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Surface Transportation Engineering Technology

A METHOD FOR THE COMPARATIVE ASSESSMENT OF THE TECHNICAL QUALITY OF DUMP TRUCKS WITH DIFFERENT STRUCTURES

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Abstract

Introduction: An analysis of the special-purpose road construction machinery market reveals an immensely diverse range of vehicles that can be used in construction. Due to this diversity, users may experience difficulties when choosing a dump truck from a range of vehicles with identical performance parameters. The final choice is often based on the user's subjective preferences and not always logically justified. This calls for designing a methodology that would make the choice of dump truck model less biased. **Purpose of the study:** The study is aimed to create a range of research and methodological tools for facilitating the comparative assessment of construction dump trucks that belong to the same category in terms of load capacity, but differ by structure. **Methods:** We compared and assessed our samples by contrasting the generalized vehicle quality parameters, as reflected by their technical quality coefficient. As research methods for collecting reference data for our assessment, we used information search, statistical analysis of information sources, expert studies, and mathematical modeling. **Results:** The comparative qualimetric assessment of the technical quality of different dump truck designs has prompted a conclusion that, when it comes to road construction, semi-trailer trucks are more preferable than chassis-based trucks. Specifically, semi-trailer dump trucks are characterized by better sustained performance, maneuvering ability, and terrain crossing capacity. **Conclusions:** The proposed method of technical quality comparative assessment allows for a more unbiased choice of dump trucks for road construction, based on analyzing their most vital performance parameters.

Keywords

Road construction, dump truck, performance parameters, technical quality, comparative assessment.

Introduction

An analysis of the special-purpose road construction machinery market reveals an immensely diverse range of vehicles that can be used in construction. This diversity may cause certain difficulties when choosing a dump truck from a range of vehicles with identical performance parameters (Faskhiev, 2016; Tselishchev and Faskhiev, 2017; Vygonnyi, 2015). The final choice is often based on the customer's subjective preferences or on the model's advertising campaign. Assessing the technical quality of various alternatives may help reduce bias (Dobromirov, 2000).

In cases of industrial product assessment, there are official guidelines (Regulatory Document RD 50-149-79) (State Committee of the USSR for Standards, 1979). They contain a list of the most important parameters out of the product's entire performance parameter range, as well as recommendations on how to use the expert evaluation method to find the weight coefficients for these parameters and subsequently determine the generalized technical quality index (which is a sum of the values obtained by multiplying each parameter by its weight coefficient). The guidelines (RD 50-149-79, 1979) contain an extensive list of technical equipment parameters that should be included in such assessments. The official recommendation is to select the most important parameters and provide the weight coefficient rationale for each industrial product on an industry-wide level, and then design a specific methodology in more detail. This method has been applied to many types of technical equipment; dump trucks, however, still lack such an assessment. Therefore, the creation of an assessment methodology, which will make it far easier for the consumer to choose the best dump truck out of a wealth of brands and models, is a highly relevant task.

Study objective, target, subject, and methods

Our objective is to design a methodology for the comparative assessment of construction dump trucks that belong to the same category in terms of load capacity, but differ by structure. Dump trucks are used for hauling bulk materials within a "storage base (quarry, railway station, pier, wholesale warehouse, etc.) — temporary storage facility at the (road) construction site" transportation system, across distances of over 10 km.

Our study targeted dump trucks with different types of structure. Modern road construction most commonly relies on single-unit dump trucks with a rigid chassis, or on semi-trailer dump trucks (Dobromirov, 2018a; Shiryaev et al., 2007). Among single-unit vehicles, greater preference is given to four-axle models, as they are more productive due to a greater body capacity (18–20 m3). In addition, the four-axle structure allows for a higher payload while staying within the recommended axle load limits. These vehicles also remain fairly efficient during medium and long hauls (ISO 337-1981) (ISO, 1981).

Semi-trailer dump trucks generally see more use for longer hauls. Their benefits include the high load capacity of the semi-trailer, even as it is used within the recommended axle load limits, as well as impressive traction and dynamic properties, ensured by the proper choice of the tractor unit (Hernandez et al., 2015; Rebrunova, 2011; Vakhlamov, 2003). Using trailers is one of the possible ways of improving vehicle performance and reducing shipping costs (Kravchenko, 2008).

The subject of our study is a method of mathematically assessing the technical quality of construction dump trucks. For the purposes of this study, we used such methods as information search, statistical analysis of information sources, expert studies, and mathematical modeling.

