transport by pouring it directly into truck box using a funnel that avoids dust emission.

Transport outside the ash landfill takes place on separately constructed roads for two-way traffic, and the maximum slope of transport roads is below 8%. The total height difference of transport outside the contour of the ash landfill is 66 m. The total length of transport from the place of loading is 2235 m.

Transport of ash inside the ash landfill is carried out along the already formed embankments and surfaces of dam and cassettes to the Cassette 3 embankment, where the material is unloaded. The transport of combustion products is planned to be carried out according to a transport scheme with a loop; the same route is used for the full and empty trucks.

During the analysis for transport calculation, a Mercedes-Benz Actros 4141 truck or trucks with similar characteristics were used. Figure 1 shows a view of the Mercedes-Benz Actros 4141 truck.

Figure 1 *Truck Mercedes-Benz Actros 4141*

Material at the truck unloading point is planned with a bulldozer or crawler loader. In order to prevent the dust raising during the truck unloading along the embankment, and in the places predicted for unloading, it is necessary to install a dewing system.

Figure 2 shows the transport route for trucks.

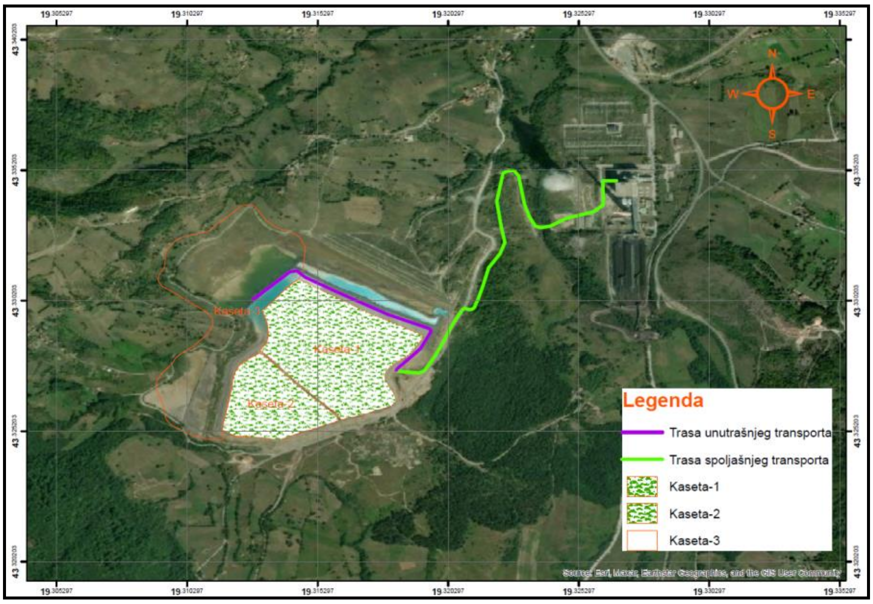

Figure 2 *Route of transport roads*

Numerical analysis of ash, slag and gypsum transport capacity - Variant 1

To meet the annual capacity needs and working conditions, transport routes, transport cycle time, work organization, etc., the MERCEDES-BENZ ACTROS 4141 trucks were used.

Analysis of the transport capacity of ash, slag and gypsum

The transport calculation was done using the simulation model-software Talpac 10.2. The software Talpac simulates the technological phases of loading and transport, based on 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 the equipment's operation, such as the cycle length, capacity, etc. [2,3,4]

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

- Operating hours of the Thermal Power Plant, 7500 h/year,
- Shift duration, 8 hours,
- Available time of the effective operation of a truck, 5300 h/year,

- 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 route slope, < 8%,
- Minimum bend radius, 15 m,
- Trucks with a carrying capacity of 25 t (box volume 15 m^3).

Ash transport calculation

The analysis was performed individually for each material separately. Considering the requirements regarding the ash transport capacity, the transport capacity for one to four trucks was analyzed.

The maximum amount of material that the truck transports in one cycle can be limited either by the load capacity of the truck or volume of its box. In this case, the box volume is the upper limit. Table 3 shows the results of ash transport calculations.

Table 3 *Summary of the ash transport calculation results*

Truck No.	Truck capacity (t/h)	System capacity (t/h)	Required capacity (t/year)	Required time to realize the required capacity (h/year)
1	51.26	51.26	420,000	8193
2	50.99	101.98	420,000	4119
3	50.89	152.7	420,000	2751
4	50.87	203.48	420,000	2064

Slag transport calculation

Considering the requirements regarding the slag transport capacity, the transport capacity for one truck was analyzed.

