

Applying information technologies to a bulldozer design

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Abstract. An analysis of the application of information technology in transport and technological machines is presented. The features of the use of information technology in the design and operation of transport equipment are given. The objectives of applying information technology at the stage of machine design are determined. The information model of the bulldozer is presented as the system comprising external environment – working equipment – caterpillar track - frame - transmission - engine - operator. A dynamic model of the bulldozer has been developed. Mathematical models of the elements of the dynamic model are presented. Also, characteristics are given which reflect the processes occurring during technological operations when using the bulldozer for carrying out excavation works. It has been established that the information model of the bulldozer makes it possible to obtain data to calculate loading of the bulldozer elements and to optimize selection of the best machine parameters at the stage of functional design.

1. Introduction

Currently, information technology is becoming increasingly important in all areas of human activity. Transport and technological machines are no exception. Computing systems are widely introduced at all stages of the life cycle of products or sets of products [1]. Models of different levels are used, depending on the complexity of the structures or processes under investigation. The complexity of the model is virtually independent of the macro- or micro-level of the process or product, but depends on the degree of its detailed consideration.

As a rule, information technology uses mathematical models of different degree of complexity. In the middle of the 20th century, mathematical models of transport machines were based on static dependencies, or systems of differential equations with a small number of degrees of freedom, but today's computer applications use systems of differential equations with a number of degrees of freedom exceeding 10^6 and more [2].

In structural design, systems based on the finite element or the boundary element methods have found widest application [3]. The application of such methods enables engineers to find the best solutions, to optimize structures, etc. [4].

In the operation of transport machines, as well as in the traffic flow management, information technologies based on the use of simulation models are widely used. The application of such technologies makes it possible to optimize transport processes taking into consideration random factors, and to solve problems that do not have an analytical solution [5].

To diagnose transport systems, information technology is used to detect symptoms of faults and to search for causes and techniques for their elimination.



In the design and operation of transport systems, it is important to correctly determine external loads acting on the load-bearing systems and working equipment of transport and technological machines. Loads are functions not only of the parameters of the external environment, but also of the parameters of the machine to be designed, since the operation of all mechanisms is connected with implementing the working operations and overcoming the forces of inertia.

2. Methods and techniques

The desire to improve the competitiveness of machines makes the manufacturers improve the quality of products. To solve problems arising from this it is necessary to resolve conflict situations; like, when, on the one hand, it is required to increase strength of structures, their reliability and durability, but on the other hand, an improvement in the quality of materials and an increase in the mass of products lead to a rise in cost and loss of competitiveness. One way is to improve the quality of calculations to order to clarify loads acting on a machine, system or unit. The solution of such problems is achievable at the stage of functional design, when it is possible to select machine parameters that most fully satisfy the target functions established [6].

The basis for the functional design of transport and technological machines is a set of dynamic, mathematical and simulational models compiled with a sufficient degree of detail. Such models should be developed on the basis of the systems approach [7]. The level of detail is set by the requirements for solving problems.

It is proposed to use information technologies for the functional design of a crawler bulldozer equipped with a front blade. The dynamic model of the bulldozer is presented in Figure 3. In accordance with the system approach, the bulldozer is considered as EXTERNAL ENVIRONMENT – WORKING EQUIPMENT - CATERPILLAR TRACK - FRAME - TRANSMISSION - ENGINE - OPERATOR. Figures 1 and 2 show dynamic models of tracks located under the road wheel and between the road wheels. The purpose of the simulation is to determine the loads arising in the systems and mechanisms of the bulldozer in the process of performing technological operations.

The dynamic model of the bulldozer presents weights of an engine, a transmission, driving and driven disks of a clutch (pump and turbine wheels of a torque converter), as well as a drive sprocket, an idler wheel, road wheels, support rollers, tracks, working equipment, and elements of conditionally mobile and conditionally stationary parts of the dragging prism.

