Proposal of Evaluation of Robotic Devices Trafficability, in Low-Endurable Terrain

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Abstract: In unit movement planning, evaluation is needed, especially for roads, bridges (width, radius, load capacity, etc.) and the trafficability of the subject terrain. In the context of vehicles – wheeled or tracked, the critical break occurs when the vehicles mire and the convoy is stalled. Currently, robotic devices are often used. This trend is reflected in the Army. That is why the trafficability of these devices needs to be investigated. Robots are performing more demanding tasks and their ability to conquer, not only the terrain but also inaccessible places, is important. The authors decided to examine the trafficability of small robotic devices in low endurable terrain. To investigate, mathematical models were used to determine the terrain trafficability for common military vehicles. The required parameters for the tested robotic devices were used in the formulas. Experimental validation was performed to determine the suitability of the mathematical methods. Comparison of the mathematical results, with the values obtained by experiment, showed that the mathematic methods for larger vehicles are also suitable for smaller tracked robotic devices. For wheeled robotic devices, the match of the results was lower. The results show that current mathematical procedures can be applied to robotic devices, however, further validation is required.

Keywords: robotic devices; trafficability; mobility; vehicle cone index; rating cone index; penetrometer

1 Introduction

Exploring terrain trafficability is currently one of the important research areas, especially in the context of the expansion of autonomous vehicles or robotic devices. The ability to assess whether it is possible to overcome a particular area, given the size of the vehicle, its weight, the characteristics of the cargo or people being carried and other vehicle characteristics, is key to accomplishing a given task. Getting from a given location to a destination is a basic function of a vehicle or robot so that it can perform its mission using additional attachments and equipment unless it is only for transportation tasks.

Terrain clearance evaluation is important in both civilian and military domains. In the civilian sector, mainly paved roads are used. However, there are countries or territories with less developed infrastructure, or where vehicle predetermination requires off-road driving. Thus, the ability to overcome rough terrain should be considered for all land vehicles (this issue is solved, for example, by farmers or foresters, whether they can go to the fields, forest, etc.). In the military, the determination of terrain trafficability is one of the tasks of engineer units, which allows them to maintain the pace of their own troops' movement. Particularly in offensive operations, when units are deployed in combat formations, the identification of mobility corridors, and conversely areas unsuitable for maneuvering by troops, is essential in their planning. As a rule, moving troops will not always use paved roads, and quantification of the possibility of unpaved terrain for reuse by specific military equipment will be required.

Greater deployment of robotic assets is expected in future conflicts. This is due to the savings of human resources and their use in tasks that are dirty, dull and dangerous [1] [2]. For unmanned ground vehicles, it will be necessary to assess their ability to be mobile over obstacles and over rough terrain. For heavier and larger robotic devices, metrics and procedures already developed for established military vehicles of similar design can be used. In the Czech Army there is used the telescopic penetrometer for evaluation and as a member of NATO, there could be also used the evaluation with the Trafficability Test Set – used by some NATO countries, as well as the US Army. With these tools the terrain could be evaluated, and the vehicles could overcome without miring.

For smaller robots, these procedures have not yet been developed for routine terrain capacity calculations, although their implementation is becoming more common. The aim of this paper is to assess the correlation between mathematical relationships to determine the unpaved terrain carrying capacity of larger vehicles and the metrics of smaller robots. To achieve this, calculations were performed with subsequent experimental validation on pyrotechnic robots deployed in Explosive Ordnance Disposal (EOD) units to confirm or refute the research assumption: Mathematical relationships designed to determine vehicle trafficability are applicable to robotic devices. This research assumption will be tested for both wheeled and tracked robotic devices.

2 Literature Review

There are several scientific papers dealing with the issue of trafficability of robotic devices. The design proposal of a personal mobility robot devices for rough terrain which is able to realize both a leg mode and a wheel mode in a simple mechanism is addressed in [3]. In [4], a wheeled robot of snake design is described, which allows it to move in difficult and dangerous areas to perform inspection and surveillance. Papers [5] [6] quantify the differences between direct visibility and teleoperation conditions when evaluating the trafficability of robots through an aperture.