The results of calculation the slag transport are shown in Table 4.

Table 4 *Results of the slag transport calculations*

Truck No.	Truck capacity (t/h)	System capacity (t/h)	Required capacity (t/year)	Required time to realize the required capacity (h/year)
1	59.93	59.93	700,00	1168

Gypsum transport calculation

Considering the requirements regarding the gypsum transport capacity, the transport capacity for one truck was analyzed.

The results of calculation thegypsum transport are shown in Table 5.

Table 5 *Results of the gypsum transport calculations*

Truck No.	Truck capacity (t/h)	System capacity (t/h)	Required capacity (t/year)	Required time to realize the required capacity (h/year)
1	7422.	74.22	154,000	2075

Reliability, the probability of no-failure operation of the truck transport system is given in Table 6. Reliability is calculated for different levels of reliability of individual trucks and a system in which they are in a parallel connection.

Table 6 *Reliability of the parallel transport system with n trucks (n = 1 – 4)*

Reliability of one truck	0.6		0.65		0.7		0.75		0.8		0.85		0.9	
Truck No.	System reliability	Q(t/year)	System reliability	Q(t/year)	System reliability	Q(t/year)	System reliability	Q(t/year)	System reliability	Q(t/year)	System reliability	Q(t/year)	System reliability	Q(t/year)
1	0.6000	162,180	0.6500	175,695	0.7000	189,210	0.7500	202,725	0.8000	216,240	0.85	229,755	0,9000	243.270
2	0.7200	389,232	0.7638	412,883	0.8050	435,183	0.8438	456,131	0.8800	475,728	0.91375	493,973	0,9450	510.867
3	0.7920	642,233	0.8282	**671,594**	0.8610	**698,185**	0.8906	**722,208**	0.9173	**743,866**	0.941375	**763,361**	0,9630	**780.897**
4	0.8376	**905,613**	0.8674	937,838	0.8937	966,295	0.9170	991,452	0.9376	1,013,733	0.955905	1,033,524	0,9722	1.051.170

The Variant 2 is a variant that was considered using the continuous transport with belt conveyors. The reduced flexibility and strict structure of continuous systems significantly reduces the set of potential solutions, and thus the space for eventual improvements and optimization of the transport system [5]. The continuous transport system will consist of a receiving conveyor to which material from the silo feeder is added, four belt conveyors, three main (stationary) and a disposal conveyor that will change its length and position depending on a disposal front. In the case of the variant solution of continuous transport, it is necessary to place bars with a pneumatic feeder or auger on the silos, as in the case of truck transport. Belt conveyors are placed after the bars, which will have a loading funnel placed on them to accept the material. The material from the hopper will fall onto the belt conveyor. From each silo one conveyor will be placed with a feeder to transport the material from the silo to the receiving belt.

The belt conveyors will be of the closed type (covered) in order to increase the time utilization and reduce the negative impact on the environment. Figure 3 shows the layout of the belt conveyor.

A self-propelled conveyor will be attached to a disposal conveyor having the function of continuous disposal of material - disposer, characteristic of the BRs-1200.

Figure 3 *View of a belt conveyor*

Selection of a self-propelled conveyor that will work as a disposer was made on the basis of the necessary structural parameters that allow the material to be deposited with an appropriate radius, i.e., at a distance enabling a safe position of the self-propelled conveyor and less movement of the conveyor belts within the system.

Figure 4 *Self-propelled conveyor BRs-1200*

Figure 5 shows a scheme of a belt conveyor for transport of gypsum, ash and slag to the place of deposition.

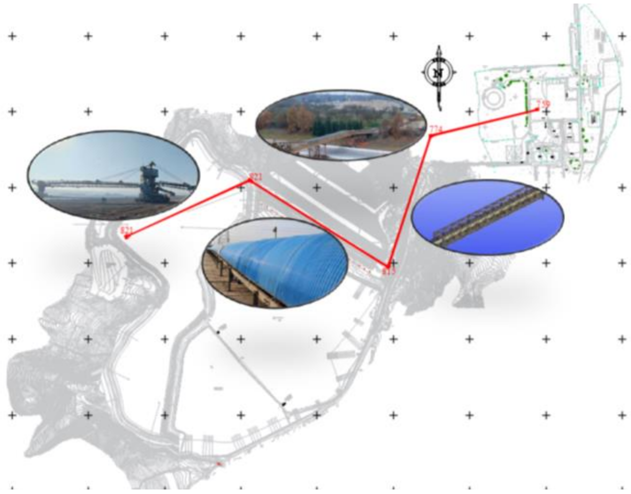

Figure 5 *Scheme of a belt conveyor for transport of ash, slag and gypsum*

The characteristics of the belt conveyor line are shown in Table 7.