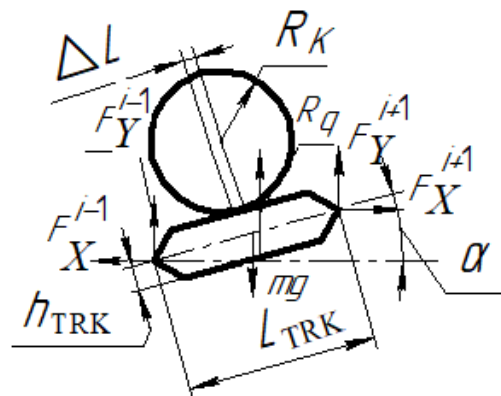


Figure 1 Dynamic model of a track located under the road wheel

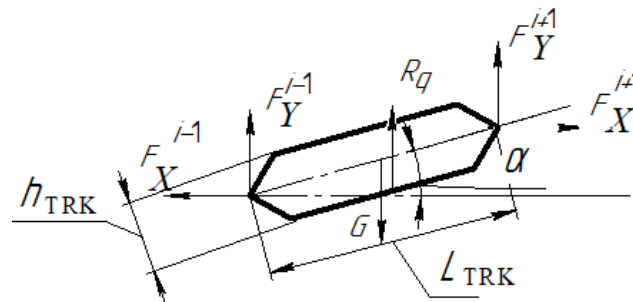


Figure 2 Dynamic model of a track located between the road wheels

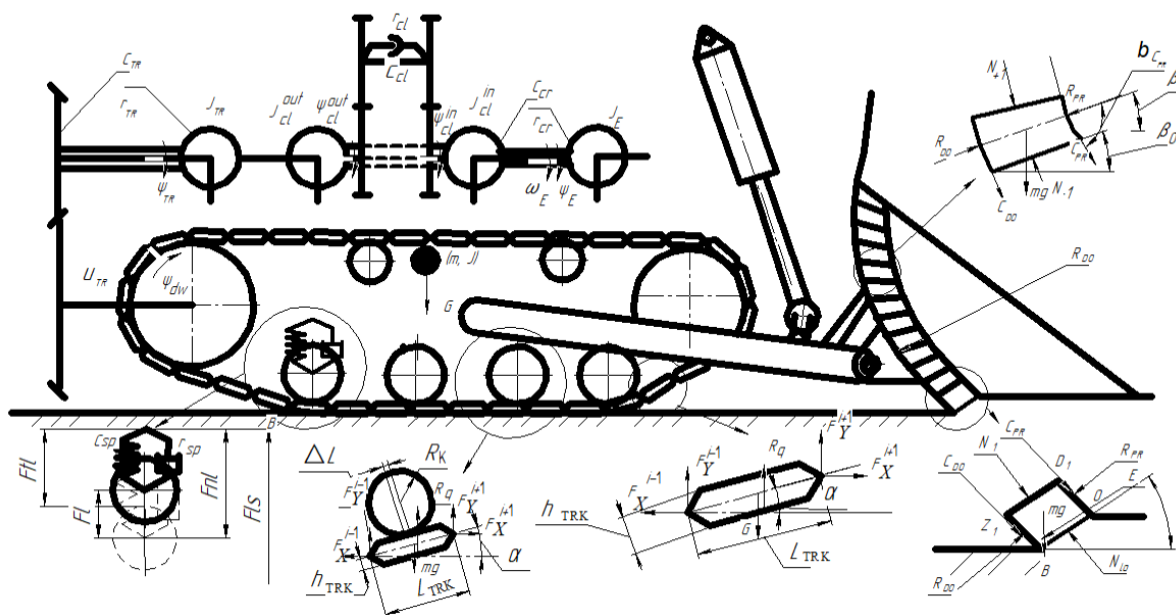


Figure 3 – Dynamic model of the bulldozer.

The model shown in Figure 3 is a complex structured system consisting of simple and complex elements. Each of the elements is presented as a dynamic model. All elements interact with the adjacent ones. This interaction is described by mathematical models.

For example, if a track is located under the road wheel, the mathematical model takes into account the interaction with adjacent tracks and the road wheel. The track has three degrees of freedom.

