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Parameters and Influences for an Evaluation System of Trafficability of Vehicles on Terrain

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Abstract

The paper deals with the investigation of parameters and influences for the system of evaluating the trafficability of vehicles through the terrain. Trafficability is one of the main aspects to ensure the movement of own troops, which falls into the main task of the Engineer troops - combat and general engineering support for all types of activities and operations of the army. Trafficability is the ability of a vehicle to move in rough terrain or on damaged roads and depends on many factors. The most used tool for determining trafficability in the Czech Army is the penetrometer. It is the PT-45 penetrometer, which is described in the Žen 2-16 Military Roads and Ways and the main evaluation criterion is the weight of the vehicle. Within the framework of international cooperation, soldiers encounter the manual FM 5-430-00-1 Design and design of roads, airports and heliports during events on the battlefield - road design, which works with a cone penetrometer and evaluates the throughput of the vehicle based on other factors such as properties of tires, ground clearance, engine power, etc. Inaccurate or incorrect evaluation leads not only to a stop the engagement of individual vehicles, but the entire convoy, which in terms of the operational task stops the manoeuvre and may lead to failure of the order. Therefore, it is important to know what parameters and influences have a fundamental influence on the system of evaluating the trafficability of vehicles, whether it would not be appropriate to add other aspects that will lead to higher accuracy of measurement, or, conversely, to exclude some. In solving this task, the authors decided to use the above-mentioned manuals and their evaluation systems. The objectives of the paper were achieved by analysis and calculations of individual parameters listed in these regulations, which affect the trafficability through the terrain, so that the degree of dependence is determined. It was found that some parameters have a major impact on trafficability and it is necessary to take into account even a slight change in these values. In contrast, other parameters are negligible as a result. These calculations confirm the suitability of updating the evaluation system for the telescopic penetrometer PT-45 to determine the trafficability of vehicles, so that it is possible to obtain more accurate results of measured values of the Czech army in the performance of tasks. .

KEY WORDS: *trafficability, penetrometer, rating cone index, vehicle cone index.*

1. Introduction

The tasks of the engineer troops are engineer support of troops and assistance to the civilians. Engineer support to troops includes engineer support to task groups (engineer reconnaissance, security, overcoming obstacles, etc.), and the removal of and disposal of unexploded ordnance and security of troops in missions. Assistance to the civilians consists of the performance of humanitarian civil protection tasks, rescue, recovery and other urgent work in the event of disasters or other serious situations threatening life, health, considerable property values or the environment (fires, floods, mass disasters, industrial accidents). [1]

During most of these tasks, members of the Engineer Corps are forced to move not only on roads, but also on dirt and forest roads. In many cases, it is necessary to overcome terrain without a pre-existing road. However, due to soil, vegetation or climatic conditions, the area of interest becomes impassable countless times and troops movement may be impeded or totally stopped. Therefore, a detailed engineer survey must be made before any movement, with particular reference to the trafficability of the terrain. The results are crucial in the subsequent selection of the most suitable route without the need for any terrain modifications. In the Army of the Czech Republic, trafficability is most often determined by the PT-45 telescopic penetrometer, which is covered by the Field Manual Žen 2-16 Military Roads and Ways [2,3] and, due to international cooperation with NATO countries, soldiers may also encounter Field Manual 5-430-00-1 [4].

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The topic of this paper is the analysis of parameters and influences that affect the vehicle's trafficability through terrain. In particular, the effects of each parameter on vehicle trafficability, the dependencies between them and the degree to which their inaccuracy affects the outcome will be investigated. The importance of the importance of evaluation is obvious from [5-9].

2. Overview of the Current Status

Trafficability is the ability of a vehicle, whether tracked or wheeled, to move over open terrain or damaged roads. Trafficability depends on many factors. Among the most important are: vehicle characteristics (weight, engine power, type of tires, etc.), soil characteristics (moisture, bulk density, etc.), terrain characteristics (roughness, vegetation, etc.) and, last but not least, climatic conditions.

