Comparative Analysis of the Mobility Assessment Methods for Tracked Vehicles

PARTYKA Jacek[1,a *]

[1]Military Institute of Engineer Technology, ul. Obornicka 136, 50-961 Wroclaw, Poland

[a]partyka@witi.wroc.pl

Keywords: Mobility, Trafficability, Tracked Vehicle, Mobility Index

Abstract. The article presents the methods of determining the mobility of tracked vehicles, as well as a comparative analysis of the mobility of these vehicles on dirt roads and soil characterised by low bearing capacity. As part of the comparative analysis, a general description of the individual mobility assessment methods is presented, along with the indicator characteristics, as well as the advantages and disadvantages of the methods, when compared to others presented in the article. In the comparative analysis of the military vehicle mobility assessment, the means, by which mobility parameters were determined, the possibility of the practical application of a given approach, as well as its accuracy were considered.

Introduction

The ability of tracked vehicles to negotiate the terrain depends primarily on the dimensions, structure and shape of a single element of the vehicle's propulsion system – continuous track. The dimensions of the tracks and their plates have a significant impact on the value of the unit pressure exerted. Pressures too high, that is exceeding the bearing capacity, cause the soil to deform, increase the rolling resistance, and thus lower the vehicle's traction capabilities [1].

There are several known methods of assessing the impact of a tracked vehicle on the ground. They serve the purpose of determining the mobility of a tracked vehicle during its movement on dirt roads and in rough, slow-go terrain.

This article includes a review of the comparative analysis of the following metrics: Vehicle Cone Index (VCI), Mean Maximum Pressure (MMP), and Vehicle Limiting Cone Index (VLCI).

VCI Method

General Description of the Method. In the Vehicle Cone Index (VCI) methods, the measure used to assess the mobility of tracked vehicles travelling on dirt roads and slow-go terrain (soft-soil) is the parameter characterizing the soil. The soil withstands the load of the tracked vehicle so that it can successfully complete the specified number of passes on the same track, usually, this means one pass or fifty passes [2].

In this method, the Mobility Index (MI) is the basis for empirically determining mobility. It takes into account the weight of the tracked vehicle, parameters related to contact pressure and grouser factor, as well as loads concentrated under the drive wheels and ground clearance. The MI is calculated from the following formula [3,4]:

$$MI = \left(\frac{p_n K_m}{0{,}01 b K_0} + K_k - K_p\right) K_{ss} K_{sb}, \tag{1}$$

where:
p_n – nominal (average) ground contact pressure, lbs/in^2;
b – track width, ins;

Materials Research Proceedings **24** (2022) 221-226 https://doi.org/10.21741/9781644902059-32

K_m – vehicle weight factor;
K_0 – grouser factor;
K_k – factor describing loads concentrated under road wheels;
K_p – ground clearance factor;
K_{SS} – engine factor;
K_{SB} – transmission factor.

Depending on the MI value, a single-pass VCI is also calculated according to the following formula:

$$VCI_1 = 7.0 + 0.2MI - \left(\frac{39.2}{MI+5.6}\right), \quad (2)$$

where: MI – tracked vehicle mobility index.

In [5], the authors state that VCI values for a single pass and 50 passes can be determined from MI estimation based on empirical equations. In research experiments, it is the Rating Cone Index (RCI) which is the parameter used to estimate the strength of the soil in a given area. It is defined as the product of the Cone Index (CI), representing the resistance to penetration into the terrain per unit cone base area, and the measure of the sensitivity of soil to strength losses under vehicular traffic called Remold Index (RI). These parameters are used to calculate the terrain trafficability and mobility of individual vehicles and vehicle columns.

Advantages of the Method. The VCI method makes it possible to easily determine the mobility of the vehicle by calculating the mobility index on the basis of technical data, as well as comparing the indicators calculated for different vehicles.

According to the US Army Field Manual [6], the knowledge of the VCI_1 and VCI_{50} parameters and the critical layer's depth adapted depending on the type of tracked vehicle, the soil and the number of passes by a given vehicle can be applied practically. Based on these data, it is possible to estimate the number of vehicles that can traverse the terrain, as shown in the example.

The following were assumed:
- vehicle type: Abrams M1A1 main battle tank;
- $CI = 65$;
- $RI = 0.8$;
- $VCI_1 = 25$ [10];
- $VCI_{50} = 58$ [10].

$$RCI_{50} = 65 \cdot 0.8 = 52$$

The increase in the VCI per tracked vehicle is the following:

$$VCI_{50} - VCI_1 = 58 - 25 = 33$$

$$\frac{VCI}{50} = \frac{33}{50} = 0.66$$

In order to determine the number of tanks that could pass under the specified terrain conditions, the calculation should be carried out in such a way that the VCI_1 was equal to the RCI or was greater than the RCI.

$$\frac{52 - 25}{0,66} = 40,09 = 41\ tracked\ vehicles$$

Materials Research Proceedings **24** (2022) 221-226 https://doi.org/10.21741/9781644902059-32

$$41 \cdot 0{,}66 = 27{,}06$$

$$27{,}06 + 25 = 52{,}06 > RCI_{50} = 52$$

Considering the above, 41 tanks could move in the given terrain conditions.