In case the track is located between the road wheels, the interaction occurs between the adjacent tracks and the soil.

The equations for the interaction with the adjacent tracks, the soil and the road wheel are drawn up based on the theory of elasticity.

$$\frac{dv_{TRK}^x}{dt} = (F_x^{i+1} - F_x^{i-1}) / m_{TRK}, \tag{1}$$

$$\frac{d v_{TRK}^y}{dt} = (F_y^{i+1} + F_y^{i-1} - m_{TRK} g + R_q - R_k \cos(\alpha)) / m_{TRK}, \tag{2}$$

$$\begin{aligned} \frac{d\omega_{TRK}}{dt} = & (F_y^{i+1} \cdot \sin(\alpha) \cdot \frac{L_{TRK}}{2} - F_y^{i-1} \cdot \sin(\alpha) \cdot \frac{L_{TRK}}{2} - \\ & - F_x^{i+1} \cdot \cos(\alpha) \cdot \frac{h_{TRK}}{2} + F_x^{i-1} \cdot \sin(\alpha) \cdot \frac{h_{TRK}}{2} - R_x \cdot \Delta L) / J_{TRK} \end{aligned} \quad (3)$$

where v_{TRK}^x , v_{TRK}^y are the velocities of the track along the abscissa and ordinate axes, ω_{TRK} is the angular velocity of the track, F_x^{i+1} , F_x^{i-1} are the forces resulting from the interaction with subsequent and previous tracks, m_{TRK} is the track weight, g is the gravitational acceleration, R_q is the microprofile reaction, R_k is the reaction between the track and the wheel, L_{TRK} is the track length, α is the inclination angle of the track relative to the horizontal axis, h_{TRK} is the track height, ΔL is the distance between the track center and the point of application of the wheel reaction, J_{TRK} is the moment of inertia for the track.

When the track is located between the road wheels, the equations describing it by the adjacent tracks have the forms:

$$\frac{dv_{TRK}^x}{dt} = (F_x^{i+1} - F_x^{i-1}) / m_{TRK} \quad (4)$$

$$\frac{dv_{TRK}^y}{dt} = (F_y^{i+1} + F_y^{i-1} - m_{TRK} g) / m_{TRK} \quad (5)$$

$$\begin{aligned} \frac{d\omega_{TRK}}{dt} = & (F_y^{i+1} \cdot \sin(\alpha) \cdot \frac{L_{TRK}}{2} - F_y^{i-1} \cdot \sin(\alpha) \cdot \frac{L_{TRK}}{2} - \\ & - F_x^{i+1} \cdot \cos(\alpha) \cdot \frac{h_{TRK}}{2} + F_x^{i-1} \cdot \sin(\alpha) \cdot \frac{h_{TRK}}{2}) / J_{TRK} \end{aligned} \quad (6)$$

The equations of the mathematical model for other locations of the tracks are composed in a similar way. The tracks can be located on the drive sprocket, the idler wheel and the support rollers, between the support rollers, on the guide and traction parts of the caterpillar assembly [8].

Different models can be used to simulate the process of soil digging [9]. The mathematical model of the process of soil digging used in this work is based on the theory of layer-by-layer soil excavation with the blade of E. I. Berestov [10]. This model makes it possible to determine the resistive forces acting against digging experienced by the bulldozer while performing technological operations, to simulate the penetration and raising of the blade during the bulldozer motion, as well as to calculate the magnitude and direction of the resistive forces acting against digging in the process of forming the dragging prism. The magnitudes of shear resistance of soil during excavation work are found by the equations that determine maximum E_{max} and minimum E_{min} values of the magnitudes of shear forces.