The evaluation of the trafficability of a robot on a tracked chassis over an artificial obstacle path containing steps is addressed in [7] [8]. Other similar investigations [9] [10] assess the mobility of a walking robot (four-legged, six-legged) in an artificial terrain simulating an urban environment with many obstacles and the presence of steps. The mobility of walking robots through terrain is investigated in papers [11-13], based on which algorithms for hexagonal six-legged robots, coordinated variable wheel-track walking mechanism and hybrid wheel-leg equipped by a lightweight micro-rover, for in situ characterization of deformable terrain and online detection of nongeometric hazards.

The mobility of wheeled robots in the terrain is addressed in [14-17]. Here, the optimization of the traction force to achieve better mobility and the effect of the normal load distribution among the individual wheels on the ability to generate traction are investigated. A robot suitable for moving in sandy terrain has also been proposed. Moreover, [18] [19] describe the development of omnidirectional wheeled robots and the testing of their agility in rough terrain. In [20], the problem of trafficability of wheeled robot in rough terrain for moving payloads in space is discussed. The motion of an autonomous wheeled robot is investigated in [21]. This paper presents a supervised learning approach to improving the autonomous mobility of wheeled robots through sensing the robot's interaction with terrain 'underfoot.'

Another area of research describes the characterization and classification of terrain using a real-time robot to determine its trafficability, where classification aims at associating terrains with one of a few predefined, commonly known categories, such as gravel, sand, or asphalt and characterization, on the other hand, aims at determining key parameters of the terrain that affect its ability to support vehicular traffic [22]. The detection of passable and impassable areas to be used for the movement of autonomous robots is investigated in [23], where an algorithm based on the analysis of the normal vector of a surface obtained through Principal Component Analysis is proposed. In [24-26] a comprehensive model is developed considering the interaction of the vehicle with the terrain and different types of roads and the related dynamic ill effects, such as rolling resistance and slip, the track line vibrations and stress.

Another work [27] aimed to provide a basis for evaluating and comparing the mobility of wheeled off-road robots with respect to terrain irregularities. To this end, well-defined existing and novel metrics were proposed. The article [28] focuses on developing an assessment tool for the performance prediction of lightweight autonomous vehicles with varying locomotion platforms on coastal terrain. Vehicle metrics are used to model the trafficability of robots which provides information for an index formula used to quantitatively compare the mobility regardless of their methods of locomotion.

The authors of this paper explore a similar approach, focusing on smaller wheeled and tracked robots, with the assessment of ground bearing capacity in relation to their metrics in calculations using formulas for larger vehicles.

To unify requirements and features, it is worth considering implementation of a classification system for unmanned ground vehicles (UGVs), which would determine their basic functional potential. The purpose of UGVs – unmanned ground vehicles - is chiefly linked to their outline dimensions:

- **Mini ground vehicles -** UGVs of a weight of up to 30 kg transported by military personnel and used to reconnoiter an area to smaller distances in relatively easy – light terrain.
- **Small ground vehicles -** UGVs of a weight of up to 300 kg, transported by vehicles to great distances, with a load-bearing capacity of around 150 kg, intended for transportation, reconnaissance of the area, for evacuation of injured personnel and for limited combat activities, with a fairly rapid travel speed and capable of overcoming the terrain.
- **Medium ground vehicles** - of a weight of up to 1500 kg, unarmored, transported by vehicles to a greater distance, with a load-bearing capacity of around 500 kg, intended for transport, reconnaissance, for evacuation of injured personnel and for limited combat activities, with a travel speed of over 25 km/h and high mobility.
- **Tactical ground vehicles -** of a weight of 3–5 t, with high mobility, a load-bearing capacity of around 1–2 t, appropriately armored depending on the container version (heavily armored combat versions and lightly armored transport versions), intended for transporting light armaments, for blanket reconnaissance, for transporting larger loads, for delivering ammunition
- **Large ground vehicles -** unmanned versions of manned combat vehicles, intended for activities in high-risk terrain with significant threat to the lives of people or in situations where there is a shortage of trained crews.

3 Tested Robots

This chapter briefly describes the pyrotechnic robots whose parameters were used for the calculations used to determine their ability to move unobstructed and with which, experimental verification of the calculated values was performed. A Defender-D2.1 ROV wheeled robot and tEODdor and Talon 5 DOF tracked robots were loaned from the EOD unit.

