Mobility of ground transport and technological vehicles

V V Belyakov1, L N Mazunova and A I Markovnina

Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Minin str., 603950, Nizhny Novgorod, Russia

E-mail: belyakov@nntu.ru

Abstract. The article provides a definition of the mobility of ground transport vehicles and transport and technological complexes. Mobility is defined as an integral characteristic of structural and operational, economic, ergonomic and environmental properties of ground mobile systems and complexes. Also, mobility characterizes the competitiveness of objects as a product. A structural diagram of the hierarchy of control tasks for transport and technological vehicles is given containing four tasks related to the field of design parameters: maintaining mobility, maintaining directional orientation, maintaining speed, eliminating critical situations when moving a transport and technological system; and also the task: to ensure environmental safety; ensuring nominal economic efficiency and ensuring the comfort of the transport and technological system.

1. Introduction

Mobility is an integral operational property of transport and technological vehicles (TTV), which determines its ability to perform the assigned task with optimal adaptability to the operating conditions and the technical condition of the vehicle itself, that is, the ability of the machine to resist external and internal factors that impede the performance of the task [1-6]. Thus, the process of maintaining mobility is key in solving the problem of ensuring the stable and safe functioning of mobile land transport vehicles and transport and technological complexes. Also, during operation, operational and structural mobility must be ensured.

2. Components of TTV mobility

Operational mobility (OM) determines the possibility of fulfilling the task under the operating conditions, including both terrain characteristics and vehicle loading modes.

Structural mobility (SM) is associated with the technical characteristics of the vehicle, which during operation can change significantly and lead to both partial loss of mobility and its complete loss. Changes in structural mobility are associated, on the one hand, with the wear of units, systems and machine parts, which leads to functional failures, and on the other hand, with structural failures caused by the "aggressiveness" of the external environment. The aggressiveness of the external environment can manifest itself in very different forms, but most often these are mechanical influences: wear and shock. Deterioration determines the failure reliability of a machine, and shock mechanical interactions can be natural due to contact with the terrain and artificial in collisions with other machines and / or objects of the external environment, as well as damage received during hostilities and terrorist acts from the effects of weapons enemy side.

Mobility (M) of a vehicle is a generalized function of operational and structural mobility.
Active and passive safety encompasses a wide range of tasks related to maintaining stable and safe traffic and do not have clear boundaries. More acceptable is the division of mobility into agility and mobility in terms of survivability.

Agility (dynamic adaptive mobility). Essentially, this term refers to the concept of "movement" or more broadly defines "readiness for a quick reaction, quick engagement in activity." All these concepts are combined into the ability to move in any conditions and are solved in three main tasks of vehicle control: maintaining the speed of movement, ensuring directional orientation, and eliminating critical situations.

The assessment of mobility and the construction of control algorithms for vehicle are performed on the basis of the following criteria: 1) by the stock of traction force; 2) power balance; 3) on course orientation (handling and maneuverability). In this case, the following solutions to the problem of maintaining mobility by mobility take place: 1) the concept of motion control \( (\lambda_P = \text{var}, \lambda_K = \text{const}, \lambda_3 = \text{const}) \) - for the given operating conditions and the given structural configuration of the vehicle, the optimal modes of motion control are determined; 2) the vehicle design concept \( (\lambda_P = \text{const}, \lambda_K = \text{var}, \lambda_3 = \text{const}) \) - for given operating conditions and selected motion control modes, a rational structural configuration of the vehicle is determined; 3) the concept of operating conditions \( (\lambda_P = \text{const}, \lambda_K = \text{const}, \lambda_3 = \text{var}) \) - for a given structural configuration of the machine and the selected motion control modes, the critical characteristics of the operating conditions are determined. Here \( \lambda_K \) - vehicle parameters, including mover parameters; \( \lambda_3 \) - characteristics of operating conditions, including properties and track parameters; \( \lambda_P \) - parameters characterizing kinematic and power modes of motion. Moreover, these parameters can be considered both separately and in the form of any complex characteristics \( \lambda \equiv \xi(\lambda_K, \lambda_3, \lambda_P) \).

Mobility in terms of survivability- ensuring control of the state of the vehicle aimed at maintaining the operability of ground transport systems and transport-technological complexes to the current state of the vehicle and the terrain. In this case, one should distinguish between partial and complete loss of performance.

The survivability of vehicles can be divided into failure, associated with wear and tear, and operational, which is determined by the functioning of the machine in the natural and climatic environment and the socio-technical sphere of activity. Thus, the viability can be associated not only with the properties of the terrain, but with the impacts from human activities, for example, man-made disasters, military operations, road traffic accidents, super-heavy (irregular) operating modes.