Table 7 *Belt conveyor line characteristics*

Belt conveyor designation	Power station elevation (m)	Return station elevation (m)	Height difference	Material lifting height at the loading point (m)	Belt conveyor length (m)	Belt conveyor slope	Belt speed (m/s)	Belt width (mm)
T1	774	759	15	1.4	350	4.3%	2.09	800
T2	815	774	41	1.4	455	9.0%	2.09	800
T3	821	815	6	1.4	540	1.1%	2.09	800
T4	821	821	0	1.8	445	0.0%	2.09	800

Calculation of the conveyor drive group

Calculation of the belt conveyor was performed according to the appropriate SRP standard, and the calculation results are shown in Table 8.

Table 8 *Summary of the belt conveyor calculations*

Belt conveyor designation	Belt conveyor length (m)	Required motor power (kW)	Installed motor power (kW)	Total no. of motors (n x 75 kW)
T1	350	38.02	44.73	1
T2	455	42.99	50.57	1
T3	540	55.86	65.72	1
T4	445	46.30	54.47	1

3 ANALYSIS OF THE OBTAINED RESULTS

Evaluation of the variant solutions was given on the basis of an economic analysis that included the capital and operating costs.

Cost analysis of the Variant 1

Table 9 shows the investments required for the purchase of equipment, facilities and works in the Variant 1.

Table 9 *Investments for the transport system in Variant 1*

Variant 1			
	Pcs.	**€**	**€**
Trucks	3	140,000	420,000
Bridge over the river	1	100,000	100,000
Construction of the road route	1	300,000	300,000
Construction of the bearing layer of road	1	80,000	80,000
Equipment for silos	3	15,000	45,000
Preparatory and auxiliary works	1	17,000	17,000
Unforeseen expenses	1	85,800	85,800
Lighting system along the road route			223,500
TOTAL		**737,800**	**1,271,300**

Table 10 shows the standardized costs of materials and energy for the truck transport.

Table 10 *Consumption standards for truck transport*

Standard	Unit (€/m^3)	Costs (€/m^3)
Fuel standard	0.641	0.1428
Oil and lubricant standard	0.051	0.0114
Standard of spare parts	0.005	0.0011
Tire standard	0.000	0.00003
TOTAL STANDARD COSTS OF TRANSPORT		**0.698**

Table 11 shows the total standard costs of the transport system.

Table 11 *Total standard costs of the truck transport system*

Operation	Standard (€/m^3)
Truck transport standard	0.698
Bulldozer operation standard	0.231
Grader operation standard	0.064
Tank operation standard	0.04
TOTAL	1.033

Table 12 shows the annual labor costs.

Table 12 *Labor costs at the annual basis*

Job position	Operator No.	Educational background	GROSS SALARY €
Manager	1	Secondary vocational education	1,286
Supervisor	4	Secondary vocational education	5,714
Truck driver	12	Highly qualified	15,429
Bulldozer operator	4	Highly qualified	5,143
Grader operator and tanker driver	8	Highly qualified	9,143
Total	29		36,714
Total for a year			**440,571**
Standard labor cost			**0.606**

The analysis of the Variant 1 has established that at the annual basis:

Standard costs €	751,009
Labor costs €	440,571

and the planned investments are realized during the first year and amount to € 1,271,300. Figure 6 shows the sensitivity analysis of investments, standard costs and labor costs. Based on the analysis results, shown in the graphic and table, it can be concluded that the standard costs have the highest sensitivity in the Variant 1.

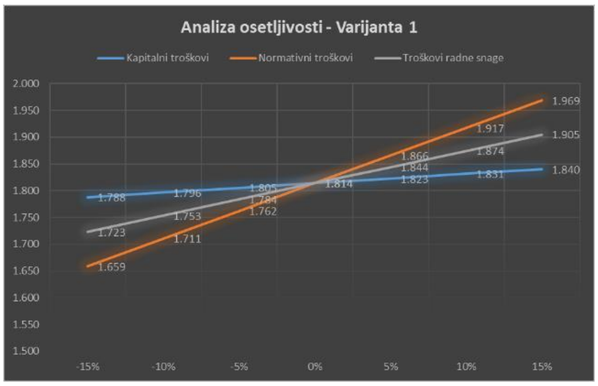

Figure 6 *Sensitivity analysis graph for the Variant 1*

Cost analysis of the Variant 2

Table 13 shows the investments required for the purchase of equipment, facilities and works in the Variant 2.

