Indicators of the efficiency for using of road-building machines at various levels of management decisions

A I Dotsenko¹ and K P Mandrovskiy¹

¹Moscow Automobile and Road Construction State Technical University (MADI), 125319, Moscow, Leningradsky prospect, 64, RUSSIAN FEDERATION

Abstract. Methods of technical and economic evaluation of road-construction machines are highly developed but their operation requires a wide list of initial data which is very difficult to obtain without monitoring systems. In modern conditions, economic factors determine the possibility of machines’ operation and the technical excellence of the machine is viewed by considering the cost of ownership and operation. This determines the relevance of the application of technical and economic assessments. In order to ensure the feasibility of applying of such technical and economic indicators towards the performance evaluation, they need to be adapted for use in monitoring systems. Modern monitoring systems allow you to monitor the technical and operational characteristics without a comparison with the indicators of the economic sphere. There is almost complete uncertainty in the methods of selection and evaluation of equipment that could be used in practice in modern conditions characterized by the presence in the market of equipment of the same purpose from different manufacturers. In such conditions, a system for collecting and processing the information with feedback would be convenient - a monitoring system for effectiveness evaluation. Feedback is necessary for creating the control actions in order to increase the efficiency or maintain it at satisfactory level - performance management. The development of methods of both technical and economic assessment which are suitable for using for road-construction machines and adapted for implementation in monitoring systems is a relevant topic of scientific research.

The concept of efficiency applies not only to machines but also to enterprises which determines the hierarchy of performance indicators for different decision-making levels. Indicators of this hierarchy can be applied to the evaluation of the technical and economic efficiency of a certain road-construction machine [1].

Natural indicators (length, time, area, volume, mass, etc.) that occur at the driver’s level, form more complex, intermediate indicators (metal consumption, productivity, energy intensity, etc.), which determine, in turn, indicators of the next level (for example, the full unit cost of production) [2; 3].

There may be the following hierarchy of indicators presented in real time by monitoring (actual), related to different decision-making levels:

- level of operator and/or on-board computer: performance indicators; indicators of the functional state of the aggregates; indicators of stock sufficiency of materials (technological, fuel and lubricants);
• level of the work supervisor at the facility: indicators of the integrated productivity of the unit (or group) of the machines; performance schedule, indicators (alarming) of the operability; indicators (alarming) of the position or direction of movement of the self-propelled machine; indicators of the physiological state of the driver or operator, indicators (alarming) of the quality of work of the machines;

• level of the Head of the enterprise: integrated indicators of the implementation of the schedule; quality indicators (emergency) of operation; indicators (emergency) of machine operability; indicators (emergency) of the schedule;

• level of regional and sectoral leader: indicators of risk to the life or health of the population of the region, indicators of the threat to the environmental situation; generalized indicators of the implementation of the schedule of works on the objects by contractors.

The efficiency of equipment exploitation may depend on decisions which the implementation is mandatory directly in the process of work as well as on strategic decisions that are appropriate for further using of equipment. Due to the fact that the collection and processing of data in automated systems may take some time, to simplify data processing it is advisable to separate the indicators obtained during the monitoring which need to be processed in real time, and the indicators that can be processed with a delay.

To simplify the separation of indicators into the two considered groups, it is advisable to distinguish such generalizing features as spatial position, state of internal systems, and product quality. For the spatial position, the following subgroups can be distinguished (real-time mode): maintaining a given trajectory of the working body in a local coordinate system tied to the object of impact; tracking the position and speed of movement of machines in the global coordinate system. The following subgroups can be distinguished for the state of the internal systems (real-time mode): registration of operator state indicators; registration of performance indicators of machines. For product quality, the following subgroups can be distinguished (real-time mode): measurement of machine performance indicators (deviation from design parameters of the surface, degree of compaction, etc.) moving in field with the global coordinate system; measurement of the performance of stationary machines in the local coordinate system.

A natural indicator of the effectiveness of machines must be available for instrumental control in order to enable automated accumulation of the indicator values in processing and decision making. Among the physiological parameters of the operator there are may be: blood pressure level; heart rate; body temperature.

