Method of development of snow mobility maps

S S Zhukov¹, V S Makarov² and V V Belyakov²

¹Nizhny Novgorod State Engineering and Economic University, Oktyabrskaya str., 22 A, 606340 Nizhny Novgorod region, Knyaginino, Russia
²Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Minina str., 24, 603950, Nizhny Novgorod, Russia

E-mail: makvl2010@gmail.com

Abstract. The article discusses the need to create mobility maps as the next stage of the development of the mobility theory of Professor Belyakov. The analysis is based on data showing that the development of “snow mobility maps” is relevant for Russia. The main stages of the methodology for constructing “snow mobility maps” are given, which include: analysis of the terrain in order to determine the characteristic zones of movement, determining the parameters of moving objects and calculation of the parameters of vehicles mobility with reference to graphic information systems.

1. Introduction

The study of the efficiency of functioning and assessment of mobility of all-terrain vehicles is based on a variety of different indicators, which characterize both the vehicle itself and the environment which it interacts with. The environment of all-terrain vehicles is the upper cover of the planet and it consists of such components as soils and grounds with plants located on it; lakes, rivers and seas; mountains and rocky massifs, roads and obstacles of natural and artificial origin, etc. All mathematical models of vehicle interaction with the motion surface are based on the physical, mechanical and geometric parameters of the environment, as well as the parameters of the vehicle mover. The main idea of efficiency lies in various indicators that characterize the amount of useful work attributed to costs. This may be the best fuel efficiency, the best value of loads or people transported per some unit (kilometer, time, rubles, etc.).

The efficiency itself is inextricably linked and is a part of mobility. Today in Russia there are different concepts of mobility. The first classic one came from the military, it is namely a set of properties that characterize both the vehicle itself and the environment which it interacts with. The environment of all-terrain vehicles is the upper cover of the planet and it consists of such components as soils and grounds with plants located on it; lakes, rivers and seas; mountains and rocky massifs, roads and obstacles of natural and artificial origin, etc. All mathematical models of vehicle interaction with the motion surface are based on the physical, mechanical and geometric parameters of the environment, as well as the parameters of the vehicle mover. The main idea of efficiency lies in various indicators that characterize the amount of useful work attributed to costs. This may be the best fuel efficiency, the best value of loads or people transported per some unit (kilometer, time, rubles, etc.).

The efficiency itself is inextricably linked and is a part of mobility. Today in Russia there are different concepts of mobility. The first classic one came from the military, it is namely a set of properties that characterize the ability of the vehicle to move in given conditions, and it is characterized by particular properties: autonomy of movement, all-terrain ability and speed. The most general definition was given by Professor V. V. Belyakov: mobility is understood as an integral operational property of transport and technological vehicles (TTV) that determines its ability to perform the task with optimal adaptability to the operating conditions and its technical state, that is, the ability of the vehicle to resist external and internal factors preventing the performance of the task [1]. This concept includes all the previous concepts of mobility and is convenient from the point of view of application in “mobility maps”, and is the next generation in the development of “Professor Belyakov's mobility theory”.

It should be noted that the task of creating “mobility maps” was set in 1971. The US Army
Materiel Command (AMC) developed a research program that combines the work of several research organizations – the U.S. Army Tank Automotive Center (ATAC), U.S. Army Engineer Waterways Experiment Station (WES), the Cold Regions Research and Engineering Laboratory (CRREL). The scientific supervisor was M. G. Becker [2]. The essence of the first model was the following: the real area of the terrain is divided into a mosaic of individual sections, within which the surface is considered sufficiently homogeneous. It allows one to use the value of the maximum speed of movement in a straight line as a measure of mobility at a section. After completing the calculations for the entire area, a map of the maximum speeds that the vehicle can develop at each point of the considered area is made. Nowadays, the model has been improved and is presented as a NATO Reference Mobility Mode (NRMM) [3-5]. It considers several “levels”, such as territorial affiliation, type and nature of soil, slope distribution, landform, etc. [6]. For each level, the “go/no go” sections’ characteristics are constructed, also, probabilistic curves of movement possibility are presented. Thus, probabilistic curves for sections surmounting are calculated and constructed for each vehicle. The main idea is linking it to GIS (geographic information system).

This approach, associated with “mobility map”, allows one to predict the probability of completing a transport and technological task. In Russia, however, there is its own specificity and scientific school. There are some scattered studies on the statistical characteristics of the support bases [7-9], but they consider only special cases. There is also a large and structured study [10], but it focuses mainly on road traffic.

2. Methods

Since large areas of Russia are covered with snow for a long period of time, and transport and technological tasks have to be performed year-round, one of the levels of mobility maps is “snow mobility maps”. Previously, the authors of the article developed a statistical model of snow cover for the Russian Federation [11, 12], which is the source data for maps.