For conducting the comparative assessment of dump trucks' technical quality, we chose the four-axle rigid chassis KamAZ 65801-68 (T5) dump truck with an 8x4 wheel configuration and the three-axle KamAZ 65206-68 (T5) tractor unit with a 6x4 wheel configuration, coupled with the three-axle NEFAZ 9509-016-30 semi-trailer (KAMAZ, 2020; Kuznetsov, 2012).

A method for the comparative assessment of dump trucks' technical quality

We compared and assessed our samples by contrasting the generalized vehicle quality parameters, as reflected by their technical quality coefficient (Dobromirov, 2018b).

The technical quality coefficient is a consumer value parameter that is determined by the features that serve as the basis for its estimated structural performance. This performance is formed by a set of integrated parameters relevant to the vehicle's functionality and mobility. We believe it reasonable to divide these parameters into three groups (clusters): functional parameters, sustained performance parameters, and maneuvering ability parameters.

The functional parameters describe how well the vehicle performs its intended function (hauling bulk materials).

The sustained performance parameters reflect the vehicle's ability to move along its freight transportation route (which may include dirt roads of average quality, semi-paved roads, and blacktop roads, as well as slopes of different angles, as permitted by the road construction guidelines) at the maximum average speed possible.

The maneuvering ability parameters determine whether the vehicle is capable of maneuvering in confined spaces (such as quarries, open-pit benches, unloading sites, including places where the soil has a low load capacity) and climbing slopes that require the vehicle to strain its traction capacity to the limit.

Table 1 breaks down these integrated features to a measurable level (singular parameters). As singular parameters, we used those most relevant to dump truck performance. Parameter choice and the assessment of the parameters' weight coefficients in the context of integrated features' formation was based on expert evaluation.

Table 1. Group distribution of singular dump truck performance parameters

Functional parameters, Q_1		Sustained performance parameters, Q_2		Maneuvering ability parameters, Q_3	
Parameter	m_{ji} *)	Parameter	m_{ji}	Parameter	m_{ji}
1. Load capacity (G_l), t	0.45	1. Engine power-to-weight ratio (N_{eng}^{max} / G_0), kW/t	0.30	1. Number of driving axles	0.10
2. Body capacity (V_b), m^3	0.35	2. Maximum speed (V_{max}), km/h	0.35	2. Maximum slope elevation (α_{max}), degrees	0.15
3. Maximum dumping angle (α_{dump}), degrees	0.10	3. Number of transmission gears	0.10	3. Minimum turning radius (R_{min}), m	0.20
4. Number of dumping directions	0.10	4. Fuel consumption en route (q_r), l/100 km	0.25	4. Dimension range (H_d), m	0.15
				5. Specific wheel pressure level along the tread pattern (p_w), kPa	0.40

*) m_{ji} is the weight coefficient for a singular parameter.

The method for the qualimetric (qualitative) assessment of the technical quality level as a generalized quality index involves finding the value of each integrated parameter Q_j, which is based on the known values of the singular parameters q_{ji} and their weight coefficients m_{ji}. Each integrated parameter is assigned a weight P_j. The generalized quality index (technical quality level K_{tc}) is a sum of values obtained by multiplying each integrated parameter by its weight coefficient.

As per our recommendations (Dobromirov, 2018b), the methodology should be applied as follows:

– selecting the integrated parameters Q_j that serve as the basis for the dump truck's generalized quality index.

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These include the functional parameters, the sustained performance parameters, and the maneuvering ability parameters. Note that the j value for these integrated parameters falls within the 1–3 range;

– breaking down each integrated parameter Q_j into singular measurable parameters q_{ji}, where i is the sequence number of each singular parameter relevant to integrated parameter j. Notably, the number of singular parameters for each Q_j is individual and may range from 1 to n;

– determining the weight coefficient m_{ji} for each parameter q_{ji} in each group j (based either on an expert evaluation or on the personal experience of the person conducting the test). Important note: each group j must meet the following condition:

$$\sum_{i=1}^{n} m_{ji} = 1 \quad (1)$$

– determining the integrated parameter value Q_j for each group of singular parameters:

$$Q_j = \sum_{i=1}^{n} m_{ji} \cdot q_{ji} \quad (2)$$

where q_{ji} is the value of singular parameter i in group j; m_{ji} is the weight coefficient of singular parameter i in group j; n is the number of singular parameters in group j.