Knowledge of the trafficability of individual vehicles has an impact on the solution of tasks in both the military and civilian spheres. This knowledge will also determine whether the vehicle is able of overcoming the terrain or whether a terrain modification, change of equipment or search a detour route is necessary. The importance of the ability to evaluate the terrain could be seen on Fig. 1. The wrong evaluated terrain leads to the mire of the vehicle [10,11].

The two different approaches are described below.

Fig. 1. Examples of wrong evaluated trafficability of terrain.

2.1 Trafficability According to the Žen 2-16

Due to the Field Manual ŽEN 2-16, the trafficability of the terrain can be determined in four ways. Firstly, it can be estimated visually, by some objectively occurring signs. For example, impassable terrain is manifested on slight slopes by lush green grass, indicating a high groundwater level, or on meadows and plains by sedge growth or a conspicuously flat surface. In the valleys, the lowest places around streams and rivers with low banks should be avoided. However, this method is very indicative and inaccurate. Another one is method which uses a human footprint to measure. A person stepping on the ground with one foot will develop a specific pressure of approximately 0,05 MPa. If the footprint is slightly depressed (creating a full footprint), it is assumed that tracked vehicles will pass over the terrain, but it is unsuitable for wheeled vehicles. The bearing capacity of the underlying layers must always be ascertained as well, as they show sagging when the trafficability is reduced, which is an indication that there is peat or swamp beneath the surface.

In order to determine the trafficability of the waterlogged ground and to ensure objectively the same and comparable results, simple tools are used: the engineer's crowbar (Fig. 2) and a PT-45 telescopic penetrometer (Fig 2). These devices are based on the principle of detecting the resistance of the soil in the penetration.

The engineer's crowbar (Fig 2) is used only for a rough assessment of ground penetration according to the depth of the crowbar's penetration when falling from a height of 0.5 m. The depth of embedment after one impact is considered as a layer of soggy soil. The trafficability is then assessed according to Table 1. The trafficability of surface-wet ground shall be determined at several locations at distances of several meters. An average value shall be determined from the data obtained.

Table 1.

Data for indicative assessment of trafficability with engineer's crowbar.

Depth of penetration of crowbar	Trafficability
up to 3 cm	unlimited
up to 5 cm	50 to 100 cars pass
up to 12 cm	individual cars will pass
over 12 cm	no cars or tanks will pass

Table 1. Data for indicative assessment of trafficability with engineer’s crowbar.

A telescopic penetrometer (Fig. 2) is an instrument designed for accurate measuring of the bearing capacity of terrain obtained with a penetrating thorn, that is pressed against the head of the penetrometer (the top cap of the device). The scale takes readings indicated by the position of the drift ring. When it is returned to the initial zero position, the pressure in MPa is read and then with an evaluation form, the bearing capacity of the terrain is determined. [2]

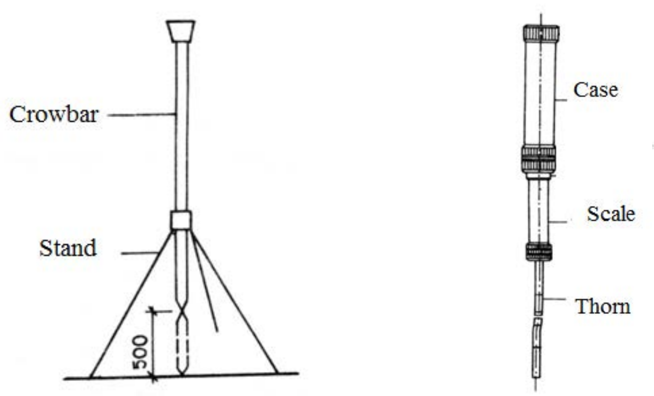

Fig. 2. Engineer's crowbar and telescopic penetrometer. [2]

2.2 Trafficability According to the FM 5-430-00-1

Another possible way of evaluation terrain trafficability is due to the Field Manual 5-430-00-1 [4]. According to it, the terrain trafficability is evaluated by comparing two indices. The RCI (rating cone index) and the VCI (vehicle cone index). On the basis of the comparison, the terrain is then marked as passable or impassable for the given vehicles and number of passes.