3.1 Defender-D2.1 ROV

The Defender ROV/UGV is a bomb disposal robot with heavy lifting capability and a powerful weight to strength ratio that helps bomb techs respond to vehicle borne improvised explosive devices and chemical, biological, radiological, and nuclear (CBRN) agents. This EOD disposal robot has a titanium frame and can deploy X-ray systems, explosive charges, and multiple disruptors in either a single or double configuration. Its disruptor mounts have integral dual lasers for accurate point of aim and judgement of target distance. The robot has a length of 1.52 m, width of 0.725 m and a height of 1.15 m (manipulator in the folded position) [29].

Figure 1
Defender-D2.1 ROV

3.2 tEODdor

The remote-controlled, heavy-duty robot tEODor is telerobot EOD and observation robot. The robot is designed to provide enhanced bomb disposal capabilities to EOD teams. It can be used to identify and disarm booby traps, fireworks, improvised explosive devices and other dangerous objects in closed areas, buildings and vehicles. It also performs reconnaissance, monitoring and investigation of objects in exceptionally dangerous conditions. The robot has a length of 1.3 m, width of 0.685 m and a height of 1.24 m. The tEODor can also be mounted with recoilless weapons for disarming impro-vised explosive devices [30].

Figure 2
Defender-D2.1 ROV

3.3 Talon 5 DOF

TALON is a lightweight, unmanned, tracked military robot. The robot is developed to protect troops and first responders against explosive threats. It can be deployed in military, first responder and law enforcement applications, and be reconfigured to conduct a range of missions, including CBRN and explosive, EOD, rescue, heavy lift, communications, security and reconnaissance, detection of mines, unexploded ordinance and improvised explosive devices. The TALON tracked military robot is powered by two lead acid rechargeable batteries, which each have a capacity of 300 Wh and provide a three-hour run time. The robot measures 0.864 m long, 0.572 m wide and 0.279 m high when arm-stowed while the ground clearance is 7 cm [31].

Figure 3
Talon 5 DOF

4 Trafficability Evaluation Systems

This paper connects two of very important task these days in the army which is mobility and robotic devices. One of the most important prerequisites of most military operations is ensuring the mobility of the units. It means determine, whether the vehicle is able to overcome the given terrain or route or not. The trafficability could be determine in many ways. It depends on the branch (agriculture, army, …), state (standards and regulations) etc. Depending on the above mentioned, different evaluation devices and systems are used to determine the trafficability. The authors focused on the engineer area because the engineer corps is responsible for the mobility including the evaluation of routes and they also operate with the robotic devices from EOD units. The intention was to verify whether the existing tools can be used. The chosen instruments and systems are described below.

4.1 Telescopic Penetrometer

This instrument is the most often used tool for evaluation of the terrain in the army. It is described in [32], where is the whole measurement procedure given and described. The telescopic penetrometer is ended with a thorn. See Fig. 4. This thorn is pressed to the soil. The instrument has a dial on which we read the pressure needed to press the thorn to different depths. Each measuring is carried out three times in one-meter distance. The number of vehicles, which can negotiate the measured area, is determined in the evaluation table.

The problem is that the evaluation is only due to the weight of the vehicle and there are only three categories – vehicle to 4.5, 9 and 15 tons. The evaluation table were converted to a graph (See Fig. 5) to be able to determine the number of devices, but the weight of the robots is so low, that the evaluation with this instrument will be very in-accurate and misleading. That is why, the authors decided not to recommend evaluate the terrain trafficability of the robotic devices with this instrument.