The main stages of developing “snow mobility maps” are:

1. determining average data on the nature of snow cover changes in the studied area;
2. identification of characteristic zones in the studied area;
3. forming a data set with information about snow cover characteristics linked to the area;
4. determining the chassis parameters of the studied TTV necessary for calculating the mobility characteristics;
5. calculation of mobility parameters (passability, efficiency, speed, fuel consumption, etc.) for each of the selected characteristic zones of the studied area;
6. developing “snow mobility maps” for the studied TTV;
7. experimental verification of the mobility parameters of TTV.

Let’s consider every stage in detail by the example of the territory near the village of Belka in the Knyaginino district of the Nizhny Novgorod region.

1. According to the developed statistical model of snow cover, the probability dependences of changes of snow height and density during the winter can be determined. The snow height and density parameters are calculated for open flat areas. Thus, the nature of changes of snow cover for a given area can be calculated based on the following dependencies:

   - The average values of the snow height: \( H = \sum_{i=0}^{4} a_i t_i^c \), cm, where \( a_i \) – empirical coefficients (\( a_0 = 2,6 \) cm, \( a_1 = 12,6 \text{ cm/tdp} \) (ten-day periods), \( a_2 = -1,9 \text{ cm/tdp}^2 \), \( a_3 = 0,16 \text{ cm/tdp}^3 \), \( a_4 = -5,8x10^{-3} \text{ cm/tdp}^3 \)), \( t_i^c \) – current conditional duration of the winter season with the established snow cover in decades (\( t_i^c = 6,15 \)). Calculating 5% and 95% probability bounds \( H_{5(95)} = H \mp e^{0,5} \cdot \sigma_H \cdot \zeta \), where \( \zeta = T_c^{-1}(e - 2) + 1 \) – empirical coefficient, \( \sigma_H \), – standard deviation for the observed area (\( \sigma_H =10 \text{ cm} \)), \( T_c \) – conditional duration of the winter season with the established snow cover (\( T_c = 15 \)).

   - The average values of the snow density: \( \rho = \sum_{i=0}^{4} b_i t_i^c \), g/cm\(^3\), where \( b_i \) – empirical coefficients (\( b_0 = 1,57 \text{ g/cm}^3 \), \( b_1 = 0,14 \text{ g/cm}^3 \text{ tdp} \), \( b_2 = -0,012 \text{ g/cm}^3 \text{ tdp}^2 \), \( b_3 = 0,67x10^{-3} \text{ g/cm}^3 \text{ tdp}^3 \)).
Calculating 5% and 95% probability bounds $\rho_{5(95)} = \rho \pm \sigma_{\rho}$, where $\sigma_{\rho}$ – standard deviation for the observed area $\sigma = 3.6 \text{ g/cm}^3$.

Figure 1. The nature of changes in the height (left) and density (right) of snow

2. At this stage, the characteristic zones of the area are determined according to their type. Roads, power lines, flat areas, rivers, lakes, forests, forest edges, glades, hills, ravines, etc. are highlighted including insurmountable sections or equivalent. In this case, such zones may be cliffs, areas with complex geometry, or impassable woodlands [13]. Figure 2 shows an example of a real area and a map with the highlighted typical sections.

Figure 2. A map of the area obtained using the Yandex Maps service (left) and a diagram showing characteristic areas (right) near the village of Belka in the Knyaginino district of the Nizhny Novgorod region

3. For each characteristic section there are conversion factors based on its features. The height of snow in various sections will be different. For example, for large woodlands, the snow height will be 1.3-1.4 times higher than that onto virgin open areas, and for riverbeds and reeds – 3 times; on the contrary, for open lake surfaces – 0.4-0.5 times, for arable lands - 0.9 times. At the same time, the density in open areas is higher than that in closed ones. For example, snow density in the forest and on a clearing of the forest is 0.85 and 0.9 times respectively less than that in the field in average. The
influence of wind on snow height is ambiguous. However, the following parameters will be typical for places with prevailing winds. For woodlands on the windward side, the snow height is up to 3 times or more higher, and for leeward side – up to 2 times less than that in open areas. As for the snow on the hill slopes, its height on the windward side is 2 times less, and on the leeward side it is 2 times higher. Small pits and ravines can be completely covered with snow, forming a flat surface with the rest of the terrain, while formally the snow height in them can be 1.5-2 times higher [14-17].

One can determine the prevailing wind direction based on observation statistics. So for the section of the studied area, the wind direction repeatability (%) looks like this.

![Figure 3](image.png)

**Figure 3.** An example of a chart of the frequency of wind direction occurrence (%)

As it can be seen from the diagram, the prevailing winds are S and SW. This will allow one to identify the areas with higher and lower snow cover heights.

4. The main parameters of the TTV chassis are the mass and geometric characteristics, parameters of the engine, the algorithm for controlling the power distribution across the movers and the parameters of the mover. These parameters are individual for each vehicle.