$$RCI < VCI \rightarrow \text{NOT GO}$$
$$RCI > VCI \rightarrow \text{GO} \quad [4]$$

The cone soil index captures the specific characteristics of the terrain. This index is influenced by soil type, humidity, instantaneous temperature, climatic conditions (snow, precipitation, etc.) and type of relief. It is determined by using the trafficability test set and it is measured in a specific critical layer, which is the level of terrain considered most important in transmitting vehicle pressure. [5]

For conventional U.S. Army vehicle types, the cone index of the vehicle is given by in tables, for all other vehicles the index can be calculated, either by the given formula or by subtraction from the appropriate chart if the vehicle parameters are known.

The most important factors are: vehicle weight, engine power, ground clearance, tires (width and outer diameter), number of wheels, number of driven axles and type of transmission. In addition, in the case of a tracked vehicle, the number of running wheels, the width of the belt and its contact length with the ground are also required.

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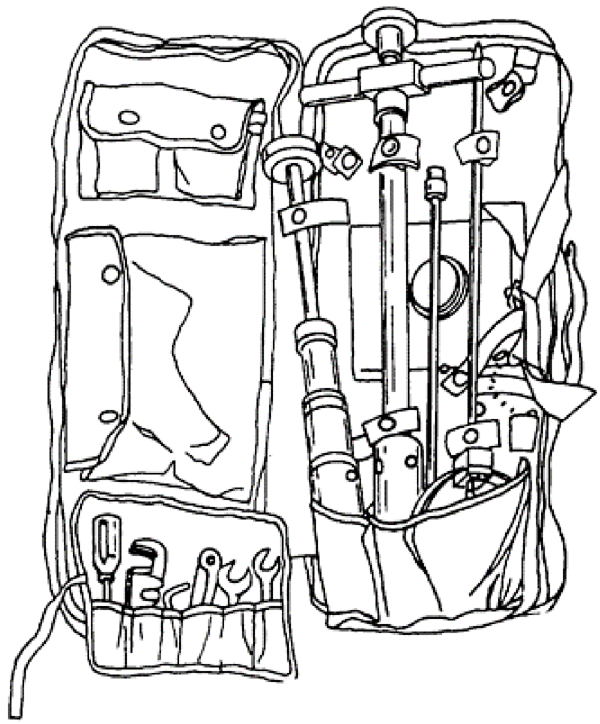

Fig. 3. Trafficability test set. [4]

The results obtained with the trafficability test set are considered to be very accurate, but are very time-consuming to work with. The large kit is prone to loss of smaller parts. Furthermore, the instruments often suffer from careless handling and irreversible damage.

It must be remembered that the obtained trafficability results are, due to climatic conditions, valid only at the time the measurements were made and for a very short time afterwards.

3. Parameters Influences the Trafficability of Terrain

When investigating terrain trafficability using the means introduced in the ACR, we often encounter situations where the measurement result does not correspond to reality. This happens mainly due to insufficient input parameters. This paper will address the different influences that affect the trafficability so that the evaluation forms can better evaluate the mobility of the vehicles. Field Manual 5-430-00-1, Design and Planning of Roads, Airfields, and Heliports During Battlefield Operations - Road Design [4], is used as a template and works with many more parameters compared to Žen 2-16 Military Roads and Roads [2]. Both of the above-mentioned regulations correctly differentiate vehicles according to chassis type, into tracked and wheeled. It is quite clear that a track develops much better terrain traversing capabilities than wheels, mainly due to the larger contact area and therefore better distribution of vehicle mass into the ground.

As part of the research work at the Department of Engineering Technology [6] [7], the dependencies between the PT-45 telescopic penetrometer and the cone penetrometer from the trafficability test set were investigated. The dependency was found after extensive measurements, so the use of the torso evaluation system of the cone penetrometer for the needs of the PT-45 can be considered. In the following subsections, the evaluation system of the trafficability measurement will be elaborated.