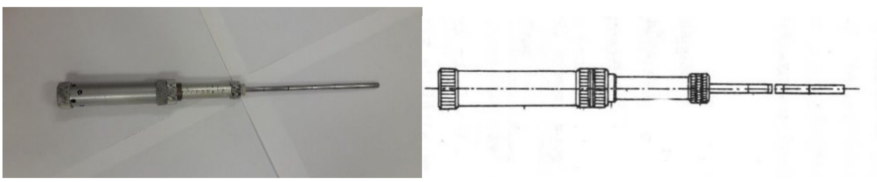

Figure 4
The telescopic penetrometer

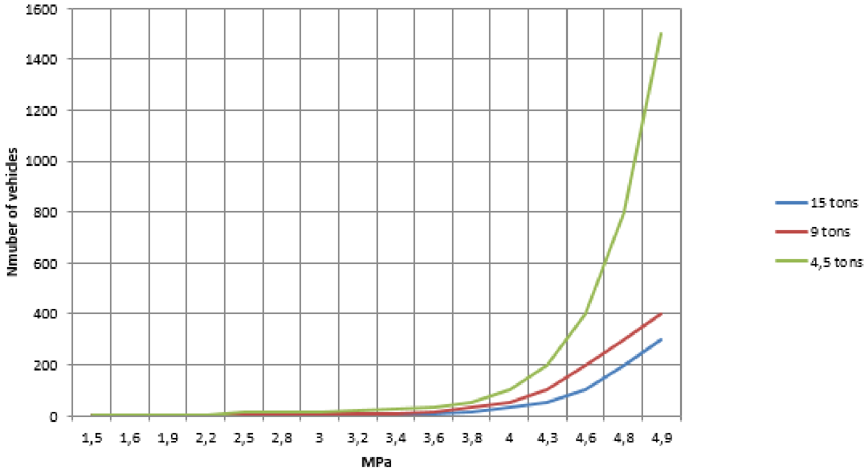

Figure 5
The evaluation graph for the telescopic penetrometer

4.2 The Trafficability Test Set

The measuring with the Trafficability test set is described in the American Field Manual 5-430-00-1 “Planning and Design of Roads, Airfields and Heliports in the Theatre of Operations – Road Design”. [33] In this field manual we determine the trafficability of the area by two indexes – rating cone index (RCI) and vehicle cone index (VCI). As soon as we know the values of these two indexes and compare them, it could be judged if the soil is trafficable for the given number of vehicles. GO means that the vehicles could go and NOT GO means that they will mire.

Rating cone index is measured with the soil-trafficability test set. See Fig. 6. This set consists of one canvas carrying case, one cone penetrometer, one soil sampler, remolding equipment and a bag of hand tools. RCI is a product of two other indexes - cone index CI and remolding index RI. The CI is measured with the cone penetrometer. It is used to determine the shearing strength of low-strength soils. When the cone is forced into the ground, the proving ring is deformed in proportion to the force applied. The amount of force required to move the cone slowly through a given plane is indicated on the dial inside the ring. This force is an index of the soil's shearing resistance and is called the soil's CI in that plane. The cone penetrometer cannot be used to measure gravels. Gravels are considered excellent for passes, and any problems can be determined by visual observation. The index RI is measured with this set as well. A piston-type soil sampler is used to extract soil samples for remolding tests. This set simulates what happens to the soil after the first vehicles have driven. Depending on the type of soil, its properties will improve (soil will be compacted) or worsen (soil will spread). The set can be seen on Figure 6. It must be remembered that measurements are valid only for the time of the measurement and short periods, thereafter, provided no weather changes occur.

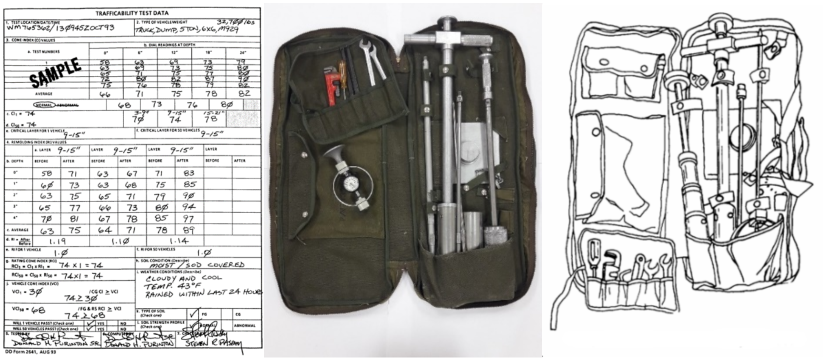

Figure 6
The trafficability test set and the evaluation form

Vehicle cone index is an index of the vehicle taking into account the characteristic of the vehicle. It is important not to think only about the weight, but also about the number of wheels, type of tires, clearance, etc. All the factors are written below. For conventional types of vehicles used in some NATO countries, the values of vehicle cone indexes are known and tabulated. But it is possible to the exact value of the vehicle cone index according to the given formula. There it is count the mobility index MI and after that you determine the vehicle cone index from a curve in a chart or by calculation due to the wheel drive. The VCI is tabulated or counted for one or fifty passes. The vehicles are divided into four classes – self-propelled tracked vehicles, self-propelled wheeled vehicles, construction equipment and trailers. And that is the fact, what the authors decided to use in such a way that the MI mobility index, resp. VCI vehicle cone indexes for robotic devices counted. The formula for counting MI (Field Manual 5-430-00-1) [33] for wheeled vehicles is:

$$MI = \left[\frac{(CPF)\times(WGTF)}{(TF)\times(GF)} + (WF) - (CF)\right] \times (EF) \times (TF) \qquad (1)$$

where:

Contact pressure factor (CPF):

$$(CPF) = \frac{2 \times weight}{(TW) \times (TOD) \times (WN)} \qquad (2)$$

Tire factor (TF):

$$(TF) = \frac{10 + TW}{100} \qquad (3)$$

Weight factor:

$$X = \frac{WGT(kips)}{AN} \tag{4}$$

Weight range (WR):

$$Weight\ range = \frac{WGT(lbs)}{AN}$$

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

Grouser factor:

	Grouser factor
With chains	1.05
Without chains	1.00

Wheel load factor (WF):

$$(WF) = \frac{WGT}{WN} \tag{5}$$

Clearance factor (CF):

$$(CF) = \frac{CL}{10} \tag{6}$$

Engine factor (EF):

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

Transmission factor (TF):

Transmission	Transmission factor
Hydraulic	1.00
Mechanical	1.05

If the vehicle is all-wheel drive, the VCI is read from the graph (Figure 7) 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.

If the vehicles are not all-wheel drive, the calculation of the mobility index re-mains the same. The vehicle cone index is then determined using the following relationship: VCI = 1.4 MI. [33].

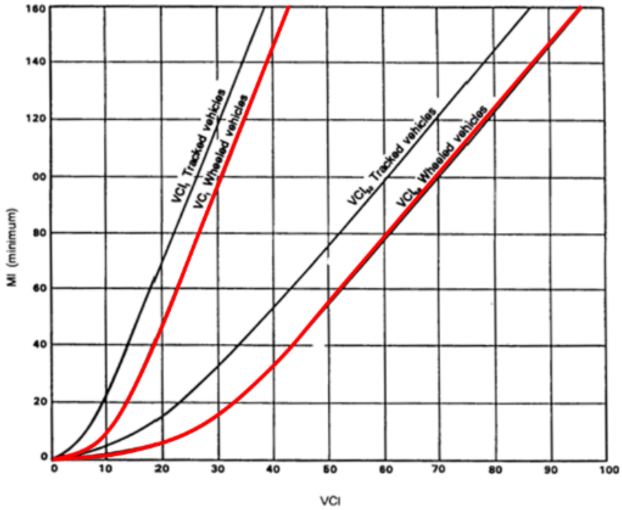

Figure 7
Estimated relation of a Ml to a VCI. [33]

For tracked vehicles, the formula of MI is following:

$$MI = \left[\frac{(CPF)\times(WGTF)}{(TF)\times(GF)} + (BF) - (CF)\right] \times (EF) \times (TF) \tag{7}$$

Where:

Contact pressure factor (CPF):

$$\begin{array}{c}contact\\ pressure\\ factor\end{array} = \frac{gross\ weight\ in\ lbs}{area\ of\ tracks\ in\ contact\ with\ ground\ in\ square\ inches} \tag{8}$$

$$(CPF) = \frac{gorss\ weight\ in\ lbs}{area\ of\ tracks\ in\ contact\ with\ ground\ in\ squate\ inches}$$

Track factor (TF):

$$(TF) = \frac{track\ width\ in\ inches}{100} \tag{9}$$

Weight factor (WF):

Less than 50 000 lb	1.00
50 000 to 69 999 lb	1.20
70 000 to 99 999 lb	1.40
100 000 lb or greater	1.80

(10)

Grouser factor (GF):

	Grouser factor
Grousers less than 1.5 inches high	1.00
Grousers more than 1.5 inches high	1.10

Bogie factor (BF):

$$BF = \frac{gross\ weight\ (lbs)}{10\,.TNBTCG\,.ATS} \tag{11}$$

where:

TNBTGC is total number of bogies on tracks in contact with ground and ATS is area of one-track shoe in square inches.

Clearance factor (CF):

$$(TF) = \frac{track\ width\ in\ inches}{100} \tag{12}$$

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

VCI is counted than in the same way as wheeled vehicles, it means due to the table in Figure 7.

5 Experiment and Results

5.1 Measurement Conditions

Firstly, the input parameters (weight, belt width, number of wheels, …) were measured for three selected robotic devices. Then the values of the VCI indexes were counted. These steps preceded the preparation of the experiment.