Among the natural indicators of the efficiency of moving machines there are the following:

• indicators characterizing the work of machine units: independent timer; the crankshaft rotational speed, rotational speed of the driving element of the propulsion unit (sprocket or wheel); fuel consumption, frequency of pressure pulsations in the hydraulic system; consumption of technological materials (if provided by the type of machine); CO and NOx content in engine exhaust;

• indicators of the scope of work performed by the machine: the volume of load carried by the machine with the moldboard; the distance of material movement dragged by moldboard; the time of material movement; the volume of material moved by the machine with a bucket; the distance of material movement by bucket; material transfer time by bucket; the volume of the excavation (pit, trench, well, ditch, etc.) dug by the machine; the time to create a notch; the volume of material transported by the machine; material transportation distance; material transportation time; surface area processed by the machine; surface processing time;

• indicators characterizing the quality of work of machines: the discrepancy between the actual and designed marks of surfaces; the discrepancy between the actual and designed degrees of compaction; the discrepancy between the actual and standard distribution densities of reagents; the discrepancy between the actual and regulatory conditions of the surface of the artificial coating.
Indicators of the work quality can be controlled by modern monitoring systems, but there are no systems that allow to obtain the integrated technical and economic indicators [4–12], i.e. this direction does not need a development.

When reaching to higher decision-making levels the natural indicators stop to be relevant but are included in (i.e. define) more complex calculated indicators.

The calculated indicators at the level of the facility manager allow an operational assessment of the effectiveness, allowing to determine the machines or groups of machines that need attention with the following formation of a control action. These indicators include:

- shift time utilization rate (determined by the duration of the engine with a nominal power or close to the last);
- productivity of machine (determined by the volume and range of the transferred material; the volume of laid material; the amount of laid material; theoretical speed; slipping; resistance to displacement; soil strength; size of the tool, working time in traction mode, etc.);
- resource capacity of production unit (for example, fuel consumption per unit volume of extracted, displaced or compacted soil, laid cement or asphalt concrete, distributed reagent, etc.).

As for the Head’s level of the enterprise, in addition to indicators of the direct assignment of the created object, it is necessary to form an idea of the work efficiency at the facility, the efficiency of the enterprise and the industry. It is also necessary to have an idea about the possible environmental consequences of working activity (for example, transport construction). Thus, for this level there are technical, economic and sanitary-environmental indicators. Technical and economic indicators are important for all interested groups - both for the work producer (contractor), and for the customer, who may be presented as an administrative organizations (authorities) and private organizations. Sanitary and environmental indicators in the context of a well-established relationship with a relatively low responsibility can be considered as significant only for the customer who belongs to the administrative structures.

These two groups of indicators essentially contradict each other, since the process of any construction is accompanied by environmental degradation. Sanitary and environmental indicators, as a rule, are transferred to the category of restrictions consisting in establishing standards for harmful effects on the environment and humans. In case of going beyond the limits of the norm, legal proceedings are initiated against the responsible persons (physical, legal) and end in fines. Thus, restrictions on sanitary and environmental indicators are ultimately reduced to indicators of the economic sphere.

A significant indicator of the work’s manufacturer (the contractor) is the profit $p_i$ for the reporting period [13]:

$$p_i = \frac{D_E - Z_E}{T_1},$$

(1)

where $D_E$ is the sum of all (gross and other) incomes for the period $T_1$; $Z_E$ - current expenses and losses for the period $T_1$; $T_1$ - the duration of the construction of the object of transport construction.

The value $D_E$ may define the sum of the contract fixed during the tender won by the manufacturer (contractor). The value $Z_E$ consists of the operating costs $Z_1$ and losses $Z_2$ on eliminating of negative effects of the construction such as changing hydrogeological conditions [13]:

$$Z_E = Z_1 + Z_2.$$

(2)

The value $T_1$ is usually fixed by the contract and depends on the amount of work $Q_E$ on the object stipulated by the contract and the productivity $P_i$ of the machines provided by the contractor [13]:

$$T_1 = \frac{Q_E}{P_i},$$

(3)

The contractor’s profit $p_i$, being a possible criterion of its effectiveness, depends on external factors ($D_E, Q_E, Z_E$) which the contractor cannot influence and factors determined by the contractor ($P_i, Z_1$) [13]:
Thus, operating costs and efficiency can be attributed to the largest indicators of the contractor’s self-control. If these indicators are combined, then the unit cost of production will be obtained.