From the above mentioned, the main task or question of the paper follows - what parameters and influences for the system of evaluating the passability of vehicles through the terrain affect the result and whether it would not be appropriate to add other aspects that will lead to even higher accuracy of measurement.

3.1 Assessment of Individual Parameters

As already mentioned, by finding a dependency between the two instruments, it is possible to use the formula for calculating the vehicle cone index (VCI) when measuring the trafficability with the telescopic penetrometer. This value is obtained by substituting the individual vehicle parameters into the formula for calculating the mobility index (MI):

$$MI = \left[\frac{\begin{pmatrix} contact \\ pressure \\ factor \end{pmatrix} \times \begin{pmatrix} weight \\ factor \end{pmatrix}}{\begin{pmatrix} tire \\ factor \end{pmatrix} \times \begin{pmatrix} grouser \\ factor \end{pmatrix}} + \begin{pmatrix} wheel \\ load \end{pmatrix} - \begin{pmatrix} clearance \\ load \end{pmatrix} \right] \times \begin{pmatrix} engine \\ factor \end{pmatrix} \times \begin{pmatrix} transmission \\ factor \end{pmatrix}$$

Where:

-contact pressure factor:

$$\begin{pmatrix} contact \\ pressure \\ factor \end{pmatrix} = \frac{2 \times gross\ weight\ in\ lbs}{\begin{pmatrix} tire \\ widt \\ in\ inches \end{pmatrix} \times \begin{pmatrix} outside\ diameter \\ of\ tires\ in\ inches \end{pmatrix} \times \begin{pmatrix} number \\ of\ tires \end{pmatrix}}$$

Tire factor:

$$\begin{pmatrix} tire \\ factor \end{pmatrix} = \frac{10 + tire\ width\ in\ inchces}{100}$$

Weight factor:

Weight factor description.

Weight range (lbs) *	Weight factor equations Y
< 2 000	Y = 0.553 X
2 000 – 13 500	Y = 0.033 X + 1.050
13 501 – 20 000	Y = 0.142 X – 0.420
> 20 000	Y = 0.278 X – 3.115
* $\frac{gross\ vehicle\ weight}{number\ of\ axle}$	$X = \frac{gross\ vehicle\ weight\ (kips)}{number\ of\ axles}$

Grouser factor:

Grouser factor description.

	Grouser factor
With chains	1.05
Without chains	1.00

Wheel load factor:

$$\begin{pmatrix} wheel \\ load \\ factor \end{pmatrix} = \frac{gross\ wight\ in\ kips}{number\ of\ wheels}$$

Clearance factor:

$$\begin{pmatrix} clearance \\ factor \end{pmatrix} = \frac{clearance\ in\ inchces}{10}$$

Engine factor:

Horsepower / ton of vehicle weight	Engine factor
≥ 10	1.00
< 10	1.05

Transmission factor:

Transmission	Transmission factor
Hydraulic	1.00
Mechanical	1.05

all from [4]

If the vehicle is all-wheel drive, the VCI is read from the graph (Figure 4) or by using the formula. On the vertical axis is the mobility index and on the horizontal axis the VCI is estimated. On the graph it is necessary to select the curves belonging to the wheeled vehicles and subtract the value for one and then fifty crossings.

Formulas for calculating the vehicle index:

VC_1 = 11.48 + 0,2 x MI - (39.2 / (MI + 3.74))
VC_{50} = 28.23 + 0.43 x MI - (92.67 / (MI + 3.67)) [4]

If the vehicles are not all-wheel drive, the calculation of the mobility index remains the same. The vehicle cone index is then determined using the following relationship: VCI = 1.4 MI. [4].

The formula shows that to determine the mobility index we need the following parameters:

– weight
– tire width
– the outer diameter of the tires
– number of axles
– number of tires
– vehicle clearance
– engine power
– type of transmission
– use of chains
– all-wheel drive.