$$E_{max} = \frac{G \sin(\alpha + \omega) + R_{DO}^0 \sin(\omega + \rho) - C_{OB} \cos(\alpha + \omega + \varphi) + C_{PR}^0 + N^0 \cos(\omega)}{\sin(\alpha + \omega + \varphi)} \quad (7)$$

$$E_{min} = \frac{G \sin\left(\frac{\pi}{2} - \alpha - \omega\right) + R_{DO}^0 \sin(\omega + \rho) + C_{PR}^0 + N^0 \cos(\omega)}{\sin(\alpha + \omega + \rho)} \quad (8)$$

where α is the cutting angle, ω is the soil-blade friction angle, R_{DO}^0 is the friction force of the zero segment of the mobile part of soil volume in the dragging prism, ρ is the angle of internal friction of soil, C_{OB} is the cohesion of soil in the shear zone, φ is the inclination angle of the zone of big shear, G is the weight of the segment of the mobile part in the dragging prism, N^0 is the reaction between the soil and the zero segment of the mobile part in the dragging prism.

The friction force of the zero segment of the mobile part of soil volume in the dragging prism is determined by the formula:

$$R_{DO}^0 = \frac{R_{PR} \cdot \sin(\beta_{C_{PR}}) + (C_{PR} + N_{i+1}^i) \sin(\beta_{C_{PR}})}{\sin(\beta_0 + \omega)}, \quad (9)$$

where R_{np} is determined by the formula:

$$R_{PR} = \frac{G \cdot \sin(\rho) + C_{PR}^X \cdot \sin(\rho) + C_{PR}^Y \cdot \cos(\rho)}{\cos(\beta_{PR} - \rho)} \quad (10)$$

where C_{PR}^x and C_{PR}^y are the horizontal and vertical components of cohesion forces between mobile and stationary parts of the dragging prism.

The magnitude of the cohesion force is determined by the formula:

$$(11)$$

where h_{PR} is the height of the selected segment in the mobile part of the dragging prism, C_r is the specific residual soil cohesion, B is the blade width.

The magnitude of the reaction between the soil and the zero segment of the dragging prism is determined by the formula:

$$N_{-1} = \frac{G \cdot \sin(\beta_{C_{PR}} + \omega) + R_{PR} \cdot \sin(\omega + \rho) + (C_{PR} + N_{+1}^i) \cdot \cos(\omega)}{\cos(\beta_0 - \beta_0^{i-1} + \omega)}, \quad (12)$$

where G is the weight of the soil segment, N_{+1}^i is the normal force of action from the subsequent segment, β_0^{i-1} is the inclination angle of the previous segment.

The calculated characteristic of the resistive forces acting against digging has a specific "sawtooth" form, obtained during the experimental studies. It has periodic rises and falls of forces, which are caused by periodic displacements of the soil relative to the bulldoze blade. The results obtained by using this model have been verified experimentally and have good convergence. The model takes into account the properties of the soil, the blade and the dragging prism. The calculation process takes into account the loading, which is formed on the excavated soil, as the dragging prism increases [11].

3. Results

Based on the mathematical models, the software has been developed which makes it possible to conduct a series of computational experiments at the stage of functional design, as well as to obtain characteristics of the processes taking place in the main systems and mechanisms of the bulldozer while performing technological operations [12]. The obtained characteristics allow optimization activities to be carried out in order to select the best combination of parameters of the systems under investigation and to achieve the specified performance indicators. In addition, the information obtained can be used for the indicators of loading, reliability and durability of individual mechanisms.

Figures 4, 5 and 6 show some of the results obtained while carrying out the simulational computational experiments to model the process of soil digging with a caterpillar bulldozer based on a 12-ton tractor.