– determining weight P_j for each integrated parameter; just as in the case of m_{ji}, the following condition needs to be met:

$$\sum\nolimits_{j=1}^{k} Pj \quad (3)$$

where k = 3;

– determining the generalized quality index — the technical quality coefficient K_{ts}

$$K_{ts} = \sum\nolimits_{j=1}^{3} P_j \cdot Q_j \quad (4)$$

The resulting value K_{ts} should be used for comparing the quality levels of different models.

We suggest ranking the weight coefficients P_j within the system of integrated dump truck parameters Q_j as follows: functional parameters P_1 = 0.3; sustained performance parameters P_2= 0.45; maneuvering ability parameters P_3 = 0.25.

Results and discussion

When collecting reference data for the K_{ts} assessment in the vehicles of choice, we used the vehicles' technical features, traction, dynamic, and power capacity parameters, as well as fuel consumption efficiency, maneuvering ability, and terrain crossing capacity (Antonov, 1970a, 1970b; Dobromirov, 2016).

The dynamic features and fuel consumption efficiency graphs, based on our calculations, are shown in Figs. 1 and 2, respectively.

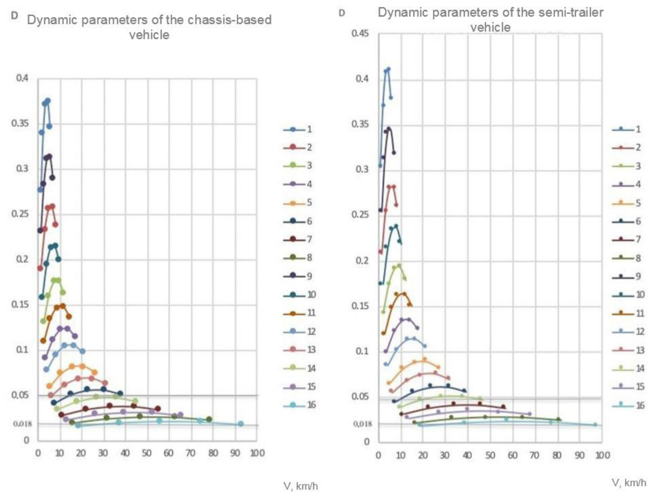

Figure 1. Dynamic features of dump trucks

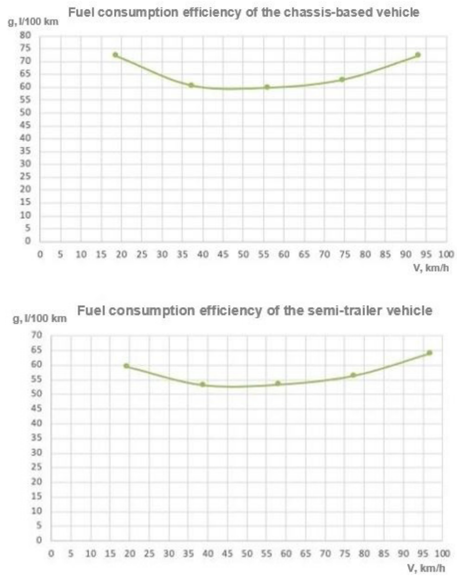

Figure 2. En-route fuel consumption graphs for vehicles moving at top gear

Then we used these parameter curves to determine the maximum vehicle speed, slope elevation, and en-route fuel consumption under typical conditions along the soil transportation route.

Figs. 3 and 4 provide diagrams that are needed to determine the vehicles' maneuvering ability parameters: the minimum turning radius (R_{min}) and the dimension range (H_d).

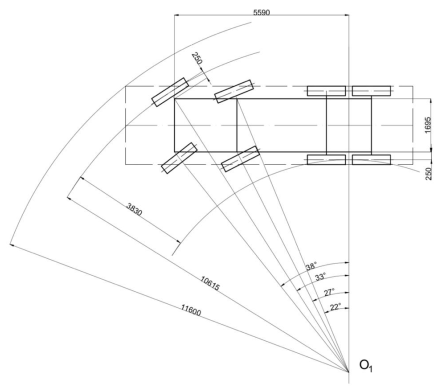

Figure 3. Diagram for determining the maneuvering ability parameters of the chassis-based vehicle