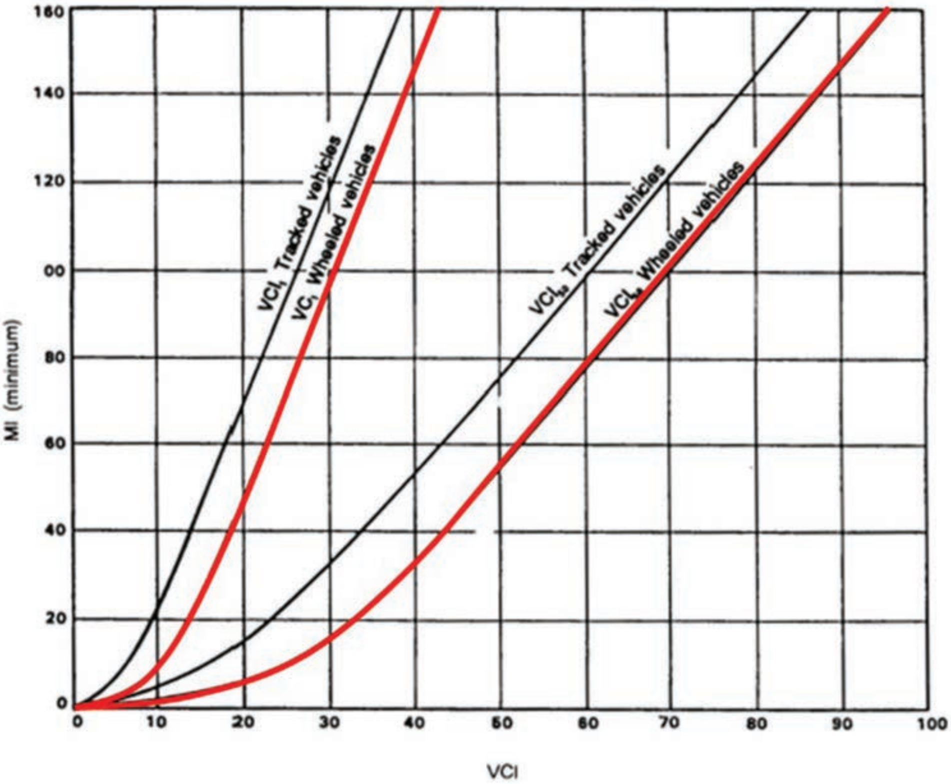

Fig. 4. Graph of the conversion of the mobility index to the vehicle cone index. [4]

The assessment of individual parameters was carried out by comparing the resulting mobility index value when the parameter was decreased or increased by 1% to 10% of its initial value. The basic tactical and technical data of the vehicle are taken as input values. The most commonly used vehicles in the Czech Armed Forces were selected, but the following subsections will describe the effect of parameter changes on the T-815 8x8 VVN.

Parameters in which vehicles of the same type may differ will be examined. These are vehicle weight, width and outer diameter of tires and vehicle ground clearance.

3.1.1. Vehicle Weight

The weight is generally considered as the main criterion that fundamentally influences the trafficability of a given vehicle. This parameter is present in all evaluation systems and is taken into account the most. As already mentioned, vehicles are divided into three weight categories when determining trafficability with PT-45, but this is the first step towards inaccuracy due to the huge variety of different vehicles. Whereas FM takes into account the instantaneous weight of the vehicle and even a small change in the weight parameter will have a very significant effect on the result. By changing the weight and inserting this value into the formula for calculating the wheeled vehicle index when evaluating the FM trafficability (Table 2), it can be observed that the effect on trafficability is directly proportional to the weight, both when the mass is increased and in the opposite direction, i.e. when the weight is reduced. On average, an input change of 1 % in the weight value results in a 1,5 % change in the final result.

Table 2.