5. The calculation of mobility is determined by the nature of the interaction of the TTV mover with the snow. For each characteristic area, the studied parameters are supposed to be different. Thus, for each selected zone, the following indicators should be determined: the forces of traction and resistance, the power spent on movement, the maximum possible movement speed and fuel consumption at the same time. These parameters should differ for various vehicles. At this stage, the calculations can be performed using conventional methods offered in classical terramechanics, and using modern simulation software.

6. Thus, for each section selected at the stage 2, which is part of a real area map, a passability parameter will be entered into compliance, which allows to evaluate the mobility of the selected vehicle when driving on snow. This will be the “snow mobility maps”.

7. This stage is experimental, it is necessary to check the adequacy of the developed models. As a rule, verification is performed within the testing tasks. If the convergence of experimental results and theoretical calculations is provided for the selected TTV, the developed model can be applied in the future.

3. Results

The article discusses the need to create snow mobility maps with reference to GIS. The main stages of the construction of "snow maps of mobility" are considered. A statistical model of changes in the characteristics of snow as a road for vehicles is presented. Empirical dependences of changes in the height and density of snow during the winter period are given for a site near the village Belka of the
Knyagininsky district of the Nizhny Novgorod region. The influence of the landscape, as well as the direction of the prevailing winds on the height and density of snow is shown.

4. Discussion
In the future, the following works will be carried out:
– the given method will be described in more detail, a flowchart for making “snow mobility maps” will be developed;
– simulation of the TTV movement will be designed taking into account the characteristics of the area;
– probabilistic charts of efficiency and mobility assessment for real samples of tracked and wheeled vehicles based on simulation will be developed;
– experimental research for test driving conditions will be conducted in order to assess the adequacy of the developed models.

Acknowledgments
This study was conducted in continuation of the research conducted in the Nizhny Novgorod scientific and practical school of transport snow and with financial support of the grants of the President of the Russian Federation No. MD-226.2020.8.

References
[1] Belyakov V et al. 2013 Mobility of ground transport and technological vehicles Transactions of NNSTU n.a. R.E. Alekseev 4 (101) 72-77
[2] Bekker M 1960 Theory of land locomotion (University of Michigan, Press) 520
[3] Next-Generation NATO Reference Mobility Model (NG-NRMM) Final Report. NATO Exploratory Team ET-148.
[4] Wong J Y et. al 2018 Comparison of simulation models NRMM and NTVPM for assessing military tracked vehicle cross-country performance. Journal of Terramechanics 80 31-48
[5] McCullough M et. al 2017 The Next Generation NATO Reference mobility model development Journal of Terramechanics 73 49–60
[6] Rybansky M et. al 2014 The impact of terrain on cross-country mobility geographic factors and their characteristics 18th International Conference of the International Society for Terrain-Vehicle Systems, ISTVS 2014. Seoul, Korea
[7] Volskaya N S 2017 Assessment of patency of wheeled vehicles when driving on uneven dirt surface MGIU 215.
[8] Volskaya N S 2008 Development of methods of support and traction characteristics of wheeled vehicles for given road and ground conditions in the areas of operation Diss. Dr. tech. Sciences. MSTU 485
[9] Bazhenov E E 2010 Development of scientific methods for predicting the operational properties of articulated ground transportation and technological vehicles Diss. Dr. tech. sciences. N. Novgorod, NNSTU
[10] Bezborodova G B and Galushko G B 1978 Modeling the movement of the car (Kiev: Vishcha schola)
[11] Makarov V S, Zeziulin D V and Belyakov V V 2013 A multi-level model of snow as a track for transport-technological machines by the example of the territory of the Russian Federation Basic research 10 270-276
[12] Makarov V, Zeziulin D and Belyakov V 2014 Prediction of all-terrain vehicles mobility in snowscape scenes Paper presented at the 18th International Conference of the ISTVS
[13] Belyakov V V et. al 2012 Simulation of the atlas of mobility maps of ground transportation and technological vehicles using the example of the Nizhny Novgorod region Materials of the 79th International Scientific and Technical Conference "Vehicle Safety in Operation" N. Novgorod. NNSTU 135-140
[14] Makarov V S et. al 2013 The formation of snow cover depending on the terrain and the
assessment of the mobility of transport and technological vehicles during the winter period

Transactions of NNSTU n.a. R.E. Alekseev 2155-160

[15] Papunin A.V. et al. 2014 About the influence of the landscape on the characteristics of the snow cover and on the passability of vehicles Transactions of NNSTU n.a. R.E. Alekseev 4(106) 331-335

[16] Makarov V S, Zeziulin D V and Belyakov V V 2014 Survey of studies on the influence of terrain on snow cover characteristics Transactions of NNSTU n.a. R.E. Alekseev 3(105)154-162

Makarov V S, Zeziulin D V and Belyakov V V 2014 Analysis of the influence of the terrain on the parameters of the snow cover International Journal of Applied and Basic Research 8-1 21-25