Table 13 *Investments for the transport system in the Variant 2*

	Type of cost	km		Pcs.	Price per unit	Total
	Equipment for silos			3	15,000	45,000
	Receiving belt with loading hoppers			1	60,000	60,000
T1	Belt conveyor	0.35		1	595,000	595,000
	Power station			1	270,000	270,000
T2	Belt conveyor	0.455		1	773,500	773,500
	Power station			1	270,000	270,000
T3	Belt conveyor	0.54		1	918,000	918,000
	Power station			1	270,000	270,000
T4	Belt conveyor	0.445		1	756,500	756,500
	Power station			1	270,000	270,000
	Loading trolley			1	70,000	70,000
	Dumper (Self-propelled dumper)			1	1,150,000	1,150,000
	Construction of a route for a conveyor belt			1	80,000	80,000
	Control and automation			1	812,700	812,700
	Bridge over asphalt road			1	50,000	50,000
	Unforeseen expenses					512,704
	Lighting system along the conveyor route					179,000
TOTAL						**7,082,404**

Table 14 shows the standardized costs of materials and energy for transport by belt conveyors.

Table 14 *Standards transport consumption by belt conveyors in the Variant 2*

Type	Standard (unit/m^3)	Quantity (unit)	Unit price (€/unit)	Unit costs (€/m^3)
Electrical energy(kWh/m^3)	2.9307		0.15	0.4396
Oil (kg/ m^3)	0.0200		5.5	0.1100
Lubricants (kg/m^3)	0.0200		5.5	0.1100
Stacks of rollers (pcs./m^3)	10%	143.2	850	0.0166
Stacks of lower rollers (pcs./m^3)	10%	71.6	550	0.0054
Stacks of damping rollers (pcs./m^3)	25%	12	950	0.0016
Drums (pcs./m^3)	10%	2	8500	0.0023
Rubber belt B=800 mm (m/m^3)	10%	179	1250	0.0304
Wipers (pcs.)	100%	2	300	0.0001
Bumper plates (pcs./m^3)	100%	2	350	0.0001
Sealing rubber (pcs.)	100%	2148	15	0.0044
TOTAL				**0.7204**

The total standard costs of material disposal in the Variant 2 are given in Table 15.

Table 15 *Total standard costs in the Variant 2*

Operation	Standard (€/m^3)
Standards of transport consumption by belt conveyors	0.7204
Standards for bulldozer operation	0.231
Standards of tank operation	0.04
TOTAL	**0.9914**

For the total masse of 727,018 m^3 (644,000 t) of ash, slag and gypsum, the total costs of standardized material during transport by belt conveyors amount to € 720,765.

Table 16 shows the annual labor costs.

Table 16 *Labor costs in the Variant 2*

Job position	Operator No.	Educational background	GROSS SALARY €
Manager	1	SSS	1,286
Supervisor	4	SSS	5,714
Belt conveyor operator	16	VKV	20,571
Dump truck operator	4	VKV	5,143
Bulldozer operator	4	VKV	5,143
Tank driver	1	VKV	1,143
Total	30		39,000
		Total for a year	**468,000**
		Standard labor cost	**0.643**

The analysis of the Variant 2 has established that at the annual basis:

Standard costs €	720,765
Labor costs €	468,000

and the planned investments are realized during the first year and amount to € 7,082,404.

Figure 7 shows the sensitivity analysis of investments, standard costs and labor costs. Based on the analysis results, shown in the graphic and table, it can be concluded that the standard costs have the highest sensitivity in the Variant 2.