Effect of vehicle trafficability as a function of weight change for T 815 8x8 VVN

Weight increased by:	Change of VCI 1	Change of VCI 50
1%	1.52 %	1.45 %
2%	3.06 %	2.92 %
3%	4.61 %	4.41 %
4%	6.17 %	5.91 %
5%	7.76 %	7.42 %
6%	9.35 %	8.95 %
7%	10.97 %	10.49 %
8%	12.59 %	12.05 %
9%	14.24 %	13.62 %
10%	15.90 %	15.21 %

Weight reduced by:	Change of VCI 1	Change of VCI 50
1%	-1.50 %	-1.44 %
2%	-2.99 %	-2.86 %
3%	-4.47 %	-4.28 %
4%	-5.93 %	-5.67 %
5%	-7.37 %	-7.05 %
6%	-8.80 %	-8.42 %
7%	-10.21 %	-9.77 %
8%	-11.61 %	-11.11 %
9%	-12.99 %	-12.43 %
10%	-14.18 %	-13.57 %

3.1.2. Tire Properties

Other influences that have already been investigated dealt with tire characteristics. These are tyre width and outer diameter. Again, this important factor is completely neglected in the calculation of the PT-45 trafficability. In the course of the research it was not surprising to find that increasing or decreasing the values mentioned had a significant effect on the result, but what was a surprising finding is that decreasing the values has a far greater effect on the trafficability than increasing them. For example, if the tyre width value is increased by 10%, the resultant value increases by 9%, whereas if the width is reduced by 10%, the vehicle's trafficability decreases by up to 12%. The same conclusion applies to the outer diameter of tyres.

Table 3.

Effect of vehicle trafficability as a function of change in tyre parameters for T 815 8x8 VVN

Width of tyre increased by:	Change of VCI 1	Change of VCI 50
1%	-1.05 %	-1.00 %
2%	-2.08 %	-1.99 %
3%	-3.08 %	-2.94 %
4%	-4.05 %	-3.88 %
5%	-5.01 %	-4.79 %
6%	-5.94 %	-5.68 %
7%	-6.85 %	-6.56 %
8%	-7.74 %	-7.41 %
9%	-8.61 %	-8.24 %
10%	-9.46 %	-9.06 %

Width of tyre reduced by:	Change of VCI 1	Change of VCI 50
1%	1.08 %	1.03 %
2%	2.18 %	2.09 %
3%	3.31 %	3.17 %
4%	4.47 %	4.28 %
5%	5.66 %	5.41 %
6%	6.88 %	6.58 %
7%	8.13 %	7.78 %
8%	9.42 %	9.01 %
9%	10.74 %	10.27 %
10%	12.09 %	11.57 %

Diameter of tyre incr. by:	Change of VCI 1	Change of VCI 50
1%	-0.65 %	-0.62 %
2%	-1.28 %	-1.22 %
3%	-1.90 %	-1.82 %
4%	-2.51 %	-2.40 %
5%	-3.11 %	-2.98 %
6%	-3.70 %	-3.54 %
7%	-4.27 %	-4.09 %
8%	-4.84 %	-4.63 %
9%	-5.40 %	-5.16 %
10%	-5.94 %	-5.69 %

Diameter of tyre reduced by:	Change of VCI 1	Change of VCI 50
1%	0.66 %	0.63 %
2%	1.33 %	1.27 %
3%	2.02 %	1.93 %
4%	2.72 %	2.60 %
5%	3.43 %	3.29 %
6%	4.16 %	3.98 %
7%	4.91 %	4.70 %
8%	5.67 %	5.43 %
9%	6.45 %	6.17 %
10%	7.24 %	6.93 %

3.1.3. Vehicle Ground Clearance

In practice, vehicle drivers try to increase vehicle ground clearance by reducing tyre pressure, i.e. underinflating tyres. This increases the contact area of the tyre but also reduces the ground clearance of the vehicle. Clearance, which is also considered to be an important vehicle characteristic in determining clearance, was not found to be significant in the calculations. There are minimal changes when moving the value to either side. Specifically, a 10% reduction in ground clearance results in only a 0.1% change in vehicle clearance.

Table 4.