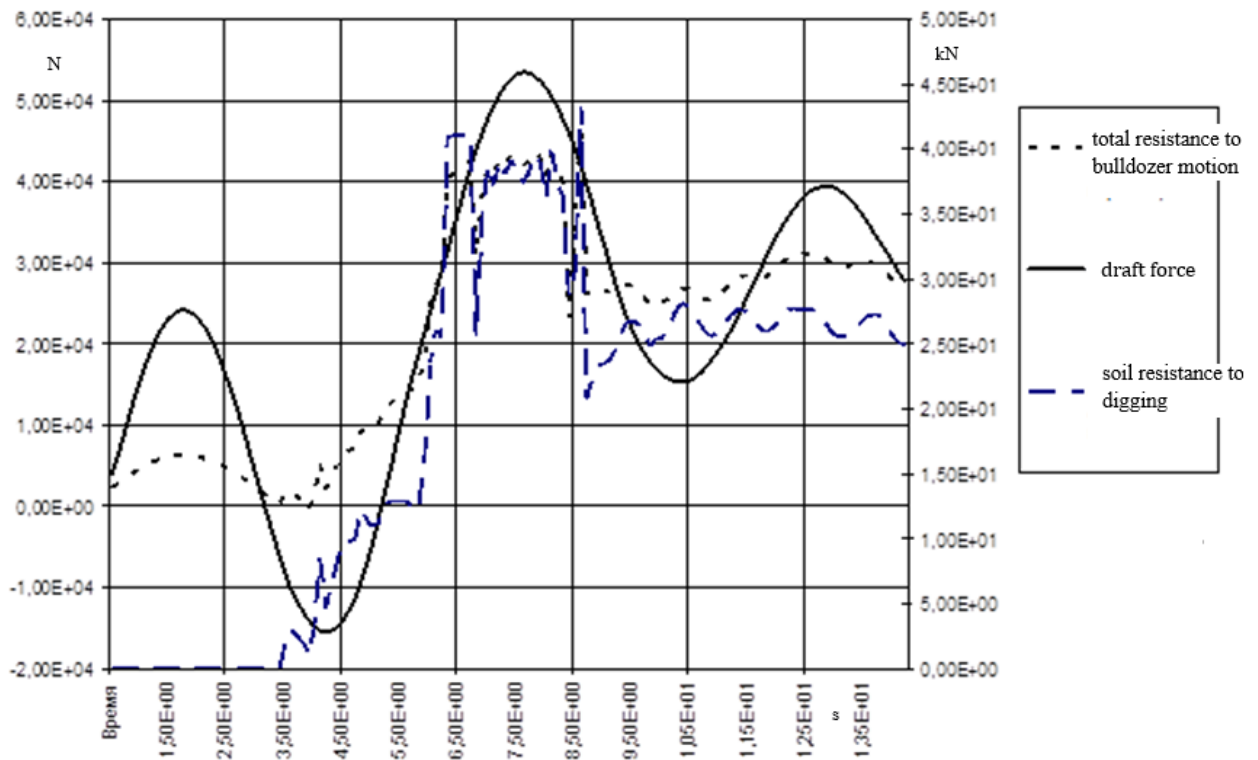


Figure 4 Draft force and total resistance to bulldozer motion are given on the left axis, soil resistance to digging is on the right axis