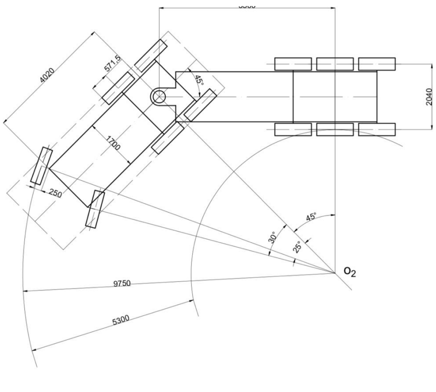

Figure 4. Diagram for determining the maneuvering ability parameters of the semi-trailer

The vehicles' terrain crossing capacity was contrasted against the average wheel-ground pressure. The wheel-ground pressure value was derived from two parameters: the average pressure in the contact area and the average pressure along the tread pattern.

In order to measure the average pressure in the contact area pc, we used the following equation:

$$p_c = \frac{G_w}{A_c} \quad , \tag{5}$$

where G_w is the vertical wheel load, N; A_c is the contour contact area, m², $A_c \approx B_t \cdot l_c$, , where B_t is the tire section width, m; l_c is the length of the tire's contact area, m.

On hard-surface pavement:

$$l_c = 2 \cdot \sqrt{r_f^2 - r_{st}^2} \quad , \tag{6}$$

where r_f and r_{st} is the free and static wheel radii, m.

The average wheel pressure along the tread pattern p_{tr} is derived from the following dependency:

$$p_{tr} = p_c / k_{tr} \quad , \tag{7}$$

where k_{tr} is the lug-to-void ratio. For the road pattern k_{tr}, ranges between 0.6 and 0.8.

In Russian practice, the usual range of wheel pressure on the hard-surface pavement is as follows: p_c≤0.6 MPa, p_{tr}≤0.85 MPa.

The KamAZ 65801-68 (T5) dump truck with an 8x4(2) wheel configuration is equipped with NR 701 12.00 R24 tires (free wheel radius 0.615 m, static wheel radius 0.575 m, tire section width B_t= 0.319 m). The maximum wheel load is 45,000 N. Accounting for these parameters, the average pressure values are as follows: p_c=0.316 MPa, p_{tr}=0.526 MPa.

The KamAZ 65206-68 (T5) tractor unit has a 6x4(2) wheel configuration and is coupled with the NEFAZ 9509-016-30 semi-trailer. The semi-trailer has three axles with one tire per each. This tractor unit is equipped with KAMA NR203315/80 R22.5 tires (free wheel radius 0.542 m, static wheel radius 0.505 m, tire section width 0.315 m). The minimum wheel load is 23,750 N.

The NEFAZ 9509-016-30 semi-trailer is equipped with KAMA NT201385/65 R22.5 tires (free wheel radius 0.542 m, static wheel radius 0.490 m, tire section width 0.385 m). The minimum semi-trailer wheel load is 45,000 N.

Our assessment has revealed that for the semi-trailer truck, p_c=0.248 MPa, p_{tr}=0.413 MPa.

Using the vehicles' technical specifications and the results of our calculations, we compiled the following table of reference data for assessing the technical quality (Table 2).

Table 2. Reference data for a comparative assessment of the dump truck technical quality

Reference data		
Parameters	KamAZ 65801-68 (T5) 	KamAZ 65206-68(T5) with the NEFAZ 9509-016-30 semi-trailer 
Load capacity G_l , kg	32,425	34,750
Configuration	8x4	6x4 + 3-axle semi-trailer
Platform capacity, m³	20	30
Dumping angle, degrees	50	45
Number of dumping directions	1	1
Gross vehicle weight G_{gross}, kg	50,000	44,000
Power capacity N_e, kW (hp)	315 (428)	315 (428)
Number of transmission gears	16	16
Static wheel radius r_{st}, m	575 ± 7	505 ± 8
Estimates		
Engine traction power Pt_{max} , N	183,657	176,591
Dynamic factor D_{max}	0.375	0.471

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Maximum speed V_{max}, km/h: blacktop (0.018) dry soil (0.05)	93.15	96
	37.6	46.5
Fuel consumption q when driving on a blacktop road, l/100 km	59.8	53.47
Slope elevation a, degrees blacktop (0.018) dry soil (0.05)	21	27
	19	25
Minimum turning radius R_{min}, m	10.615	9.75
Dimension range H_d, m	3.83	5.3
Average pressure of the wheel's contact surface on the ground p_c, N/cm^2	31.57	24.8
Average wheel pressure along the tread pattern p_{tr}, N/cm2	52.61	41.33