Effect of vehicle trafficability as a function of change in clearance for T 815 8x8 VVN

Clearence increased by:	Change of VCI 1	Change of VCI 50
1%	-0.01 %	-0.01 %
2%	-0.02 %	-0.02 %
3%	-0.03 %	-0.03 %
4%	-0.04 %	-0.04 %
5%	-0.05 %	-0.05 %
6%	-0.06 %	-0.06 %
7%	-0.07 %	-0.07 %
8%	-0.08 %	-0.08 %
9%	-0.09 %	-0.08 %
10%	-0.10 %	-0.09 %

Clearence reduced by:	Change of VCI 1	Change of VCI 50
1%	0.01 %	0.01 %
2%	0.02 %	0.02 %
3%	0.03 %	0.03 %
4%	0.04 %	0.04 %
5%	0.05 %	0.05 %
6%	0.06 %	0.06 %
7%	0.07 %	0.07 %
8%	0.08 %	0.08 %
9%	0.09 %	0.08 %
10%	0.10 %	0.09 %

5.1.4. Evaluation of the Assessment of Parameters

The importance of vehicle weight has been clearly confirmed by the investigation so far. When the mass changes within units of percentages, the overall mobility of the vehicle changes considerably and it is therefore inappropriate to classify vehicles into weight classes, as is the case with the evaluation system for the telescopic penetrometer PT-45.

It should be noted that the above percentage changes in vehicle throughput cannot be taken as dogma. See the following table for a comparison of the 10% loss in vehicle weight. It was found that the T 815 8x8 VVN experiences twice the increase in throughput as the LRD Defender 110 off-road vehicle. This result is mainly due to the different axle and wheel counts of the compared vehicles.

Table 5.

Change in trafficability for LRD Defender 110 (left) and T-815 VVN (right)

Weight reduced by:	Change of VCI 1	Change of VCI 50
1%	-0.74 %	-0.71 %
2%	-1.48 %	-1.42 %
3%	-2.22 %	-2.12 %
4%	-2.96 %	-2.83 %
5%	-3.70 %	-3.53 %
6%	-4.44 %	-4.24 %
7%	-5.17 %	-4.94 %
8%	-5.91 %	-5.64 %
9%	-6.64 %	-6.34 %
10%	-7.37 %	-7.04 %

Weight reduced by:	Change of VCI 1	Change of VCI 50
1%	-1.50 %	-1.44 %
2%	-2.99 %	-2.86 %
3%	-4.47 %	-4.28 %
4%	-5.93 %	-5.67 %
5%	-7.37 %	-7.05 %
6%	-8.80 %	-8.42 %
7%	-10.21 %	-9.77 %
8%	-11.61 %	-11.11 %
9%	-12.99 %	-12.43 %
10%	-14.18 %	-13.57 %

3.2 Proposal of New Parameter

During the field experiments, another parameter was discovered that no evaluation system had worked with before. The influence of the driver skills was identified as a previously overlooked factor. The same types of vehicles had significant differences in their passage through the terrain when driven by different drivers. The T-815 truck was studied. Vehicle was driven by an older specialist driver who has more than eight years' experience with the vehicle, was able to traverse the entire terrain. However, the driver, who had only been driving the vehicle for few months, got stuck after about 20 metres.

4. Conclusions

The main tasks of the engineer troops include engineer measures to secure the movement of their own troops. Accurate assessment of terrain trafficability is crucial for subsequent troop movements not only during exercises but also during crisis situations and others. [12]

In solving this task, the authors decided to use the most used evaluation systems in the Czech army. There were analysed and calculated the individual parameters mentioned in these field manuals which affect the terrain trafficability, so that the dependency rates could be determined. It was found that some parameters have a major influence on the trafficability and it is necessary to take into account even a slight change in these values. In contrast, other parameters are negligible in the result. These conclusions and results should further lead to a better evaluation system of trafficability of terrain and thus to ensure better mobility of troops [13]. This paper should be taken as an introduction to this issue and will be followed by a proposal of a new evaluation system, which will have to be assessed in the field measurements.

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