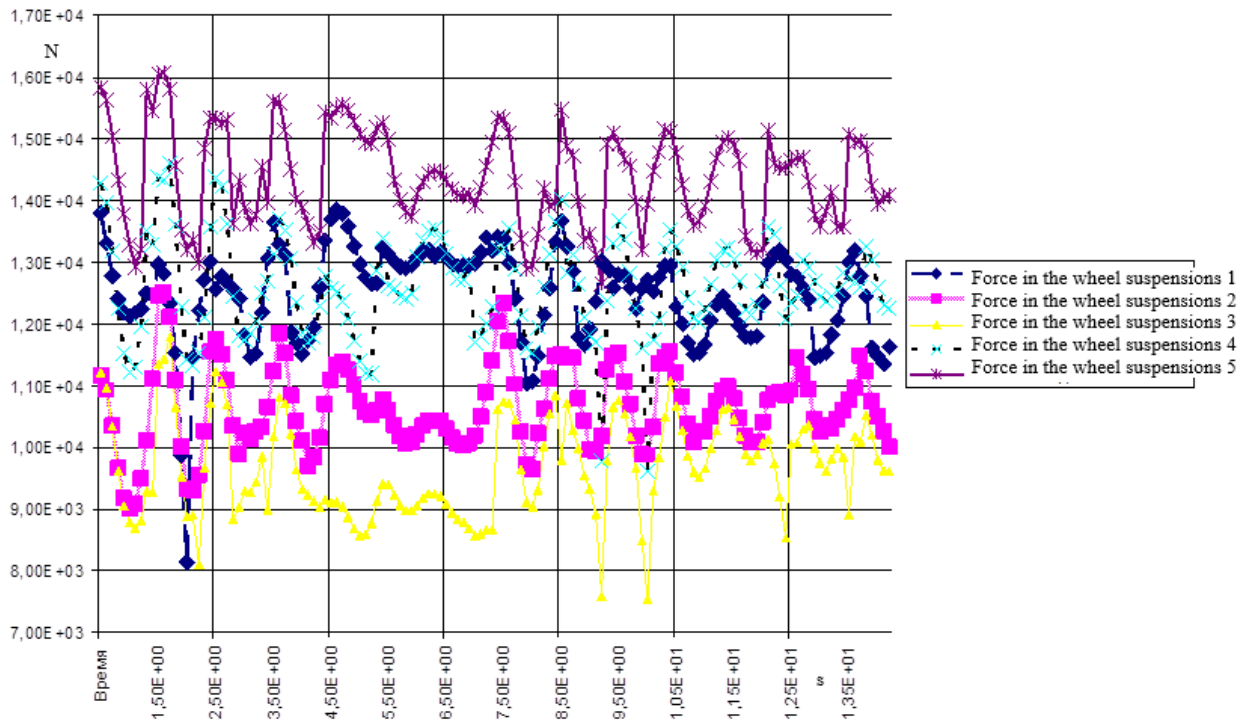


Figure 5 Forces in the wheel suspensions according to the legend.

4. Discussion

The study of the characteristics obtained during the simulation experiments with use of the information model of the bulldozer makes it possible to establish patterns that arise during technological operations and to identify the cause-and-effect relationship between quantitative and qualitative indicators of the processes. There is a possibility of conducting virtual studies of the processes occurring in the working equipment, the suspension system, the transmission and the engine. The simulation model determines the magnitudes of dynamic factors, the magnitudes and the direction of forces acting in the working equipment and the caterpillar track. The information obtained provides a wealth of material for carrying out strength calculations, analyzing the reliability and durability of the structure, as well as for determining the ways of upgrading the machine and conducting the analysis with the aim of increasing the efficiency of bulldozers.