Table 3 illustrates K_{ts} assessment results for the dump trucks that we are comparing

Table 3. Assessment results for generalized and integrated parameters

Parameter		Parameter value q_{ji}		Parameter weight coefficient m_{ji}	KamAZ 65801-68	KamAZ 65206-68 + Nefaz semi-trailer
Functional parameters						
1	Load capacity, t	32.425	34.75	0.45	14.6	15.64
2	Body capacity, m^3	20	30	0.35	7	10.5
3	Dumping angle, degrees	50°	45°	0.1	5	4.5
4	Number of dumping directions	1	1	0.1	0.1	0.1
					26.7	30.74
	$Q_1(P_1 = 0.3)$				8.01	9.22
Sustained performance parameters						
1	Power-to-weight ratio, kW/t	6.3	7.16	0.3	1.89	2.15
2	Maximum speed, km/h	93.15	96	0.35	32.6	33.6
3	Number of transmission gears	16	16	0.1	1.6	1.6
4	Fuel consumption en route, l/100 km	59.8	59.8	0.25	10.05	11.63
					46.14	48.98
	$Q_2(P_2 = 0.45)$				20.76	22.04
Maneuvering ability parameters						
1	Number of driving axles	2	2	0.1	0.2	0.2
2	Maximum slope elevation, degrees	21°	27°	0.15	3.15	4.05
3	Minimum turning radius, m	10.615	9.75	0.2	1.877	2.05
4	Dimension range, m	3.83	5.3	0.15	0.93	0.705
5	Specific wheel pressure along the tread pattern, N/cm2	52.61	41.33	0.4	0.956	5.468
					7.113	12.47
	$Q_3(P_3 = 0.25)$				1.77	3.12
	K_{tc}				30.54	34.38

Our analysis of the generalized and integrated technical quality parameters makes it clear that using a semi-trailer dump truck for construction purposes would be preferable to using a chassis-based truck. Specifically, the semi-trailer dump truck is characterized by better maneuvering ability, sustained performance, and terrain crossing capacity, while also being capable of carrying larger loads.

Conclusions

The proposed method of technical quality comparative assessment allows for a more unbiased choice of dump trucks for road construction, based on analyzing their most vital performance parameters.

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МЕТОДИКА СРАВНИТЕЛЬНОЙ ОЦЕНКИ ТЕХНИЧЕСКОГО УРОВНЯ САМОСВАЛОВ РАЗЛИЧНЫХ КОМПОНОВОЧНЫХ СХЕМ

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Аннотация

Анализ рынка специальной техники для дорожно-строительной отрасли показывает огромное разнообразие применяемых автомобилей в сфере строительного производства. По этой причине достаточно проблематичным является выбор потребителем автосамосвалов из линейки машин, идентичных по выходным показателям эксплуатационных свойств. Часто он базируется на индивидуальных субъективных предпочтениях потребителя и не всегда оказывается обоснованным. Поэтому разработка методического аппарата, обеспечивающего объективность выбора модели, является актуальной. **Цель исследования:** Разработка научно-методического аппарата для сравнительной оценки строительных автосамосвалов одного класса грузоподъемности, но различного конструктивного исполнения. **Методы:** Сравнительная оценка образцов проводилась путем сопоставления обобщенных показателей качества машин, определяемых коэффициентами их технического уровня. В качестве научных методов получения исходных данных для оценки использовались информационный поиск, статистическая обработка информационных материалов, экспертные исследования и математическое моделирование. **Результаты:** Проведенная на основе предложенной методики сравнительная квалиметрическая оценка технического уровня самосвалов различного конструктивного исполнения дает основание признать, что использование седельного автопоезда в условиях дорожного строительства будет предпочтительнее, чем машины рамной конструкции. Это обусловлено тем, что седельный автопоезд с самосвальным полуприцепом обладает более высокой маршевой подвижностью, маневренностью и проходимостью. **Выводы:** Предложенная методика сравнительной оценки технического уровня позволяет, основываясь на анализе наиболее значимых показателей эксплуатационных свойств, повысить объективность выбора самосвальной техники для дорожно-строительных работ.

Ключевые слова

Дорожно-строительное производство, автосамосвал, эксплуатационные свойства, технический уровень, сравнительная оценка.