The experiment took place at very low endurable terrain. This was because of the need of a place, where it can be approved, that the robotic devices will mire or not. The place of experiment was marked after one-meter distance. In these the load capacity of the soil was measured by the penetrometer and the remolding test set. Then the robotic devices perform the passes, and it was monitored whether they will overcome the area or not.

The marked low endurable terrain, measurement with cone penetrometer and measuring of the features of robotic device

5.2 Vehicle Cone Index of Robotic Drones

VCI were counted according to the formulas in Field Manual. The following tables show the input data for MI calculations. Robotic devices were divided into tables according to wheeled or tracked.

Table 1

Features of the tracked robotic devices

Feature	TALON	TEODor
Weight (kg)	64	375
Length of track touch (mm)	650	930
Track width (mm)	153	110

Grouser height (mm)	20	11
Bogies (mm)	62	35
Clearance (mm)	85	106
Engine power (kw)	1	3
Number of wheels	6	10
Transmission	M	M

Table 2
Features of the wheeled robotic devices

Feature	**Defender**
Weight (kg)	275
Tire width (mm)	175
Outer diameter of tires (mm)	415
Number of axles	3
Number of tires	6
Clearance (mm)	160
Engine power (kw)	2
Chains	No
Transmission	M

According to the above formulas, following MI and subsequently VCI data were calculated:

Table 3
The MI and VCI indexes of the robotic devices

Vehicle	**MI**	**VCI_1**
TALON	4.47	4.04
TEODor	58.88	18.20
Defender	0.73	2.85

5.3 Rating Cone Index of Terrain

The evaluation of terrain was made by the trafficability test set. Firstly, it has to be determined the following important parameters:

Type of soil: Fine (determined from soil samples taken at the measured place)

Profile: Abnormal (evident from the values measured by the penetrometer)

Critical layer: 3 – 9” (it depends on the type of vehicle)

RI: 0.92 (measured due to the manual – soil sampling and resistance before and after simulation of passes)

CI: CI at particular points – see Table 5

RCI: Equal to RI x CI, see Table 5

In the following tables are the values measured with the cone penetrometer. It is the resistance to thorn penetration. It was measured in different depth (0, 6, 12 and 18 inches), see Table 4.

Table 4
The values of the penetrometric measurements

	0"	6"	12"	18"
1	0	20	60	190
2	0	20	50	130
3	0	25	160	180
4	0	50	160	180
5	0	80	160	80
6	0	30	80	120
7	0	20	40	160
8	0	50	60	220
9	0	30	80	260
10	15	15	20	120
11	0	20	90	220

	0"	6"	12"	18"
1	0	30	60	200
2	0	30	60	140
3	0	30	140	220
4	0	20	220	220
5	0	70	90	100
6	0	20	60	140
7	0	30	80	220
8	10	40	40	220
9	0	15	40	220
10	20	20	80	120
11	10	25	80	220

	0"	6"	12"	18"
1	0	25	50	200
2	0	18	50	130
3	0	38	100	180
4	0	100	220	220
5	0	60	120	190
6	0	40	80	120
7	0	20	50	220
8	10	90	90	220
9	0	25	80	220
10	20	20	25	200
11	0	15	140	200

From the values in the Table 4 there were counted the cone indexes for particular place and the value was then multiplied by the rating index, which was made and measured by the remolding test set. The final rating cone indexes could be seen in the Table 5.

Table 5
The results of the penetrometric measurements

	CI	RI	RCI	TALON	tEODor	Defender
1	26	0.92	24	GO	GO	GO
2	24	0.92	22	GO	GO	GO
3	48	0.92	44	GO	GO	GO
4	78	0.92	72	GO	GO	GO
5	65	0.92	60	GO	GO	GO
6	33	0.92	30	GO	GO	GO
7	25	0.92	23	GO	GO	GO
8	47	0.92	43	GO	GO	GO
9	27	0.92	25	GO	GO	GO
10	19	0.92	17	GO	NOT GO	GO
11	36	0.92	33	GO	GO	GO

5.4 Evaluation of the Experiment

In the experiment the vehicle cone indexes of the robotic devices were first evaluated (see Table 3). Then a low-bearing terrain was selected and was measured with a cone penetrometer and evaluated for robotic devices (See Tables 4 and 5). Finally, the particular robotic devices performed the individual passes (See Fig. 9) to confirm or refute whether the trafficability of robotic devices could be evaluated with existing instrument used for evaluation of vehicles.