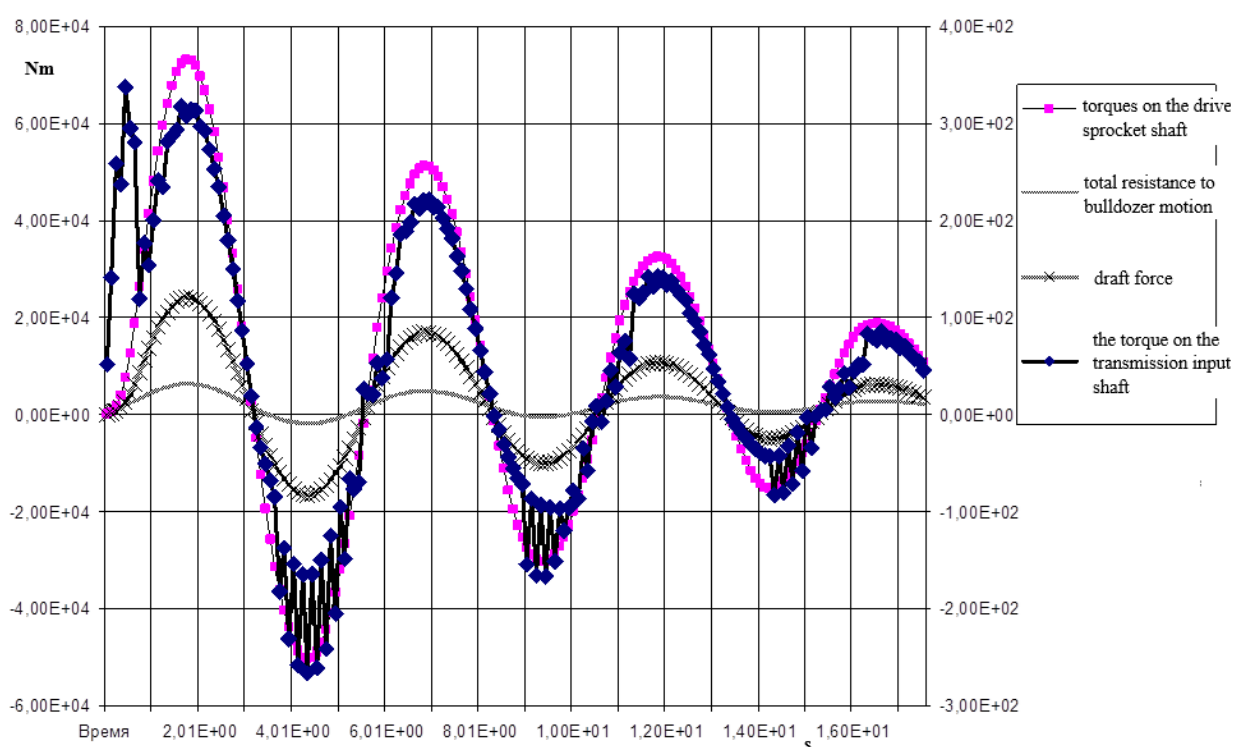


Figure 6 Torques on the drive sprocket shaft, the transmission input shaft, total resistance to bulldozer motion, draft force. The torque on the transmission input shaft is on the auxiliary axis.

5. Conclusion

Information technology is becoming increasingly important in the design of machines. It provides reduction of costs required to run experimental research, and makes it possible to reduce costs of the development work. The application of information technology in functional design allows determining the effect of parameters of the systems under study on their characteristics. The application of information technology in the form of software simulation systems provides information about the effect of parameters and relative position of parts and mechanisms on the characteristics of the machine as a whole. When modeling a crawler bulldozer, it becomes possible to theoretically determine the magnitudes of forces and their direction in the interacting systems, which is impossible, or requires considerable material costs while conducting full-scale experiments.

When designing tracked vehicles for earthworks, it is important to consider the machine as a single model, which presents the systems and mechanisms having a significant impact on the characteristics and indicators under study.

References

- [1] A P Galvão, S T Fernandes, P M L Moura de Oliveirac, A BanerjeeaJosé, A B Montevechic 2018 *Computers & Industrial Engineering* **124** 474-492.
- [2] Zhang L, Zeigler B P, Yuanjun Li 2019 - *Introduction to Model Engineering for Simulation Model Engineering for Simulation*.
- [3] A Armin, R Fotouhi, W Szyszkowski 2014 *Finite Elements in Analysis and Design* **92** 1-11.
- [4] *Finite Element Method. A Practical Course*, available at: <https://www.sciencedirect.com/book/9780750658669/finite-element-method>.
- [5] Micro-simulation modelling for traffic safety: A review and potential application to heterogeneous traffic environment *IATSS Research*, available at: <https://www.sciencedirect.com/science/article/pii/S0386111217302133>.
- [6] Y-M Deng, G A Britton S B Tor 2000 *Computer-Aided Design* **32** 889-899.
- [7] Tarasik V P 2004 *Matematicheskoe modelirovanie tekhnicheskikh sistem* (Minsk : Novoe znanie).
- [8] Leskovets I V, Leonenko O V, Buzhinskij A D 2014 *Mexanizaciya stroitel`stva* № **9** 39-44.
- [9] Y Qinsen, S Shuren 1994 *Journal of Terramechanics* **31** 55-65.
- [10] Berestov E I 2017 *Nauchny`e osnovy` vzaimodejstviya rabocheho oborudovaniya zemlerojno-transportny`x mashin s gruntom* (Mogilev: Belorus.-Ros. un-t).
- [11] Berestov E I, Leskovecz I V 2010 *Vestnik Poloczkiego gosudarstvennogo universiteta. Seriya V: Promy`shlennost`. Prikladny`e nauki* **3** 45-52.
- [12] Leskovets I V 2011 *Stroitel`naya nauka i texnika* **5** 48-51.