Thus, the comparison of the RCI with VCI indicates the ability of a given vehicle to negotiate the given soil condition for a given number of passes. The VCI method is very useful for determining the mobility of moving vehicles off-road, as it is a function of the potential vehicle ground contact pressure and the soil strength.

Disadvantages of the Method. The mobility index does not take into account soil parameters (its type and properties), on which the tracked vehicle travels.

The cone index has a limited range of applicability for the soil critical layer and only pertains to fine-grained and coarse-grained soils. This method is not used in the case of frozen ground, as well as for the road surface covered with a layer of snow [2].

Comparison to Other Methods. The VCI method, similarly to the Mean Maximum Pressure (MMP) method presented in the article, later on, takes into account the value of the maximum pressures and the geometrical dimensions of the vehicle undercarriage. Currently, these two basic analytical methods, developed based on experimental studies, are used alternatively for military vehicle cross-country mobility. Both methods are equivalent to each other and can be used interchangeably, taking into account that given acceptable mobility in the VCI method corresponds to a specific limit value of the MMP parameter.

The MMP Method

General Description of the Method. The Mean Maximum Pressure method concerns the assessment of tracked vehicles' ability to overcome terrain and roads with low load capacity and is based on the analysis of the maximum pressures occurring under the wheels of the vehicle track system. For a low bearing capacity soil terrain to be traversed, its bearing capacity must not be exceeded by the average value of the peak stresses under the drive wheels of a track system (MPP). This value was determined from the following empirical relationship [7,8]:

$$MMP = \frac{1.26W}{2nb(td)^{0.5}}\ [kPa] \tag{3}$$

where:

W – vehicle weight, kN;

n – the number of roadwheel per one track of the vehicle;

b – track width, m;

d – road wheel outer diameter, m;

t – track pitch, m.

Advantages of the Method. The MMP values are well-correlated with the $VCI_{(RCI)}$ values obtained from multiple passes for high plasticity clayey soils according to the following formula:

$$VCI_{(RCI)} = 0.83\ MMP \tag{4}$$

According to the author of [4], the MMP calculation method is less labour-intensive in comparison with the VCI method. Because the MMP method was developed to determine the peak pressures and is based on the results of the interaction of the drive train and power transmission systems on the ground, it should be considered more reliable.

Disadvantages of the Method. In [5], Wong et al. are of the opinion that the MMP parameter is insufficient to fully assess the possibility of movement of tracked vehicles on dirt roads.
In this situation, it is necessary to use a correlation approximation between the VCI and MMP, to facilitate the assessment of cross-country mobility, according to the following relationships:

$$VCI_1 = 0.096\, MMP \tag{5}$$

$$VCI_{50} = 0.27\, MMP \tag{6}$$

The usefulness of the method is limited to the design and upgrade (modernization) of track systems, as well as the evaluation of the existing designs in terms of their capability to negotiate low bearing capacity soil.

Comparison to Other Methods. After taking into account the RI, the MMP index is comparable to the $VCI_{1(CI)}$ value. The MMP method enables a comparative assessment of the MI with the parameters of the VCI method, as well as VCI_1 and VCI_{50}, for selected tracked vehicles of different weights, as shown in Table 1.

Table 1. *Comparison of the parameters determining the relative mobility of tracked vehicles [5]*

TV 1, 2, 3 = Tracked Vehicle	**Weight of the System** [kg]	**MMP** [kPa]	**MI**	**VCI_1**	**VCI_{50}**
TV 1	26 000,00	148	66	24	55
TV 2	28 000,00	165	77	26	60
TV 3	29 000,00	211	89	29	66

As a result of the analysis of the data in Table 1, it was possible to conclude that the value of all the analysed indicators used in the presented methods is increasingly dependent on the weight of a given vehicle. The largest percentage increase (around 17%) was noted for the MMP index and the vehicles marked as TV2 and TV3.

The weight-dependent increase in the remaining parameters, namely MI, VCI_1 and VCI_{50}, relative to TV1, TV2 and TV3 vehicles is insignificant, and for these parameters amounts to 1%, 4%, and 1%, respectively.

VLCI Method

General Description of the Method. The Vehicle Limiting Cone Index (VLCI) is an analytical method in which the tractive force (traction) is determined depending on the measured soil bearing capacity. In this method, the Mobility Number (MN) for tracked vehicles is defined in the following manner [9]:

$$MN_{DERA} = \frac{CI \cdot n \cdot b \cdot t^{0,5} \cdot d^{0,5}}{W} = \frac{1.26 \cdot CI}{MMP}\ , \tag{7}$$

where, after transformations, the minimum bearing capacity of the soil which would ensure that the terrain could be traversed (VLCI) by tracked vehicles, assumes the form:

Materials Research Proceedings **24** (2022) 221-226 https://doi.org/10.21741/9781644902059-32

$$VLCI = \frac{1.56 \cdot W}{2 \cdot n \cdot b \cdot t^{0.5} \cdot d^{0.5}}, \tag{8}$$

where:
W – vehicle weight, kN;
n – the number of roadwheel per one track of the vehicle;
b – track width, m;
d – road wheel outer diameter, m;
t – track pitch, m.