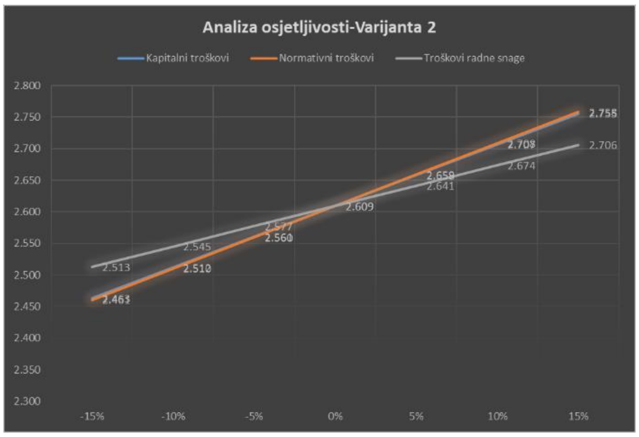

Figure 7 *Sensitivity analysis graph for the Variant 1*

4 DISCUSSION

Total investment and specific investment and operating costs are given in Table 17.

Table 17 *Total investment and specific investment and operating costs*

Comparison of variants					
	Investments (€)	Specific KAPEX (€/m^3)	Specific OPEX (€/m^3)	Labor force	Total (OP+KAP) (€/m^3)
Variant 1	1,271,300	0.1749	1.0330	0.6060	1.8139
Variant 2	7,082,404	0.9496	0.9914	0.6437	2.5847

Based on the values, shown in Table 17, it is concluded that the total specific costs expressed per m^3 in the Variant 2 are 42% higher compared to the Variant 1, which would represent the basic economic parameter for selection a more favorable variant.

In addition to this parameter, the formation of a new continuous transport system would also imply formation of the new specific capacities in a part of equipment maintenance, which represents an additional investment cost as well as the need to hire the additional personnel. From this aspect, the Variant 1 is more favorable.

5 CONCLUSION

The analysis carried out according to the basic techno-economic parameters gives preference to the Variant 1, but in addition to the economic assessment, the following two aspects of the transport system are also important, namely the environmental and system reliability in terms of the system readiness to respond to the request of the thermal power plant in real time with the appropriate capacity. From the ecological aspect, both variants are acceptable, that is, both modes of transport can be arranged with minimization the impact on the environment. When it comes to reliability, the reliability of these systems was specially analyzed, where the basic requirement was that it must be in a continuous operation in parallel with the Thermal Power Plant, that is, ensure all times the removal of slag, gypsum and ash with the required capacity considering the small volumes of silos.

Continuous operation equipment is characterized by a high degree of reliability, which ranges from 0.92 to 0.95 for the belt conveyors and from 0.9 to 0.95 for the conveyors (self-propelled conveyors) with a belt.

A continuous system on transport is a system consisting of 6 elements connected in series. In the case of high reliability of each system elements (0.95 belt conveyors, 0.92 depositor), the reliability of continuous system is 0.712. Figure 9 shows the schematic presentation of the serial continuous transport system.

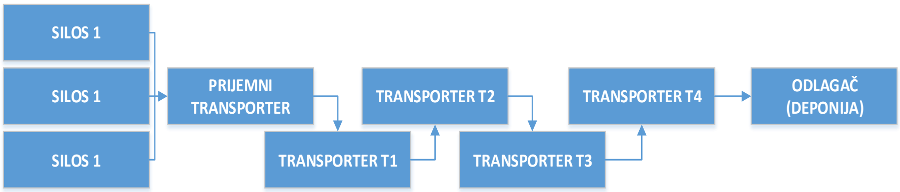

Figure 8 *Layout of a serial continuous transport system*

Contrary to this system, a discontinuous truck transport system enables the system to operate even in case of partial failure, i.e., malfunction, of one or two trucks (Figure 9).

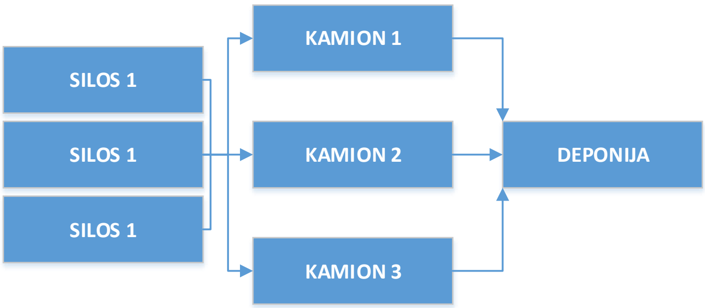

Figure 9 *Layout of a parallel discontinuous transport system*

Since this parallel structure of the truck transport system enables more reliable functioning of the system (reliability for three trucks and an individual probability of operation of 79% is 96%), it represents a significant advantage in selection a transport system in conditions of very limited material bin capacities.

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