As the main criterion for assessing the technical and economic efficiency, it is advisable to choose the unit cost of production including the cost of ownership (SEPV):

\[ SEPV = \frac{C_1}{P_2} \cdot \frac{1}{T_2 \cdot T_3 \cdot n_1 \cdot P_2} \cdot C_0, \]  

where \( C_1 \) is the cost of machine-shift with reduced costs of ownership (thousand rubles); \( P_2 \) - operational replacement performance (production unit / shift); \( T_2 \) - the life of the machine (years); \( T_3 \) - the number of days in a year (days); \( n_1 \) - the number of shifts in day; \( C_0 \) - the cost of the car (thousand rubles).

At the regional and federal level, it is necessary to guide by higher level indicators in order to assess the effectiveness of the implementation of budgetary funds and to assess the sanitary and environmental safety of the region. To do this, you can use the following indicators: the timing of the construction of the object; the expected profit of other economic entities from the commissioning of the object; socio-economic consequences of the facility commissioning; budget expenditures on control compliance with the rules of construction and eliminate its negative consequences.

1. Conclusion

Thus, by depending on the level of decision making there is a significant number of indicators. Some of these indicators are used for direct control on the machines, so they must be available in real time. The other part can be obtained with some delay. To assess the effectiveness of road-construction machines, the decision-making levels of the Head of the company and the work manager at the facility are important, whose operating costs and productivity can be attributed to the largest indicators of self-control, i.e. there is the owner’s possibility to correct these indicators.

Reference

[1] Shestopalov K K and Mandrovskiy K P 2015 Overview and analysis of remote-control systems for road machines // Road Power 61 34-7
[2] Golkina G E 2015 Possibilities of ERP-systems to control the cost of production// Modern trends in the development of science and technology 1-5 44-7
[3] Tikhonov A A 2007 Production cost and financial performance: what comes first?// Vestnik of the Financial University 1 132-41
[4] DotsenkoA I and Mandrovskiy K P 2018 Improving the quality of asphalt concrete pavement of roads by monitoring the parameters of road machines in the course of work [Electronic resource] // Interstroymeh-2018 Materials of the international scientific and technical conference - M : National Research Moscow State University of Civil Engineering, 223-7 - Access mode: http://mgsu.ru/resources/izdatelskaya-deyatelnost/izdaniya/izdaniya-otkrit dostupa/2018/conf_inter_stroy_mex2018 pdf
[5] Concord-GPS Monitoring system of transport objects [Electronic resource] - Access mode: http://www.konkord-gps.ru/ (access date: 07.28.15).
[6] NPP "Transnavigation", Automated system for monitoring passenger traffic [Electronic resource]. - Access mode: http://www.transnavi.ru/projects/asmpp/about/about.php (access date: 07/01/17).
[7] Saarenketo T Monitoring the condition of roads with low traffic [Electronic resource]. - Access mode: http://www.roadex.org/wp-content/uploads/2014/01/RussianTranslation4.pdf (access date: 06.30.17).
[8] Mandrovskiy K P 2016 Analysis of monitoring systems for road-building machines and the concept of a performance management system // Vestnik of the Moscow Automobile and Road Construction State Technical University (MADI) 1(44) 26-33

[9] Mandrovskiy K P 2016 Possible prospects for the development of monitoring systems for road machines in performance management and technical audit // Mechanization of construction 77 - 10 47-52

[10] Banker R D, Charnes A and Cooper W W 1984 Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis // Management Science 30(9) 1078-92

[11] Cooper W W, Seiford L M and Tone K 2006 Data envelopment analysis. A comprehensive text with models, applications, references and DEA-solver software.– 2-nd edition. New York: Springer, 528

[12] Sakhapov R, Makhmutov M M, Nikolaeva R and Gatiatullin M 2018 Asphalt granulate coating for roadsides International Scientific Conference on Energy, Environmental and Construction Engineering (EECE-2018) electronic edition. "MATEC Web of Conferences" C. 03014.

[13] Kustarev G V, Shestopalov K K, Karasev G N and Mandrovskiy K P 2010 Development of scientific foundations and electronic resources of the monitoring system for assessing the effectiveness of road-construction, airfield and utility vehicles: a report on research and development. - M.: Moscow Automobile and Road Construction State Technical University (MADI) 50