Survivability can be divided into structural and functional components. If the study of the structural component of survivability is mainly reduced to identifying vulnerabilities in the topology of the system and determining the degree of their influence on the integrity of the system, then the study of the functional component of survivability is reduced to determining the ability of the system to solve the problems facing it with the changing capabilities of its elements.

Evaluation of the vehicle's survivability for failure reliability is carried out according to the criterion of the probability of failure-free operation, and in terms of operational reliability - the probability of serviceability in a post-accident or damaged state.

3. Calculation of mobility TTV

A comprehensive assessment of the mobility of land transport vehicles and transport and technological complexes is based on a system of criteria and limiting conditions:

by agility

\[
\Delta P_{\varphi}(\Phi_{\varphi}, \Phi_f, \lambda) \rightarrow \max_{\lambda_{\in \Lambda}} \Delta P_{\varphi}(\Phi_{\varphi}, \Phi_f, \lambda) \geq 0, \quad (2)
\]

\[
W_{\varphi}(\Phi_{\varphi}, \lambda) \rightarrow \min_{\lambda_{\in \Lambda}} W_{\varphi}(\Phi_{\varphi}, \lambda) \geq \left[ W_f(\Phi_f, \lambda) + \Delta W(\Phi_{\varphi}, \Phi_f, \lambda) \right], \quad (3)
\]
The methodology for assessing the competitiveness of ground TTV is as follows: 1) to split the problem into sub-problems; 2) express the estimated indicators in dimensionless form; 3) a result of which a number of indicators should be either taken as a reciprocal value, or as a result of solving the problem of maintaining mobility, which are determined by survivability and taking into account other characteristics. The solutions are directly related only to the limited tasks of maintaining the mobility of automotive vehicles and transport and technological machines created on its basis. However, there are other options for solving the problem of maintaining mobility, which are determined by the function «var-const» in relation to parameters \( \lambda_k, \lambda_s, \lambda_p \). In this case, the most interesting is the complex solution of the mobility problem, when \( \lambda_k = \text{var}, \lambda_s = \text{var}, \lambda_p = \text{var} \), that is, an assessment of the competitiveness of existing, modified or newly created vehicles.

For a qualitative and quantitative assessment of the competitiveness of automotive vehicles, a number of methods can be proposed: building an expert system, finding regression, qualimetry and multi-criteria optimization [6]. At the same time, the latter method is aimed not so much at assessing the quality of the existing structure as at the choice of rational technical, technological, operational and consumer parameters of the designed vehicle. This method, unlike the first three, can be combined with an automatic design system, and the quality of an existing vehicle from others can be assessed as their deviation from the optimal standard, which is generally also done in other methods. However, other methods do not allow making a mathematically accurate choice of rational parameters of the designed automotive equipment.

The competitiveness of automotive vehicles is understood as such a complex property of a particular machine, which determines its quality in accordance with the actual values of technical, technological, operational and consumer indicators, which characterizes its ability to compete with similar models of vehicles produced (developed) by competing firms.

The methodology for assessing the competitiveness of ground TTV is as follows: 1) to split the estimated characteristics to numerical indicators; 2) express the estimated indicators in dimensionless form; 3) accept the condition that the growth of the indicator determines the increase in efficiency, as a result of which a number of indicators should be either taken as a reciprocal value, or as a result of

\[
\Phi_R (\Phi_\phi, \Phi_f, \lambda) \rightarrow \min \text{ at } \Phi_R (\Phi_\phi, \Phi_f, \lambda) \leq 0; \tag{4}
\]

by survivability
\[
R_{\text{su}} (\Phi_\phi, \Phi_f, \lambda, t) \rightarrow \max \text{ at } R_{\text{su}} (\Phi_\phi, \Phi_f, \lambda, t) \geq R_{\eta} (\Phi_\phi, \Phi_f, \lambda, t); \tag{5}
\]

\[
R_{\text{su}} (\Phi_{\text{su}}, \lambda, t) \rightarrow \max \text{ at } R_{\text{su}} (\Phi_{\text{su}}, \lambda, t) \geq R_{\gamma} (\Phi_{\text{su}}, \lambda, t). \tag{6}
\]