Figure 9
Robotic devices Tallon, Defender and tEODor mired in the terrain

According to the results of the terrain evaluation with cone penetrometer the robotic devices Tallon and Defender had to overcome the terrain, tEODor had to mire. It can be seen in the Figure 9. The tEODor should mire, and it really mired in the supposed distance. The Defender should overcome the entire section of terrain, but as it can be seen from the Figure 10 the device mired in the distance of 10 meters.

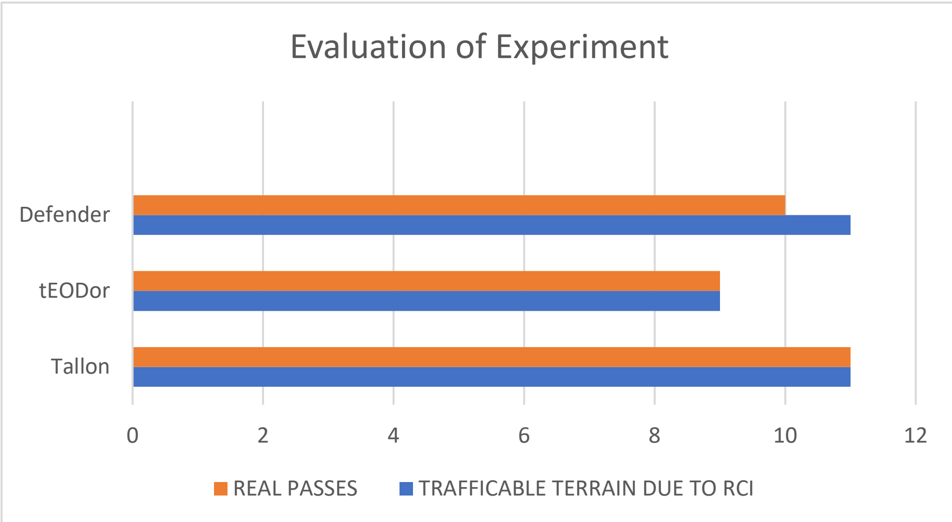

Figure 10
The Evaluation of the experiment

6 Discussion

At the beginning of the research, the use of both types of penetrometers to evaluate unpaved terrain for driving robotic vehicles was considered. However, a closer analysis of the use of the telescopic penetrometer showed that the results obtained by the measurements were of considerable scatter and unsuitable for smaller robotic vehicles. Thus, in further research, only the cone penetrometer was used to evaluate the terrain trafficability.

According to the calculation vehicle cone indexes and measurement of low-bearing terrain it was determined that the vehicles would drive the specified section of terrain along its entire length, and one would mire. For tracked vehicles, the experiment confirmed the accuracy of the calculations. The tEODor vehicle even mired at the exact calculated location. However, the Defender wheeled vehicle covered the entire measured section without miring.

Thus, it can be concluded that the research assumption: Mathematical relationships designed to determine vehicle trafficability are applicable to robotic devices has been confirmed for tracked robotic devices. For wheeled robotic devices the research assumption was not confirmed. However, it has been shown that VCI can be calculated for both wheeled and tracked robotic devices and the passage of the wheeled device was correctly calculated at nine out of ten measured points. Thus, the direction of research is correct, and more measurements need to be made with more types of robots, in more types of soils under different climatic conditions.

Conclusions

Due to an increasing use of robotic devices, it is necessary to know and be able to evaluate, their trafficability through any terrain. This paper assesses the evaluation of three robotic assets, that were provided by the EOD unit. The evaluation used a cone penetrometer, that is being implemented for use by the United States Army. Through computation and experiments, the correlation between the mathematical relationships, used to calculate vehicle terrain trafficability and the parameters of the tested tracked robotic assets, was confirmed. For the wheeled robotic vehicle, the experiment did not confirm the stated research assumption. This type of research is very important, because the authors did not find other papers concerning the computation of trafficability of small robotic devices, while this issue is currently very topical, due to the in-creasing introduction of these devices in all areas of human life. Simultaneously, these are expensive devices, where a wrong estimation or calculation of the trafficability of a device could lead from the impossibility to accomplish the task to its damage or even destruction.

The proposals for determining the unobstructed movement of robotic devices proposed in this paper, could be fully functional, however, further measurements need to be completed.

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Conflicts of Interest

The authors declare no conflicts of interest.

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