Advantages of the Method. High correlation of estimated tractive forces and the values recorded during tests using a mobile tester are possible thanks to the mobility number (MN) formula adopted in the VLCI method.

Disadvantages of the Method. The VLCI method can be used to estimate the available tractive forces on clayey soils. However, when using the method for other types of soil, for example, the sandy and the clayey ones, the indicators produced may be significantly flawed.

Comparison to other methods. The VLCI parameter as represented by the formula (8), points to values higher than those calculated using the MMP method.

In the case of tracked vehicles, the mobility parameters determined via the VLCI method was proven to be approximately 30% higher than the one calculated using the VCI method, and 26% higher than those resulting from the use of the MMP method.

The VLCI method, based on the measurement of the tractive force, clearly overstates the value of the necessary bearing capacity of the soil in relation to the value determined using the MMP method, based on the trafficability tests using real tracked vehicles.

Summary

Mobility analysis is an important element of military logistics planning and execution activities. The integrated data on the terrain and operational parameters of the vehicle is used by the commanding officer to make decisions regarding the movement of tracked vehicles or their columns.

The methods of determining the mobility of tracked vehicles on dirt roads or in cross-country terrain presented in the article are based on empirical dependencies.

A serious limitation in the development of an empirically-reliable model of a tracked vehicle is the lack of reliable experimental data from the tests performed on low bearing capacity soils [10].

The Polish Army utilizes field methods, based on (probably experimental) mapping of vehicle mobility as a function of directly or indirectly determined soil bearing capacity (known as natural soil strength, shear force, soil resistance and California Bearing Ratio (CBR)) and vehicle ground pressure [11] to determine the permissible number of vehicles crossings over a given area.

Currently, the tracked vehicle mobility is determined with the use of the available methods for determining soil trafficability under field conditions. These include methods utilizing instruments which enable the determination of soil parameters, mainly the bearing capacity of the soil measured directly or indirectly, as well as the densitometry, for determining soil trafficability with the use of a self-recording penetrometer. A professional assessment of trafficability is also supported by interesting technological solutions that are a part of military vehicle equipment. One such example is an on-board device for determining the terrain trafficability which is part of the on-board equipment of the Wheeled Engineer Reconnaissance Vehicle.

The use of novel measuring instruments and IT solutions as part of the mobility assessment methods will significantly affect the quality and speed of land trafficability measurements, as well as facilitate optimal mobility assessment for military vehicles.

References

[1] A. Surowiecki, Z. Golemo, P. Saska. Wpływ zbrojenia tymczasowej nawierzchni drogowej na rozkład naprężeń w podłożu, WSOWL, Wrocław, 2004.

[2] J.Y. Wong, P. Jayakumarb, E. Tomac, J. Preston-Thomas. A review of mobility metrics for next generation vehicle mobility models, Journal of Terramechanics 87 (2020) 11-20. https://doi.org/10.1016/j.jterra.2019.10.003

[3] Y.J. Wong. Theory of ground vehicles 3rd Ed., McGrow-Wiley, Hoboken, 2001.

[4] M. Łopatka. Metody określania zdolności pokonywania terenu o niskiej nośności, Biuletyn WAT 10 (2004) 49-66.

[5] Y.Ch.D. Wong, H.H.S. Lim, W.Q.W. Chan. An Assessment of Land Vehicles' Trafficability, DSTA Horizons (2016), pp. 54-63.

[6] FM 5-430-00-1 AFJPAM 32-8013, Vol I. Planning and design of roads, airfields, and heliports in the theater of operations – road design, Headquarters, Department of the Army Department of the Air Force, August 1994.

[7] D. Rowland. Tracked vehicle ground pressure and its effect on soft ground performance, Proc. 4th Int. Conf. of the International Society for Terrain-Vehicle Systems, Stockholm, 1972.

[8] D. Rowland, J.W. Peel. Soft ground performance prediction and assessment for wheeled and tracked vehicles, Institute of Mechanical Engineering 205 (1975) 81.

[9] E.B. Maclurin. The use of mobility numbers to describe the in-field tractive performance of pneumatic tyres, Proc. 10th Int. of the International Society for Terrain-Vehicle Systems Conf., Harper Adams University, 2003.

[10] M. Łopatka, W. Płocharz, A. Rubiec, K. Zembrowski. Badania nośności terenów podmokłych w aspekcie ich przejezdności, Logistyka i Nauka 3 (2015) 2929-2936.

[11] T. Ratajczak, Z. Kamyk. Metody wyznaczania przejezdności gruntu w warunkach polowych, Inżynieria wojskowa, problemy i perspektywy, V Konferencja Naukowo-Techniczna, 22-24.09.2008 (2008), Wrocław, 151 – 162.