The criteria are built depending on the parameters of the interaction of the mover with the track \( \Phi_\phi, \Phi_f \) and taking into account other characteristics \( \lambda \equiv \xi (\lambda_k, \lambda_s, \lambda_p) \). Here \( \Delta P_\phi \) – stock of traction force, \( W_\phi \) – traction power, \( \Delta W = W_{\text{gy}} - W_f \) – stock of engine power, \( W_{\text{gy}} \) – engine power, \( W_f \) – resistance power, \( R_R \) – generalized function of the radius of curvature of the trajectory, \( R_{\text{oh}} \) – failure-free probability, \( R_{\eta} \) – limiting probability of failure-free operation of equipment under optimal operating conditions and vehicle manufacturing technology; \( R_{\text{su}} \) – performance probabilities in a post-accident or affected state, \( \Phi_{\text{su}} \) – generalized function of the intensity of emergency or damaging impact, \( R_{\gamma} \) – the limiting probability of equipment operability after a given (in calculations) intensity of an emergency or damaging effect, \( t \) – operating time or exposure time according to the considered type of reliability.

The presented system of criteria (2) - (6) with limiting conditions can be reduced to a more substantiated system of objective functions:

\[
\Phi_\phi (\lambda) \rightarrow \max \text{ at } \lambda \in \Lambda, \Phi_f (\lambda) \rightarrow \min \text{ at } \lambda \in \Lambda, v (\lambda) \rightarrow \max \text{ at } \lambda \in \Lambda, \rho (\lambda) \rightarrow \min \text{ at } \lambda \in \Lambda, R (\lambda) \rightarrow \max \text{ at } \lambda \in \Lambda. \tag{7}
\]

Where \( \Phi_\phi \) – generalized function of adhesion of the vehicle mover to the support base; \( \Phi_f \) – generalized function of resistance to movement of the vehicle; \( v \) – speed; \( \rho \) = \( R_{\text{oh}} / B \) – relative turning radius, where \( B \) – track, \( R \) – probability of failure-free operation of the vehicle as a function \( R = (R_{\text{oh}}, R_{\text{su}}) \) failure and operational reliability.

The solution to the problem of multicriteria optimization by the presented system of equations (7) is described in detail in [5, 6].
subtracting from one; 4) repeated values should be counted as many times as they occur, which will determine their ranking (weight significance); 5) all assessments should be taken modulo; 6) the number of estimated characteristics for compared different types of TTV should be the same. The greatest difficulty is the assessment of aesthetic indicators. It can be carried out on the basis of probabilistic estimates based on the results of consumer surveys or experts. Probabilistic assessments can be used as the basis for the scoring characteristics of aesthetics of the machine. However, one should not neglect the well-known statement that “tastes differ”, and this is the most difficult task. From this point of view, the most suitable for assessing the competitiveness of automotive vehicles is the method of constructing expert systems [6].

Then an express model of the competitiveness of a vehicle, broken down by structural blocks, in general form can be represented by the following system of equations:

\[
\begin{align*}
\lambda_i (\lambda) &\rightarrow \text{extr} ; \\
\lambda_i (\lambda) &\rightarrow \text{extr} ; \\
\lambda_i (\lambda) &\rightarrow \text{max} ; \\
\lambda_i (\lambda) &\rightarrow \text{min} ; \\
\lambda_i (\lambda) &\rightarrow \text{extr} ; \\
\lambda_i (\lambda) &\rightarrow \text{extr} ;
\end{align*}
\]

(8)

\[
\begin{align*}
\lambda_i (\lambda) &\rightarrow \text{max} ; \\
\lambda_i (\lambda) &\rightarrow \text{max} ; \\
\lambda_i (\lambda) &\rightarrow \text{max} ;
\end{align*}
\]

(9)

Where \( a_i (\lambda) \in A \), \( (i = 1,2,\ldots,11) \); \( \lambda = \xi (\lambda_k, \lambda_n, \lambda_r, \lambda_t) \) at \( \lambda_k = \text{var} , \ \lambda_n = \text{var} , \ \lambda_r = \text{var} , \ \lambda_t = \text{var} , \ \lambda_n = \text{var} . \ Objective functions (9) refer to the vehicle as a whole.

Examples of solving the problem of optimization of objective functions (7-9) in order to find a rational design of a vehicle in given operating conditions on the basis of multi-criteria optimization are considered in the works [5, 6].

![Figure 1. Hierarchy of TTV management tasks](image-url)
4. Conclusion
As a result, it can be concluded that the conceptual diagram of the hierarchy of control tasks to ensure the mobility of the TTV, considered in [5], can be presented in the form of a diagram shown in Figure 1. It includes not only four tasks related to the field of design parameters (maintaining mobility, maintaining directional orientation, maintaining speed, eliminating critical situations when moving the transport and technological system), but also tasks: ensuring environmental safety; ensuring nominal economic efficiency and ensuring the comfort of the transport and technological system.

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